VDOT NOVA – Centric ITS Architecture

COMMUNICATIONS PLAN v 1.0

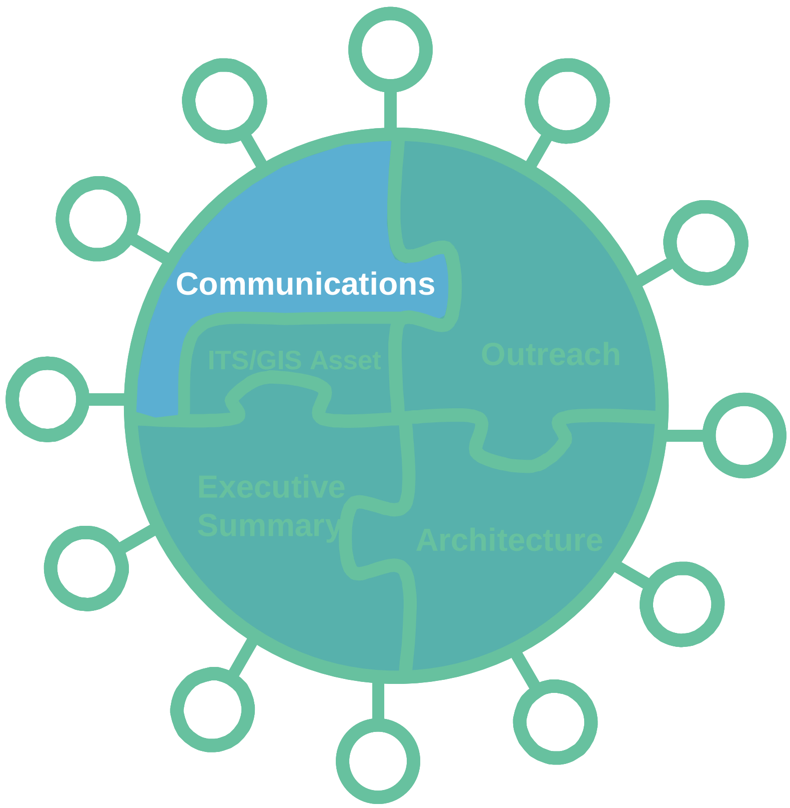

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This Virginia Department of Transportation (VDOT) Northern Virginia (NOVA) District Communications Plan documents the communications plan development process and its relationship to the Outreach and System Architecture efforts, translates the system architecture interconnects and information flows into stakeholder communications requirements, presents related communications infrastructure, evaluated various communications technologies, and provides recommendations on investing in communications to support the system architecture.

The VDOT NOVA District, with the assistance from On-Call Consultants, embarked on a rather aggressive program to define an Intelligent Transportation System (ITS) Architecture. This program required a substantial stakeholder Outreach process and included the development of a Communications Plan to directly support the stakeholder requirements and the VDOT NOVA-centric ITS Architecture. This report is one in series of five related documents that present the major NOVA ITS program components. The series includes the following reports:

- Executive Summary
- Outreach
- System Architecture
- Communications Plan
- ITS/GIS Asset Baseline

The purpose of the Communications Plan is to provide guidance and recommendations to VDOT NOVA District and the regional stakeholders on investing in and deploying communications infrastructure and/or establishing services that will provide direct benefit to the NOVA ITS Architecture. In addition to this, the Plan is intended to serve as a reference document on communications technologies as they relate to ITS. Communications technologies and networks are widely recognized as a vital aspect of any ITS initiative. This is especially true for the NOVA ITS program because of the functions and services VDOT provides to the District and also due to the unique responsibility VDOT has regionally, given the physical proximity of the NOVA District to Washington, D.C. and the state of Maryland.

In order to allow users to easily navigate through the NOVA ITS Architecture, a brief description of each section is presented below:

NOVA ITS Architecture – Presents the reader with the high-level methodology used to develop the Communications Plan to directly support the physical ITS system architecture. IT also acclimates the reader as to why there is a Communications Plan as well as the factors that went into its development.

Stakeholder Requirements – Presents the list of stakeholders (VDOT and non-VDOT) organized by functional areas.

Communications Infrastructure & Services – Identifies existing and planned regional communications infrastructure or other communications services of VDOT and the stakeholders.

Candidate Technologies – Presents various communications technologies and services currently available and projected to be available within the timeframe of the Communications Plan.

Standards – Provides a thorough review of the National Transportation Communication ITS Protocol (NTCIP) along with consideration of its application to ITS. It also addresses the center-to-center and center-to-field standards considered for the VDOT NOVA ITS architecture.

Evaluation Criteria & Alternatives Analysis – This section presents the criteria used to evaluate the candidate technologies and potential system architectures.

Communications Architecture – Presents the logical and physical communications architectures to support the deployment of the NOVA ITS architecture.

Infrastructure Deployment – Takes into consideration the deployment of the NOVA ITS communications architecture and overall network evolution and makes recommendations to support the overall project goals and objectives established for NOVA ITS.

Communications Plan Maintenance Strategy – Presents an overall strategy for VDOT to maintain the Communications Plan.

The reader is encouraged to review the document in sequence to develop an increased understanding of the natural relationship between the Communications Plan and the NOVA ITS System Architecture. However, each section has also been written and organized such that it can be reviewed independently as reference material. The modular sections are also intended to allow VDOT a straightforward manner in which to maintain and update the Plan. The reader is also encouraged to review the related project documents to better understand the overall direction of the VDOT ITS Program within the NOVA District and how local and regional transportation provisions will be provided.

2 NOVA ITS SYSTEM ARCHITECTURE

This section reaffirms the relationship of the Communications Plan to the System Architecture (thoroughly defined in a separate document). This section presents the reader with the high-level methodology used to develop the Communications Plan to directly support the physical ITS system architecture. An explanation of the "Sausage Diagram" is provided as the basis for considering the various types of communications technologies applicable to support the architecture (i.e., "candidate technologies"). A discussion of the Interconnects and Information Flows is provided as well to set the foundation for the alternatives analysis and the stakeholder requirements imposed on such interconnects and flows. In general, this section acclimates the reader as to why there is a Communications Plan and the various factors (discussed below) that went into its development.

2.1 NOVA ITS SYSTEM ARCHITECTURE

There is a direct relationship between the NOVA ITS Systems Architecture and the Communications Plan - it is one of support. That is, the purpose of the Communications Plan is to support the deployment (or realization) of the System Architecture. In order to properly establish this relationship, a certain baseline understanding of the System Architecture is required. This section provides the necessary background and sets the foundation for the development of the Communications Plan, and subsequent recommendations.

This section is not intended to be an all-inclusive description of the NOVA ITS System Architecture - as there is another project report that covers all aspects of the System Architecture in great detail. The reader is encouraged to refer to, as needed, the NOVA ITS System Architecture Report. This report is available from VDOT or can be downloaded from the project web site - http://www.vdot-itsarch.com.

2.2 “SAUSAGE DIAGRAM”

The highest level representation of the NOVA ITS System Architecture, as derived from the National ITS Architecture, is the Interconnect Diagram shown by Figure 1. This figure, commonly referred to as the "Sausage Diagram" because of the shape of the objects representing the communications subsystems, identifies those National ITS Architecture subsystems that are present in the NOVA ITS System Architecture.

The Sausage Diagram also identified the types of communications technologies that are traditionally (and likely to be) used to support the flow of information between the various subsystems. For the purposes of the NOVA ITS System Architecture, the following high-level definitions apply (adapted directly from the National ITS Architecture).

Wide Area Wireless Communications: provide communications via a wireless device between a user and an infrastructure-based system. Since the NOVA ITS Architecture is center-to-center (C2C)-based, wide area wireless communications technologies don't have a direct application under this definition because there are no traveler subsystems that are supported. However, there are vehicle subsystems that are included and can be served by wide area wireless communications technologies and services.

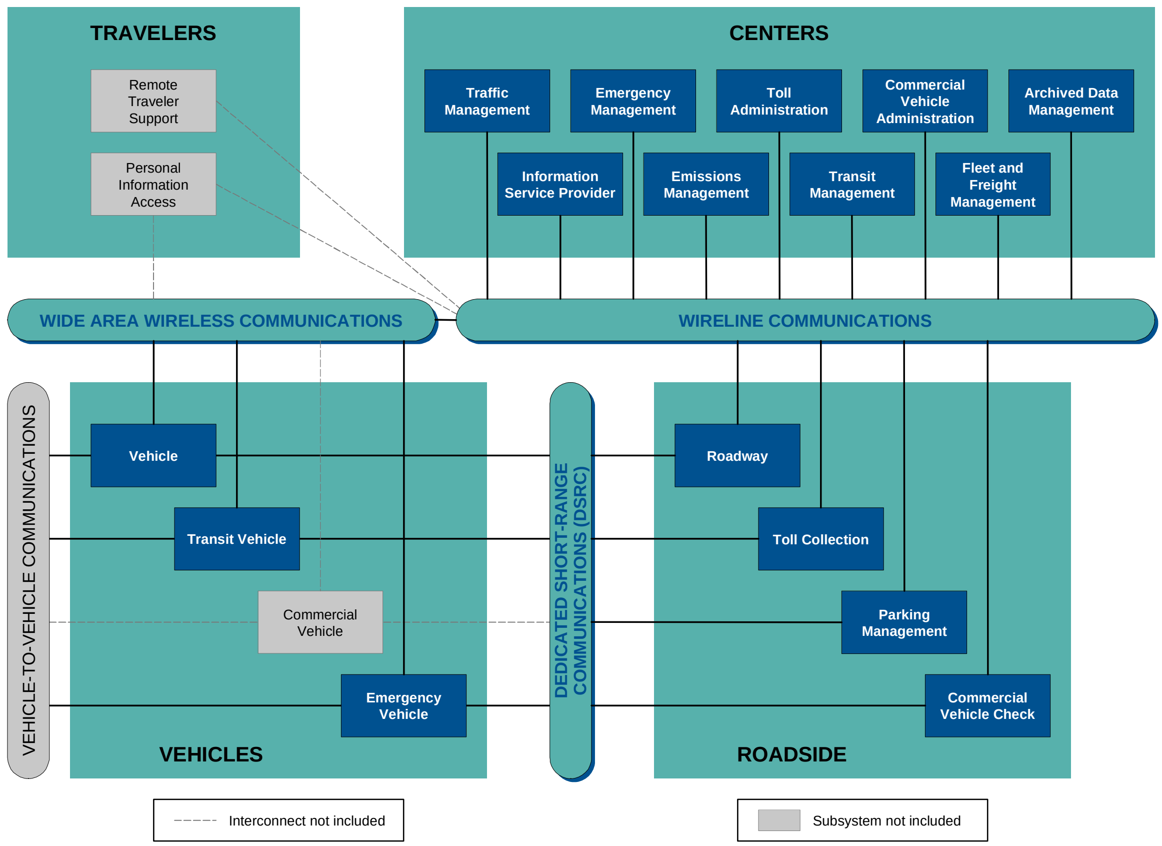

Figure 1 – NOVA ITS Architecture Subsystems and Communications

Wireline Communications: provide communications via landline infrastructure between stationary sources (facilities). Being C2C-based, these technologies comprise most of the NOVA ITS Architecture communications recommendations.

Vehicle-to-Vehicle Communications: provide dedicated wireless communications between vehicles. These systems are line-of-site and also characterized by offering high data rate transmission with low probability of error. Although the NOVA ITS Architecture includes Vehicle Subsystems, it does not provide support for direct vehicle-to-vehicle communications. Information that is exchanged with vehicles is done by way of a VDOT facility (center).

Dedicated Short-Range Communications (DSRC): provide close-proximity wireless communications between vehicles and the roadside infrastructure. DSRC systems are typically associated with location-specific applications (e.g., electronic toll collection, commercial vehicle operations). DSRC technologies and systems are viable options for the NOVA ITS Architecture.

These technologies and associates services are further presented and evaluated for specific application to the NOVA ITS Architecture in Section 5 - Candidate Technologies.

2.3 INTERCONNECTS AND INFORMATION FLOWS

The National ITS System Architecture defines an Interconnect as a communications path that carries information between subsystems and terminators in the physical architecture (i.e., as represented by the "Sausage Diagram"). This is the next level down in detail as one further explores the NOVA ITS Architecture. The confirmed Interconnects identify those actual subsystems (VDOT or stakeholder facilities) that are either already or are required to be connected for the sake of exchanging information and improving operations. Essentially, and from a communications perspective, the Interconnects identify who is or needs to talk to whom - and this establishes the baseline for developing the communications architecture for NOVA.

A sample Interconnect diagram is shown by Figure 2. The complete set of Interconnects is documented in the System Architecture report.

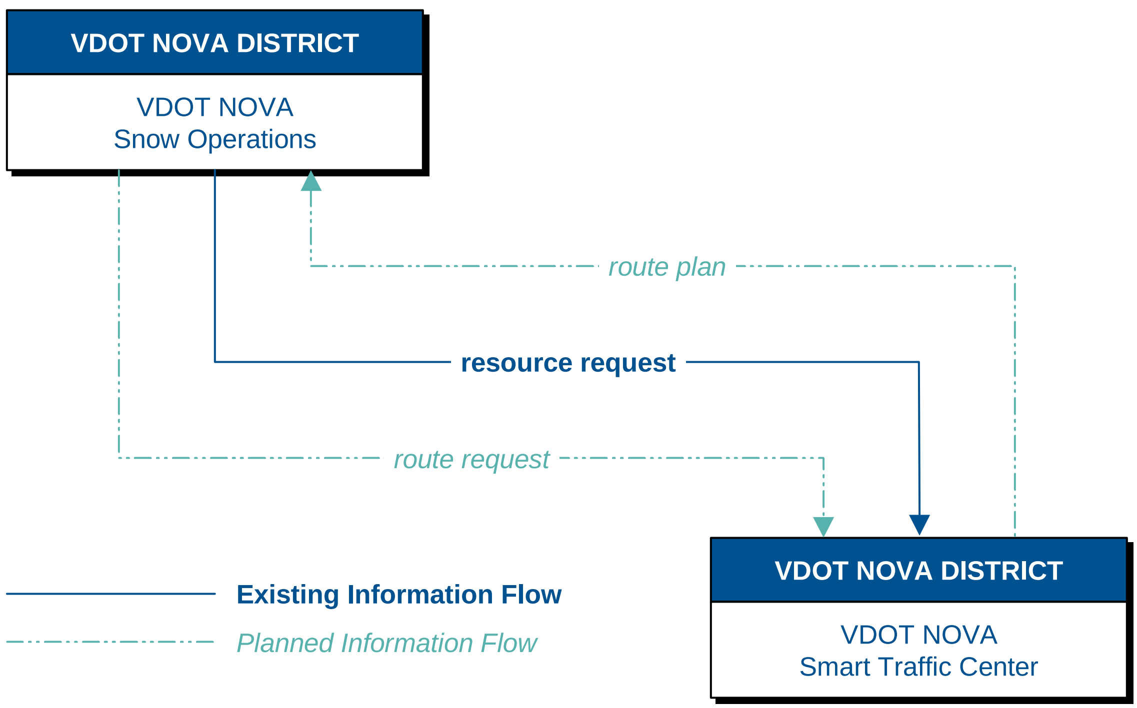

Figure 2 – System Architecture Interface Diagram (Example)

Having established which centers or facilities or vehicles are required to interconnect, the next step and lower level of detail, is to establish the actual information that needs to be exchanged across the Interconnect. This is represented by defined Information Flows (see Figure 2). The information flows are specific VDOT and stakeholder requirements regarding the contents of the messages to be exchanged with other stakeholder and VDOT facilities included among the Interconnect definitions. The Information Flows present a further refined level of detail required in order to extract communications-specific requirements upon which to base recommendations. The Information Flows have been defined according to Table 1. These definitions are based on the national ITS Architecture Information Flows, customized accordingly to serve the operations of VDOT and the stakeholders (as noted by the "*").

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
air quality information	Aggregated region-wide measured air quality data and possible pollution incident information. Note this flow contains ozone data.
Archive analysis requests	A user request that initiates data mining, analytical processing, aggregation or summarization, report formulation, or other advanced processing and analysis of archived data. The request also includes information that is used to identify and authenticate the user and support electronic payment requirements, if any.
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.
Archive coordination	Catalog data, meta data, published data, and other information exchanged between archives to support data synchronization and satisfy user data requests.
Archive request confirmation	Confirmation that an archive request has been received and processed with information on the disposition of the request
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.
archived data product requests	A user-specified request for archived data products (i.e. data, meta data, or data catalogs). The request also includes information that is used to identify and authenticate the user and support electronic payment requirements, if any.
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.
closure coordination	Coordination between subsystems regarding construction and maintenance closure times and durations.
closure data *	This flow represents road closure data that can be used to populate the GIS database.
current network conditions	Current traffic information, road conditions, and camera images that can be used to locate and verify reported incidents, and plan and implement an appropriate response.
emergency archive data	Logged incident information that characterizes the identified incidents and provides a record of the corresponding incident response. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
emergency dispatch requests	Emergency vehicle dispatch instructions including incident location and available information concerning the incident.
emergency dispatch response	Request for additional emergency dispatch information (e.g., a suggested route) and provision of en-route status.
emergency traffic control request	Special request to preempt the current traffic control strategy in effect at one or more signalized intersections or highway segments. For example, this flow can request all signals to red-flash, request a progression of traffic control preemptions along an emergency vehicle route, or request another special traffic control plan.
emergency traffic control response	Status of the special traffic signal control strategy implemented in response to the emergency traffic control request.
emergency vehicle tracking data	The current location and operating status of the emergency vehicle.
emissions data	Emissions data and associated imagery collected by roadside equipment.
environmental conditions	Current environment conditions (e.g., air temperature, wind speed, surface temperature) as measured by environmental sensors and communicated by supporting field equipment.
equipment maintenance status	Current status of field equipment maintenance actions.
event plans	Plans for major events possibly impacting traffic.
external reports	Traffic and incident information that is collected by the media through a variety of mechanisms (e.g., radio station call-in programs, air surveillance).
fault reports	Reports from field equipment (sensors, signals, signs, controllers, etc.) which indicate current operational status.
freeway control data	Control commands and operating parameters for ramp meters, dynamic message signs, mainline metering/lane controls and other systems associated with freeway operations.
freeway control status	Current operational status and operating parameters for ramp meters, dynamic message signs, mainline metering/lane controls and other control equipment associated with freeway operations.
GIS database information *	The information provided through the GIS database is: Fiber optic duct locations, accident locations, speed information on county road segments, and map updates.
highway control status	Current traffic control equipment status that indicates operational status and right-of-way availability to the non-highway transportation mode at a multimodal crossing.
HOV data	Current HOV lane information including both standard traffic flow measures and information regarding vehicle occupancy in HOV lanes.
HOV restrictions status	This flow represents the STC providing NOVA Local Transit Centers with HOV restriction information to aid transit agencies in managing their routes.
HRI advisories	Notification of Highway-Rail Intersection equipment failure,

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
	intersection blockage, or other condition requiring attention, and maintenance activities at or near highway rail intersections.
HRI control data	Data required for HRI information transmitted at railroad grade crossings and within railroad operations.
HRI request	A request for highway-rail intersection status or a specific control request intended to modify HRI operation.
HRI status	Status of the highway-rail intersection equipment including both the current state or mode of operation and the current equipment condition.
incident command information	Information that supports local management of an incident. It includes resource deployment status, hazardous material information, traffic, road, and weather conditions, evacuation advice, and other information that enables emergency personnel in the field to implement an effective, safe incident response.
incident command request	Request for resources, commands for relay to other allied response agencies, and other requests that reflect local command of an evolving incident response.
incident data	Data and imagery from the roadside supporting incident detection and verification.
incident information	Notification of existence of incident and expected severity, location, time and nature of incident.
incident information request	Request for incident information, clearing time, severity. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.
incident report	Report of an identified incident including incident location, type, severity and other information necessary to initiate an appropriate incident response.
incident response coordination	Incident response procedures, resource coordination, and current incident response status that are shared between allied response agencies to support a coordinated response to incidents. This flow also coordinates a positive hand off of responsibility for all or part of an incident response between agencies.
incident response status	Status of the current incident response including traffic management strategies implemented at the site (e.g., closures, diversions, traffic signal control overrides).
incident status	Information gathered at the incident site that more completely characterizes the incident and provides current incident response status.
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.
local signal priority request	Request from a vehicle to a signalized intersection for priority at that intersection.
maint and constr administrative information *	General administrative data interchanges between ITS and non-ITS maintenance and construction systems. This includes:

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
	interfaces to purchasing for equipment and consumables resupply, interfaces to human resources that manage training and special certification for field crews and other personnel, and interfaces to contract administration functions that administer and monitor the work performance for maintenance and construction contracts.
maint and constr dispatch status *	Current maintenance and construction status including work data, operator status, crew status, and equipment status.
maint and constr work plans *	Future construction and maintenance work schedules and activities including anticipated closures with anticipated impact to the roadway, alternate routes, anticipated delays, closure times, and durations.
maintenance resource request *	Request for road maintenance resources that can be used in the diversion of traffic (cones, portable signs), clearance of an incident, and repair of ancillary damage.
media information request	Request from the media for current transportation information.
multimodal crossing status	Indication of operational status and pending requests for right-of-way from equipment supporting the non-highway mode at multimodal crossings.
parking information	General parking information and current parking availability.
parking lot data request	Request for parking lot occupancy, fares, and availability. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.
parking lot reservation confirmation	Confirmation for parking lot reservation.
parking reservations request	Reservation request for parking lot.
probe data	Aggregate data from probe vehicles including location, speed for a given link or collection of links.
public affairs information coordination *	Responsible for addressing the media during severe incident situations and providing an overall customer service roll for VDOT.
railroad advisories	Real-time notification of railway-related incident or advisory.
red light running system data *	This flow provides the STSS with data regarding the number of violations recorded at intersections equipment with red light running cameras.
remote surveillance control	The control commands used to remotely operate another center's sensors or surveillance equipment so that roadside surveillance assets can be shared by more than one agency.
request for right-of-way	Forwarded request from signal prioritization, signal preemption, pedestrian call, multi-modal crossing activation, or other source for right-of-way.
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
	well as a one-time request for information.
request toll collection suspension	The STC can request to suspend toll collection based on an incident on the surface the requires motorist to utilize the Dulles Toll Road as an alternate route.
request transit information	Request for transit service information and current transit status.
resource deployment status	Status of traffic management center resource deployment identifying the resources available and their current deployment status.
resource request	A request for traffic management resources to implement special traffic control measures, assist in clean up, verify an incident, etc.
reversible lane status	Current reversible lane status including traffic sensor and surveillance data and the operational status and mode of the reversible lane control equipment.
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.
roadside archive data	A broad set of data derived from roadside sensors that includes current traffic conditions, environmental conditions, and any other data that can be directly collected by roadside sensors. This data also indicates the status of the sensors and reports of any identified sensor faults.
roadway information system data	Information used to initialize, configure, and control roadside systems that provide driver information (e.g., dynamic message signs, highway advisory radio, beacon systems). This flow can provide message content and delivery attributes, local message store maintenance requests, control mode commands, status queries, and all other commands and associated parameters that support remote management of these systems.
Route plan	Tailored route provided by ISP in response to a specific request.
Route request	Request for a tailored route based on given constraints.
Sensor and surveillance control	Information used to configure and control sensor and surveillance systems at the roadside.
Signal control data	Information used to configure and control traffic signal systems.
Signal control status	Status of surface street signal controls.
Suggested route	Suggested route for a dispatched emergency vehicle that may reflect current network conditions and the additional routing options available to en-route emergency vehicles that are not available to the general public.
Toll demand management request	Request to change the demand for toll road facility use through pricing or other mechanisms.
Toll instructions	Demand management toll pricing information based on current congestion.
Toll Transactions	Detailed list of transactions from a toll station. Note this flow contains good and bad tag data.
Traffic archive data	Information describing the use and vehicle composition on transportation facilities and the traffic control strategies employed. Content may include a catalog of available

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
	information, the actual information to be archived, and associated meta data that describes the archived information.
Traffic control coordination	Information transfers that enable remote monitoring and control of traffic management devices. This flow is intended to allow cooperative access to, and control of, field equipment during incidents and special events and during day-to-day operations. This flow also allows 24-hour centers to monitor and control assets of other centers during off-hours, allows system redundancies and fail-over capabilities to be established, and otherwise enables integrated traffic control strategies in a region.
Traffic control priority request	Request for signal priority at one or more intersections along a particular route.
Traffic equipment status	Identification of field equipment requiring repair and known information about the associated faults.
Traffic flow	Raw and/or processed traffic detector information which allows derivation of traffic flow variables (e.g., speed, volume and density measures).
Traffic images	High fidelity, real-time traffic images suitable for surveillance monitoring by the operator or for use in machine vision applications.
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.
Traffic information for media	Report of current traffic conditions, incidents, maintenance activities and other traffic-related information prepared for public dissemination through the media.
Traffic information for transit	Current and forecasted traffic information and incident information.
Transit archive data	Data used to describe and monitor transit demand, fares, operations, and system performance. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.
Transit incident information	Information on transit incidents that impact transit services for public dissemination.
Transit incident information	Information on transit incidents that impact transit services for public dissemination.
Transit information request	Request for transit operations information including schedule and fare information. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.
Transit multimodal	Transit schedule information for coordination at modal

Table 1 – VDOT NOVA ITS Architecture Information Flow Definitions

Flow Name	Flow Description
information	interchange points.
Transit system data	Current transit system operations information indicating current transit routes, the level of service on each route, and the progress of individual vehicles along their routes for use in forecasting demand and estimating current transportation network performance.
Traveler archive data	Data associated with traveler information services including service requests, facility usage, rideshare, routing, and traveler payment transaction data. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.
Traveler information for media	General traveler information regarding incidents, unusual traffic conditions, transit issues, or other advisory information that has been desensitized and provided to the media.
TRMS coord	Coordination information between local/regional transit organizations including schedule, on-time information and ridership.
Vehicle location	Location of vehicle and other vehicle characteristics which are exchanged between vehicle subsystems.
Vehicle probe data	Vehicle probe data indicating identity, route segment identity, link time and location.
weather information	Accumulated forecasted and current weather data (e.g., temperature, pressure, wind speed, wind direction, humidity, precipitation, visibility, light conditions, etc.).
winter maintenance dispatch information *	Information used to dispatch maintenance vehicles for winter maintenance and other special seasonal maintenance tasks. This information includes routing information, traffic information, road restrictions, incident information, weather information, maintenance schedule data, dispatch instructions, personnel assignments, and corrective actions.
work zone information *	Summary of maintenance and construction work zone activities affecting the road network including the nature of the maintenance or construction activity, location, impact to the roadway, expected time(s) and duration of impact, anticipated delays, alternate routes, and suggested speed limits.
work zone status *	Status of maintenance work zone.

The Information Flow definitions presented in Table 1 provide the basis for relating the ITS System Architecture to a Communications Architecture. In and of themselves, the definitions do not directly equate to a communications architecture. An intermediate step is required in order to translate the definitions into communications requirements. This translation is presented in Section 3 - Stakeholder Requirements.

2.4 ITS ARCHITECTURE & COMMUNICATIONS PLAN DEVELOPMENT

The process of developing the NOVA ITS System Architecture is represented by the flowchart in Figure 3. This process is described in detail in the System Architecture report. The process clearly identified where the stakeholder had direct input to and review of the process (i.e., Outreach). Essentially, the process entails developing a Strawman architecture based on existing and available information and further refining the architecture based on stakeholder review and input.

The development of the Communications Plan was done in parallel with the finalization of the System Architecture, as shown in Figure 3. The Strawman Architecture was so carefully defined, it was a rather complete definition of the architecture to be expected at the outcome of the development process. It was based on this Strawman definition that the communications analysis specific to the NOVA architecture began. Prior to this, communications technologies and standards information was able to be independently collected and assimilated - to be further refined after the architecture was complete. For additional information about the System Architecture development process, refer to the System Architecture report.

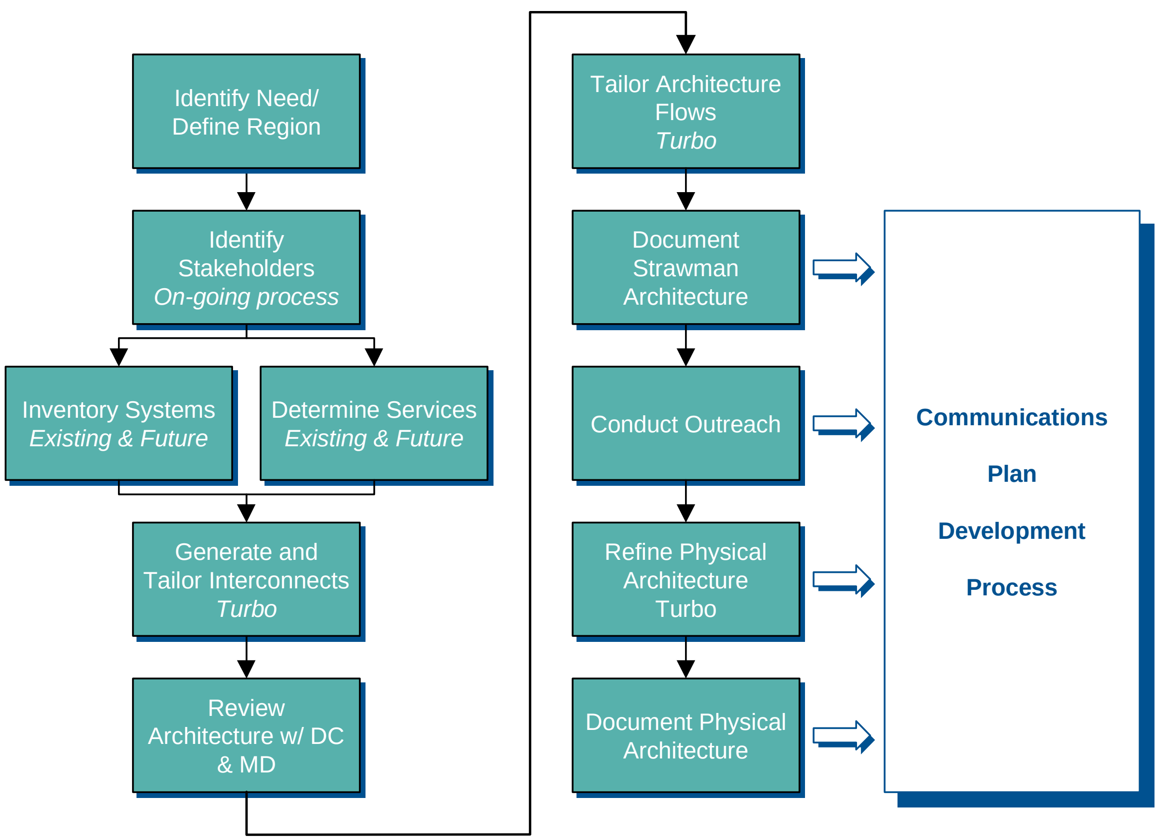

Figure 3 – ITS Architecture and Communications Plan Development Relationship

The detailed Communications Plan development process is shown by Figure 4. The major steps in the process include the following:

Step #1: The first step in the process focuses on determining architecture requirements and defining the Logical Communications architecture.

Step #2: Outreached to stakeholders to determine existing and planned communications infrastructure and services.

Step #3: Candidate communications technologies and architecture alternatives were identified and presented. Any relevant center-to-center and center-to-field standards were also researched and considered.

Step #4: The candidate technologies and architecture alternatives were evaluated based on specific criteria and an optimal solution was obtained.

Step #5: The Communications Plan was developed based on the prior recommendations.

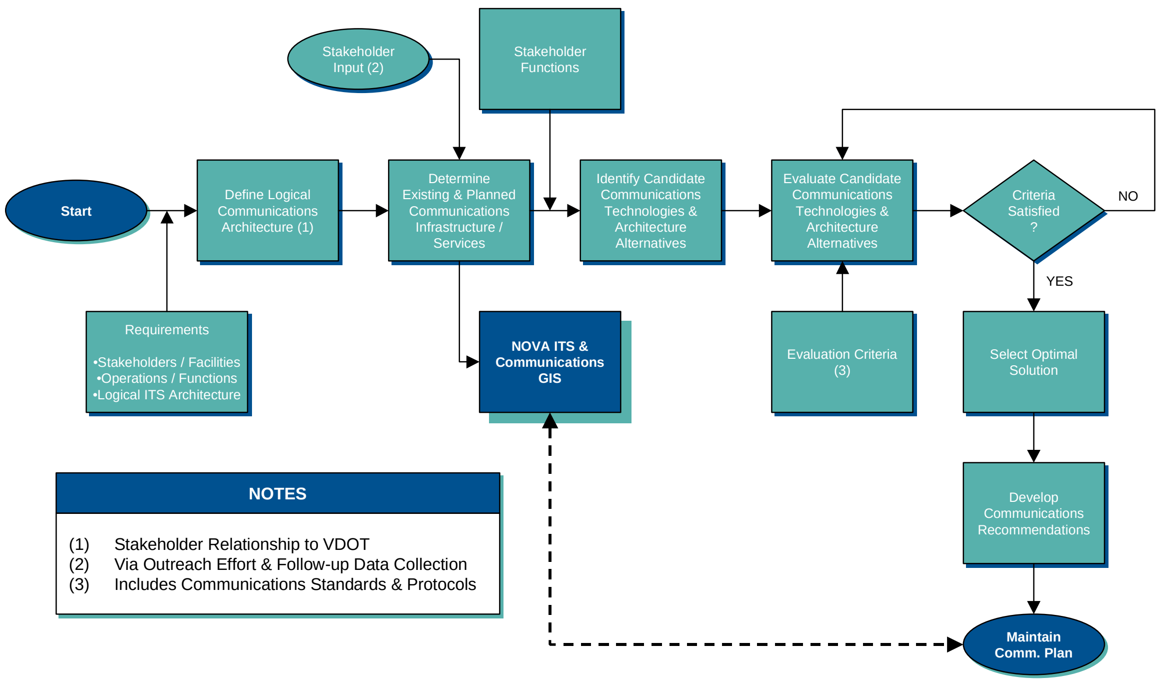

Figure 4 – Communications Plan Development Process

A major component to the Communication Plan and its development was the construction of an enhanced ITS asset and communications infrastructure Geographic Information System (GIS). This interactive and visual database tool supported the decision-making process associated with identifying gaps in the existing infrastructure and developing recommendations on the most effective way to augment the infrastructure to support the ITS System Architecture. The results of the GIS effort are noted in Section 4 - Communications Infrastructure and Services. The GIS is also an aspect of the recommended Communications maintenance strategy, further discussed in Section 9. Additional details about the GIS are included in the ITS/GIS Asset Baseline 1.0 report available from the project web site.

3 STAKEHOLDER REQUIREMENTS

This section will present the list of VDOT and non-VDOT stakeholders, organized by functional areas (consistent with the outreach process). This section will be organized by stakeholder functional group. This section will reference the outreach project deliverable, as necessary to direct the reader to additional relevant information. The stakeholder-imposed operational requirements set for the Information Flows will be presented. As applicable, the requirements will be tabulated and organized by common requirements imposed on each information flow. The requirements presented in this section will be related to the technical criteria established and presented in the Alternatives Analysis section, but will be more concerned with the operational aspects of the stakeholders and how they intend to use the VDOT information (video, voice, and data). Requirements to be presented and defined include:

- Information format (video, voice, and/or data)
- Information timeliness / latency tolerances
- Mission critical information / redundancy
- Existing or desired link (timeframe to establish)
- Frequency of information exchange [Note - "frequency" here means how often and doesn't imply (radio) frequency of a communications channel / system.]

Based on the stakeholder requirements, a project bandwidth will be established for Information Flows. This defined bandwidth (low, medium, high) will be used during the evaluation of the Candidate Technologies. As possible, an actual data load value (e.g., x - y Kbps) will be established.

3.1 NOVA STC

The VDOT NOVA STC information flows are shown below in Table 2:

Table 2 – VDOT NOVA STC Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.			X
Archive coordination	Catalog data, meta data, published data, and other information exchanged between archives to support data synchronization and satisfy user data requests.			X
Archive request confirmation	Confirmation that an archive request has been received and processed with information on the disposition of the request		X	X
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.		X	X

Table 2 – VDOT NOVA STC Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.			X
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.	X	X	X
closure coordination	Coordination between subsystems regarding construction and maintenance closure times and durations.		X	X
current network conditions	Current traffic information, road conditions, and camera images that can be used to locate and verify reported incidents, and plan and implement an appropriate response.	X	X	X
emergency traffic control response	Status of the special traffic signal control strategy implemented in response to the emergency traffic control request.			X
freeway control data	Control commands and operating parameters for ramp meters, dynamic message signs, mainline metering/lane controls and other systems associated with freeway operations.			X
hov restrictions status	This flow represents the STC providing NOVA Local Transit Centers with HOV restriction information to aid transit agencies in managing their routes.			X
incident information	Notification of existence of incident and expected severity, location, time and nature of incident.	X	X	X
incident information request	Request for incident information, clearing time, severity. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
local signal priority request	Request from a vehicle to a signalized intersection for priority at that intersection.			X
maint and constr administrative information *	General administrative data interchanges between ITS and non-ITS maintenance and construction systems. This includes: interfaces to purchasing for equipment and consumables resupply, interfaces to human resources that manage training and special certification for field crews and other personnel, and interfaces to contract administration functions that administer and monitor the work performance for maintenance and construction contracts.			X
maintenance resource request *	Request for road maintenance resources that can be used in the diversion of traffic (cones, portable signs), clearance of an incident, and repair of ancillary damage.		X	X
media information request	Request from the media for current transportation information.		X	X
parking lot data request	Request for parking lot occupancy, fares, and availability. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
public affairs information coordination *	Responsible for addressing the media during severe incident situations and providing an overall customer service roll for VDOT.	X	X	X

Table 2 – VDOT NOVA STC Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
request toll collection suspension	The STC can request to suspend toll collection based on an incident on the surface that requires motorist to utilize the Dulles Toll Road as an alternate route.		X	X
resource deployment status	Status of traffic management center resource deployment identifying the resources available and their current deployment status.		X	X
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.			X
roadway information system data	Information used to initialize, configure, and control roadside systems that provide driver information (e.g., dynamic message signs, highway advisory radio, beacon systems). This flow can provide message content and delivery attributes, local message store maintenance requests, control mode commands, status queries, and all other commands and associated parameters that support remote management of these systems.		X	X
Route plan	Tailored route provided by ISP in response to a specific request.			X
Sensor and surveillance control	Information used to configure and control sensor and surveillance systems at the roadside.			X
Traffic archive data	Information describing the use and vehicle composition on transportation facilities and the traffic control strategies employed. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X
Traffic control coordination	Information transfers that enable remote monitoring and control of traffic management devices. This flow is intended to allow cooperative access to, and control of, field equipment during incidents and special events and during day-to-day operations. This flow also allows 24-hour centers to monitor and control assets of other centers during off-hours, allows system redundancies and fail-over capabilities to be established, and otherwise enables integrated traffic control strategies in a region.	X	X	X
Traffic equipment status	Identification of field equipment requiring repair and known information about the associated faults.			X
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.	X	X	X
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X
Traffic information for media	Report of current traffic conditions, incidents, maintenance activities and other traffic-related information prepared for public dissemination through the media.	X	X	X
Traffic information for transit	Current and forecasted traffic information and incident information.	X	X	X
Transit information request	Request for transit operations information including schedule and fare information. The request can be a subscription that			X

Table 2 – VDOT NOVA STC Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	initiates as-needed information updates as well as a one-time request for information.			
Transit multimodal information	Transit schedule information for coordination at modal interchange points.			X
Traveler information for media	General traveler information regarding incidents, unusual traffic conditions, transit issues, or other advisory information that has been desensitized and provided to the media.	X	X	X

3.2 INCIDENT AND EMERGENCY MANAGEMENT

There are a number of Incident and Emergency Management stakeholders in the NOVA ITS Architecture and Communications Plan and they are:

- VDOT NOVA Safety Service Patrol
- VDOT Maintenance Special Operations
- Virginia State Police
- Arlington County Police and Fire
- Fairfax County Police and Fire
- Prince William County Police and Fire
- Loudoun County Fire and Rescue
- Prince William County Office of Public Safety
- Arlington County Emergency Communications Center
- City of Alexandria Police and Fire
- Fairfax City Police and Fire
- Falls Church Police and Fire
- Herndon Police
- Vienna Police
- Leesburg Police
- Manassas Police

The information flow definitions for the Incident and Emergency Management stakeholders are listed in Table 3 below:

Table 3 – Incident & Emergency Management Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.			X
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.		X	X

Table 3 – Incident & Emergency Management Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.			X
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.	X	X	X
closure coordination	Coordination between subsystems regarding construction and maintenance closure times and durations.		X	X
current network conditions	Current traffic information, road conditions, and camera images that can be used to locate and verify reported incidents, and plan and implement an appropriate response.	X	X	X
emergency dispatch requests	Emergency vehicle dispatch instructions including incident location and available information concerning the incident.		X	X
emergency dispatch response	Request for additional emergency dispatch information (e.g., a suggested route) and provision of en-route status.		X	X
emergency traffic control request	Special request to preempt the current traffic control strategy in effect at one or more signalized intersections or highway segments. For example, this flow can request all signals to red-flash, request a progression of traffic control preemptions along an emergency vehicle route, or request another special traffic control plan.		X	X
emergency traffic control response	Status of the special traffic signal control strategy implemented in response to the emergency traffic control request.			X
emergency vehicle tracking data	The current location and operating status of the emergency vehicle.		X	X
equipment maintenance status	Current status of field equipment maintenance actions.			X
freeway control data	Control commands and operating parameters for ramp meters, dynamic message signs, mainline metering/lane controls and other systems associated with freeway operations.			X
GIS database information *	The information provided through the GIS database is: Fiber optic duct locations, accident locations, speed information on county road segments, and map updates.			X
incident command information	Information that supports local management of an incident. It includes resource deployment status, hazardous material information, traffic, road, and weather conditions, evacuation advice, and other information that enables emergency personnel in the field to implement an effective, safe incident response.	X	X	X
incident information	Notification of existence of incident and expected severity, location, time and nature of incident.	X	X	X
incident information request	Request for incident information, clearing time, severity. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
incident report	Report of an identified incident including incident location, type, severity and other information necessary to initiate an appropriate incident response.		X	X
incident response coordination	Incident response procedures, resource coordination, and current incident response status that are shared between allied response agencies to support a coordinated response		X	X

Table 3 – Incident & Emergency Management Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	to incidents. This flow also coordinates a positive hand off of responsibility for all or part of an incident response between agencies.			
incident response status	Status of the current incident response including traffic management strategies implemented at the site (e.g., closures, diversions, traffic signal control overrides).		X	X
incident status	Information gathered at the incident site that more completely characterizes the incident and provides current incident response status.			X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
maint and constr work plans *	Future construction and maintenance work schedules and activities including anticipated closures with anticipated impact to the roadway, alternate routes, anticipated delays, closure times, and durations.		X	X
maintenance resource request *	Request for road maintenance resources that can be used in the diversion of traffic (cones, portable signs), clearance of an incident, and repair of ancillary damage.		X	X
parking lot data request	Request for parking lot occupancy, fares, and availability. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
public affairs information coordination *	Responsible for addressing the media during severe incident situations and providing an overall customer service roll for VDOT.	X	X	X
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
resource deployment status	Status of traffic management center resource deployment identifying the resources available and their current deployment status.		X	X
resource request	A request for traffic management resources to implement special traffic control measures, assist in clean up, verify an incident, etc.	X	X	X
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.			X
roadway information system data	Information used to initialize, configure, and control roadside systems that provide driver information (e.g., dynamic message signs, highway advisory radio, beacon systems). This flow can provide message content and delivery attributes, local message store maintenance requests, control mode commands, status queries, and all other commands and associated parameters that support remote management of these systems.		X	X
Route plan	Tailored route provided by ISP in response to a specific request.			X
Route request	Request for a tailored route based on given constraints.			X
Sensor and surveillance control	Information used to configure and control sensor and surveillance systems at the roadside.			X
Suggested route	Suggested route for a dispatched emergency vehicle that may reflect current network conditions and the additional routing		X	X

Table 3 – Incident & Emergency Management Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	options available to en-route emergency vehicles that are not available to the general public.			
Toll demand management request	Request to change the demand for toll road facility use through pricing or other mechanisms.			X
Traffic archive data	Information describing the use and vehicle composition on transportation facilities and the traffic control strategies employed. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X
Traffic control coordination	Information transfers that enable remote monitoring and control of traffic management devices. This flow is intended to allow cooperative access to, and control of, field equipment during incidents and special events and during day-to-day operations. This flow also allows 24-hour centers to monitor and control assets of other centers during off-hours, allows system redundancies and fail-over capabilities to be established, and otherwise enables integrated traffic control strategies in a region.	X	X	X
Traffic equipment status	Identification of field equipment requiring repair and known information about the associated faults.			X
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.	X	X	X
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X
Traffic information for media	Report of current traffic conditions, incidents, maintenance activities and other traffic-related information prepared for public dissemination through the media.	X	X	X
Traffic information for transit	Current and forecasted traffic information and incident information.	X	X	X
Transit incident information	Information on transit incidents that impact transit services for public dissemination.		X	X
Transit information request	Request for transit operations information including schedule and fare information. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.			X
Transit system data	Current transit system operations information indicating current transit routes, the level of service on each route, and the progress of individual vehicles along their routes for use in forecasting demand and estimating current transportation network performance.			X
Traveler information for media	General traveler information regarding incidents, unusual traffic conditions, transit issues, or other advisory information that has been desensitized and provided to the media.	X	X	X
winter maintenance dispatch information *	Information used to dispatch maintenance vehicles for winter maintenance and other special seasonal maintenance tasks. This information includes routing information, traffic information, road restrictions, incident information, weather information, maintenance schedule data, dispatch instructions, personnel assignments, and corrective actions.		X	X
work zone information *	Summary of maintenance and construction work zone activities affecting the road network including the nature of the maintenance or construction activity, location, impact to the roadway, expected time(s) and duration of impact, anticipated		X	X

Table 3 – Incident & Emergency Management Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	delays, alternate routes, and suggested speed limits.			
work zone status *	Status of maintenance work zone.		X	X

3.3 TRAFFIC OPERATIONS

There are a number of Traffic Operations stakeholders in the NOVA ITS Architecture and Communications Plan and they are:

- VDOT NOVA Smart Traffic Center
- VDOT NOVA Smart Traffic Signal System
- VDOT Dulles Toll Road
- Dulles Greenway
- City of Falls Church Signal System
- City of Fairfax Signal System
- City of Alexandria Signal System
- Arlington County Traffic Engineering
- City of Manassas Signal System
- City of Manassas Park Signal System
- Town of Herndon Signal System
- Town of Leesburg Signal System
- Town of Vienna Signal System
- District of Columbia Department of Public Works
- Maryland SHA CHART Program
- District of Columbia Traffic Management Center
- Maryland Transportation Authority
- National Park Services

The information flow definitions for the Traffic Operations stakeholders are listed in Table 4 below:

Table 4 – Traffic Operations Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.			X
Archive request confirmation	Confirmation that an archive request has been received and processed with information on the disposition of the request		X	X
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.		X	X

Table 4 – Traffic Operations Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.			X
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.	X	X	X
closure coordination	Coordination between subsystems regarding construction and maintenance closure times and durations.		X	X
closure data *	This flow represents road closure data that can be used to populate the GIS database.			X
current network conditions	Current traffic information, road conditions, and camera images that can be used to locate and verify reported incidents, and plan and implement an appropriate response.	X	X	X
emergency traffic control response	Status of the special traffic signal control strategy implemented in response to the emergency traffic control request.			X
emergency vehicle tracking data	The current location and operating status of the emergency vehicle.		X	X
emissions data	Emissions data and associated imagery collected by roadside equipment.	X		X
equipment maintenance status	Current status of field equipment maintenance actions.			X
event plans	Plans for major events possibly impacting traffic.		X	X
external reports	Traffic and incident information that is collected by the media through a variety of mechanisms (e.g., radio station call-in programs, air surveillance).	X	X	X
freeway control data	Control commands and operating parameters for ramp meters, dynamic message signs, mainline metering/lane controls and other systems associated with freeway operations.			X
GIS database information *	The information provided through the GIS database is: Fiber optic duct locations, accident locations, speed information on county road segments, and map updates.			X
hri advisories	Notification of Highway-Rail Intersection equipment failure, intersection blockage, or other condition requiring attention, and maintenance activities at or near highway rail intersections.			X
hri control data	Data required for HRI information transmitted at railroad grade crossings and within railroad operations.			X
hri request	A request for highway-rail intersection status or a specific control request intended to modify HRI operation.			X
incident information	Notification of existence of incident and expected severity, location, time and nature of incident.	X	X	X
incident information request	Request for incident information, clearing time, severity. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
incident report	Report of an identified incident including incident location, type, severity and other information necessary to initiate an appropriate incident response.		X	X
incident response coordination	Incident response procedures, resource coordination, and current incident response status that are shared between allied response agencies to support a coordinated response		X	X

Table 4 – Traffic Operations Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	to incidents. This flow also coordinates a positive hand off of responsibility for all or part of an incident response between agencies.			
incident response status	Status of the current incident response including traffic management strategies implemented at the site (e.g., closures, diversions, traffic signal control overrides).		X	X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
local signal priority request	Request from a vehicle to a signalized intersection for priority at that intersection.			X
maint and constr work plans *	Future construction and maintenance work schedules and activities including anticipated closures with anticipated impact to the roadway, alternate routes, anticipated delays, closure times, and durations.		X	X
media information request	Request from the media for current transportation information.		X	X
multimodal crossing status	Indication of operational status and pending requests for right-of-way from equipment supporting the non-highway mode at multimodal crossings.			X
parking lot data request	Request for parking lot occupancy, fares, and availability. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
resource deployment status	Status of traffic management center resource deployment identifying the resources available and their current deployment status.		X	X
resource request	A request for traffic management resources to implement special traffic control measures, assist in clean up, verify an incident, etc.	X	X	X
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.			X
roadway information system data	Information used to initialize, configure, and control roadside systems that provide driver information (e.g., dynamic message signs, highway advisory radio, beacon systems). This flow can provide message content and delivery attributes, local message store maintenance requests, control mode commands, status queries, and all other commands and associated parameters that support remote management of these systems.		X	X
Route plan	Tailored route provided by ISP in response to a specific request.			X
Route request	Request for a tailored route based on given constraints.			X
Sensor and surveillance control	Information used to configure and control sensor and surveillance systems at the roadside.			X
Signal control data	Information used to configure and control traffic signal systems.			X
Toll demand management request	Request to change the demand for toll road facility use through pricing or other mechanisms.			X

Table 4 – Traffic Operations Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Traffic archive data	Information describing the use and vehicle composition on transportation facilities and the traffic control strategies employed. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X
Traffic control coordination	Information transfers that enable remote monitoring and control of traffic management devices. This flow is intended to allow cooperative access to, and control of, field equipment during incidents and special events and during day-to-day operations. This flow also allows 24-hour centers to monitor and control assets of other centers during off-hours, allows system redundancies and fail-over capabilities to be established, and otherwise enables integrated traffic control strategies in a region.	X	X	X
Traffic control priority request	Request for signal priority at one or more intersections along a particular route.			X
Traffic equipment status	Identification of field equipment requiring repair and known information about the associated faults.			X
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.	X	X	X
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X
Traffic information for media	Report of current traffic conditions, incidents, maintenance activities and other traffic-related information prepared for public dissemination through the media.	X	X	X
Traffic information for transit	Current and forecasted traffic information and incident information.	X	X	X
Transit information request	Request for transit operations information including schedule and fare information. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.			X
Transit system data	Current transit system operations information indicating current transit routes, the level of service on each route, and the progress of individual vehicles along their routes for use in forecasting demand and estimating current transportation network performance.			X
Traveler information for media	General traveler information regarding incidents, unusual traffic conditions, transit issues, or other advisory information that has been desensitized and provided to the media.	X	X	X
work zone information *	Summary of maintenance and construction work zone activities affecting the road network including the nature of the maintenance or construction activity, location, impact to the roadway, expected time(s) and duration of impact, anticipated delays, alternate routes, and suggested speed limits.		X	X
work zone status *	Status of maintenance work zone.		X	X

3.4 TRANSIT

Transit stakeholders in the NOVA ITS Architecture and Communications Plan are:

- Virginia Department of Rail and Public Transit

- Virginia Railway Express
- Rail Operations – CSX and Norfolk Southern
- Washington Metropolitan Area Transportation Authority
- Potomac and Rappahannock Transportation Commission
- Omni Ride – Prince William County
- Arlington Regional Transit – Arlington County
- Virginia Railway Express
- City-University-Energy Saver Bus – Fairfax City
- DASH Bus Service – Alexandria City
- LCTA and Express Bus – Loudoun County
- Fairfax Connector – Fairfax County
- Fairfax County FASTRAN Services
- Falls Church Bus
- Springfield (TAGS Metro Springfield Circulator)
- Maryland Mass Transit Administration

The information flow definitions for the Transit stakeholders are listed in Table 5 below:

Table 5 – Transit Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.			X
Archive request confirmation	Confirmation that an archive request has been received and processed with information on the disposition of the request		X	X
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.		X	X
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.			X
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.	X	X	X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
local signal priority request	Request from a vehicle to a signalized intersection for priority at that intersection.			X
parking information	General parking information and current parking availability.			X
railroad advisories	Real-time notification of railway-related incident or advisory.		X	X
request for right-of-way	Forwarded request from signal prioritization, signal preemption, pedestrian call, multi-modal crossing activation, or other source for right-of-way.			X

Table 5 – Transit Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.			X
Signal control status	Status of surface street signal controls.			X
Traffic control priority request	Request for signal priority at one or more intersections along a particular route.			X
Traffic equipment status	Identification of field equipment requiring repair and known information about the associated faults.			X
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.	X	X	X
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X
Transit archive data	Data used to describe and monitor transit demand, fares, operations, and system performance. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X
Transit incident information	Information on transit incidents that impact transit services for public dissemination.		X	X
Transit information request	Request for transit operations information including schedule and fare information. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.			X
Transit system data	Current transit system operations information indicating current transit routes, the level of service on each route, and the progress of individual vehicles along their routes for use in forecasting demand and estimating current transportation network performance.			X

3.5 PLANNING

Planning stakeholders in the NOVA ITS Architecture and Communications Plan are:

- VDOT NOVA Geographic Information System
- VDOT NOVA Sections: Transportation Planning, Location & Design, Land Development, Traffic Engineering, Environmental, NOVA Residencies
- Metropolitan Washington Council of Governments
- Tri-Regional Architectures
- Northern Virginia Transportation Commission
- Fairfax County – Planning
- Prince William County – Planning
- Loudoun County – Planning
- Arlington County – Planning

- City of Alexandria – Planning
- City of Falls Church – Planning
- City of Fairfax – Planning
- City of Manassas – Planning
- City of Manassas Park – Planning
- Town of Herndon – Planning
- Town of Leesburg – Planning
- Town of Vienna – Planning
- VDOT Data Management Division
- VDOT Traffic Engineering Division – Mobility Data Store
- Smart Travel Lab - UVA
- Universities – George Mason and Virginia Tech Falls Church
- Federal Highway Administration Regional Resource Center

The information flow definitions for the Planning stakeholders are listed in Table 6 below:

Table 6 – Planning Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
Archive analysis requests	A user request that initiates data mining, analytical processing, aggregation or summarization, report formulation, or other advanced processing and analysis of archived data. The request also includes information that is used to identify and authenticate the user and support electronic payment requirements, if any.		X	X
Archive analysis results	Processed information products, supporting meta data, and any associated transaction information resulting from data mining, analytical processing, aggregation or summarization, report formulation, or other on-line processing and analysis of archived data.			X
Archive coordination	Catalog data, meta data, published data, and other information exchanged between archives to support data synchronization and satisfy user data requests.			X
Archive request confirmation	Confirmation that an archive request has been received and processed with information on the disposition of the request		X	X
archive requests	A request to a data source for information on available data (i.e. "catalog") or a request that defines the data to be archived. The request can be a general subscription intended to initiate a continuous or regular data stream or a specific request intended to initiate a one-time response from the recipient.		X	X
archive status	Notification that data provided to an archive contains erroneous, missing, or suspicious data or verification that the data provided appears valid. If an error has been detected, the offending data and the nature of the potential problem are identified.			X
archived data product requests	A user-specified request for archived data products (i.e. data, meta data, or data catalogs). The request also includes information that is used to identify and authenticate the user and support electronic payment requirements, if any.		X	X
archived data products	Raw or processed data, meta data, data catalogs and other data products provided to a user system upon request. The response may also include any associated transaction information.	X	X	X
emergency archive data	Logged incident information that characterizes the identified	X		X

Table 6 – Planning Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	incidents and provides a record of the corresponding incident response. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			
GIS database information *	The information provided through the GIS database is: Fiber optic duct locations, accident locations, speed information on county road segments, and map updates.			X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
probe data	Aggregate data from probe vehicles including location, speed for a given link or collection of links.		X	X
request for traffic information	Request for traffic information that specifies the region/route of interest, the desired effective time period, and other parameters that allow preparation of a tailored response. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
road network use	Aggregated route usage and associated travel data from clients for planning and analysis.			X
Traffic archive data	Information describing the use and vehicle composition on transportation facilities and the traffic control strategies employed. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X
Transit archive data	Data used to describe and monitor transit demand, fares, operations, and system performance. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X

3.6 INTERNAL VDOT

Internal VDOT stakeholders can be further grouped into the VDOT Central Office, FHWA, & other VDOT Districts:

- VDOT ITS Division
- VDOT Maintenance – ICAS
- VDOT Richmond District STC
- VDOT Hampton Roads STC
- VDOT Fredericksburg District ITS
- VDOT Culpeper District ITS
- VDOT Lynchburg District ITS
- VDOT Staunton District STC
- VDOT Salem District ITS
- VDOT Bristol District ITS
- VDOT Maintenance – TEOC
- FHWA

And Internal VDOT NOVA groups:

- VDOT NOVA Transportation Communication Center
- VDOT NOVA Technical Construction
- VDOT NOVA Snow Operations
- VDOT NOVA Equipment and Facilities
- VDOT NOVA Infrastructure Management
- VDOT NOVA Maintenance Construction
- VDOT NOVA Public Affairs

The information flow definitions for the Internal VDOT stakeholders are listed in Table 7:

Table 7 – Internal VDOT Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
archived data product requests	A user-specified request for archived data products (i.e. data, meta data, or data catalogs). The request also includes information that is used to identify and authenticate the user and support electronic payment requirements, if any.		X	X
closure coordination	Coordination between subsystems regarding construction and maintenance closure times and durations.		X	X
emergency dispatch requests	Emergency vehicle dispatch instructions including incident location and available information concerning the incident.		X	X
emergency vehicle tracking data	The current location and operating status of the emergency vehicle.		X	X
equipment maintenance status	Current status of field equipment maintenance actions.			X
event plans	Plans for major events possibly impacting traffic.		X	X
external reports	Traffic and incident information that is collected by the media through a variety of mechanisms (e.g., radio station call-in programs, air surveillance).	X	X	X
fault reports	Reports from field equipment (sensors, signals, signs, controllers, etc.) which indicate current operational status.			X
GIS database information *	The information provided through the GIS database is: Fiber optic duct locations, accident locations, speed information on county road segments, and map updates.			X
incident information	Notification of existence of incident and expected severity, location, time and nature of incident.	X	X	X
incident response coordination	Incident response procedures, resource coordination, and current incident response status that are shared between allied response agencies to support a coordinated response to incidents. This flow also coordinates a positive hand off of responsibility for all or part of an incident response between agencies.		X	X
incident response status	Status of the current incident response including traffic management strategies implemented at the site (e.g., closures, diversions, traffic signal control overrides).		X	X
ISP coordination	Coordination and exchange of transportation information between centers. This flow allows a broad range of transportation information collected by one ISP to be redistributed to many other ISPs and their clients.	X	X	X
maint and constr administrative information *	General administrative data interchanges between ITS and non-ITS maintenance and construction systems. This includes: interfaces to purchasing for equipment and consumables resupply, interfaces to human resources that manage training and special certification for field crews and			X

Table 7 – Internal VDOT Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	other personnel, and interfaces to contract administration functions that administer and monitor the work performance for maintenance and construction contracts.			
maint and constr work plans *	Future construction and maintenance work schedules and activities including anticipated closures with anticipated impact to the roadway, alternate routes, anticipated delays, closure times, and durations.		X	X
maintenance resource request *	Request for road maintenance resources that can be used in the diversion of traffic (cones, portable signs), clearance of an incident, and repair of ancillary damage.		X	X
media information request	Request from the media for current transportation information.		X	X
parking information	General parking information and current parking availability.			X
parking lot data request	Request for parking lot occupancy, fares, and availability. The request can be a subscription that initiates as-needed information updates as well as a one-time request for information.		X	X
public affairs information coordination *	Responsible for addressing the media during severe incident situations and providing an overall customer service roll for VDOT.	X	X	X
resource request	A request for traffic management resources to implement special traffic control measures, assist in clean up, verify an incident, etc.	X	X	X
roadside archive data	A broad set of data derived from roadside sensors that includes current traffic conditions, environmental conditions, and any other data that can be directly collected by roadside sensors. This data also indicates the status of the sensors and reports of any identified sensor faults.			X
Route plan	Tailored route provided by ISP in response to a specific request.			X
Route request	Request for a tailored route based on given constraints.			X
Suggested route	Suggested route for a dispatched emergency vehicle that may reflect current network conditions and the additional routing options available to en-route emergency vehicles that are not available to the general public.		X	X
Traffic control coordination	Information transfers that enable remote monitoring and control of traffic management devices. This flow is intended to allow cooperative access to, and control of, field equipment during incidents and special events and during day-to-day operations. This flow also allows 24-hour centers to monitor and control assets of other centers during off-hours, allows system redundancies and fail-over capabilities to be established, and otherwise enables integrated traffic control strategies in a region.	X	X	X
traffic information	Current and forecasted traffic information, road and weather conditions, incident information, and pricing data. Either raw data, processed data, or some combination of both may be provided by this architecture flow.	X	X	X
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X
Transit archive data	Data used to describe and monitor transit demand, fares, operations, and system performance. Content may include a catalog of available information, the actual information to be archived, and associated meta data that describes the archived information.			X

Table 7 – Internal VDOT Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
winter maintenance dispatch information *	Information used to dispatch maintenance vehicles for winter maintenance and other special seasonal maintenance tasks. This information includes routing information, traffic information, road restrictions, incident information, weather information, maintenance schedule data, dispatch instructions, personnel assignments, and corrective actions.		X	X
work zone information *	Summary of maintenance and construction work zone activities affecting the road network including the nature of the maintenance or construction activity, location, impact to the roadway, expected time(s) and duration of impact, anticipated delays, alternate routes, and suggested speed limits.		X	X
work zone status *	Status of maintenance work zone.		X	X

3.7 ELECTRONIC PAYMENT

Electronic Payment stakeholders in the NOVA ITS Architecture and Communications Plan are:

- VDOT Dulles Toll Road/Smart Tag
- Dulles Greenway
- Maryland MTAG Electronic Toll Collection System
- VDOT Fiscal Division – Smart Tag Center
- I-95 Corridor Coalition – EZ Pass
- Metropolitan Washington Council of Governments
- Metropolitan Washington Airport Authority
- Virginia Railway Express
- Washington Metropolitan Area Transportation Authority
- Local transit services (see Transit)

The information flow definitions for the Transit stakeholders are listed in Table 8 below:

Table 8 – Electronic Payment Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
incident response coordination	Incident response procedures, resource coordination, and current incident response status that are shared between allied response agencies to support a coordinated response to incidents. This flow also coordinates a positive hand off of responsibility for all or part of an incident response between agencies.		X	X
probe data	Aggregate data from probe vehicles including location, speed for a given link or collection of links.		X	X
request toll collection suspension	The STC can request to suspend toll collection based on an incident on the surface that requires motorist to utilize the Dulles Toll Road as an alternate route.		X	X
Toll demand management request	Request to change the demand for toll road facility use through pricing or other mechanisms.			X
Toll instructions	Demand management toll pricing information based on current congestion.			X
Toll Transactions	Detailed list of transactions from a toll station. Note this flow			X

Table 8 – Electronic Payment Information Flow Definitions

Flow Name	Flow Description	Flow Format		
		Video	Voice	Data
	contains good and bad tag data.			
Traffic information coordination	Traffic information exchanged between TMC's. Normally would include incidents, congestion data, traffic data, signal timing plans, and real-time signal control information.	X	X	X

4 COMMUNICATIONS INFRASTRUCTURE AND SERVICES

This section identifies existing and planned regional communications infrastructure or other communications services of VDOT and the stakeholders. Information on stakeholders was either collected directly from stakeholder contacts or from the Multi-Jurisdictional Transportation Telecommunications Study[1].

4.1 VDOT NOVA STC

VDOT owns and maintains a number of different communications media throughout the Northern Virginia (NOVA) region. The coverage area includes portions of I-66, I-95, and I-495/I-95, as well as I-395. The communications media provides connectivity to a number of ITS field components (CCTV, VMS, Ramp meters, Gate controllers, Vehicle detectors, and Lane Control Signals, etc.) via controller cabinets and facilitates center-to-center and center-to-field communications for some VDOT facilities. On I-66 and I-395, inside the Beltway (I-495), there is existing coaxial and twisted wire pair cables installed up to the Smart Traffic Center (STC). Portions of the twisted wire pair cable and all of the coaxial cable will be removed as part of another project on both interstates. Thereafter, communication links to VDOT controller cabinets will be via newly installed fiber optic cable. See Figures 5 and 6 for the location of existing VDOT NOVA twisted wire pair and coaxial cable, respectively.

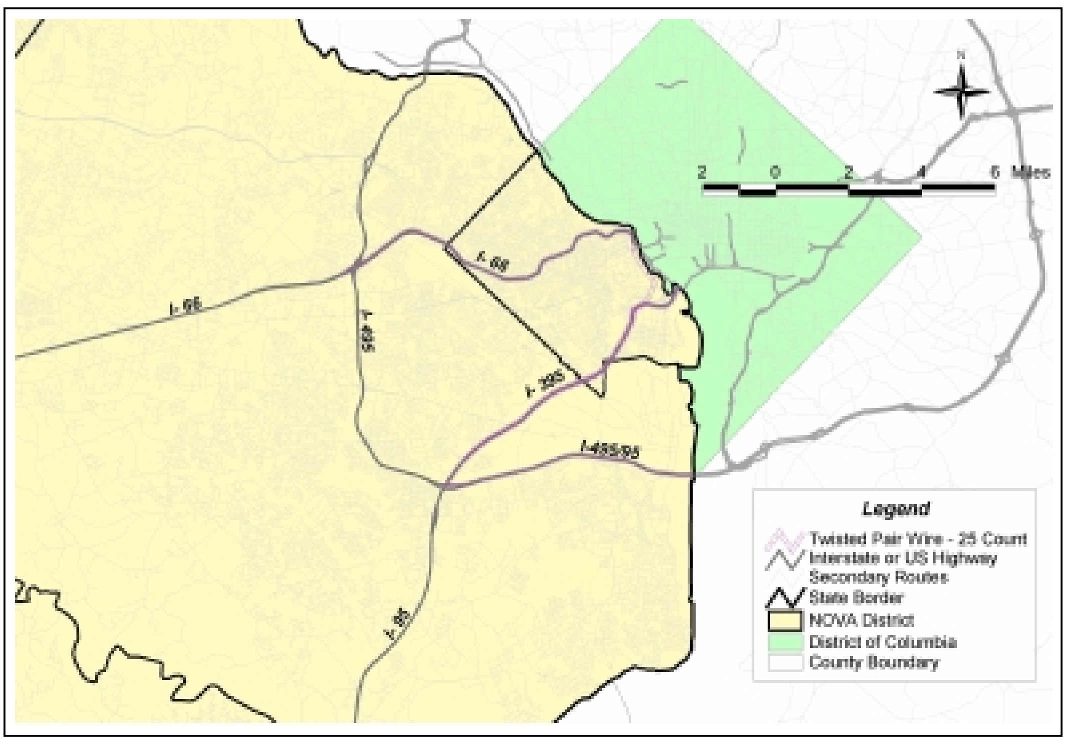

Figure 5 – VDOT NOVA Twisted Wire Pair Cable Locations

[1] "Multi-Jurisdictional Transportation Telecommunications Study for MD SHA and MWCOG", Computer Sciences Corporation and PB Farradyne, June 2000

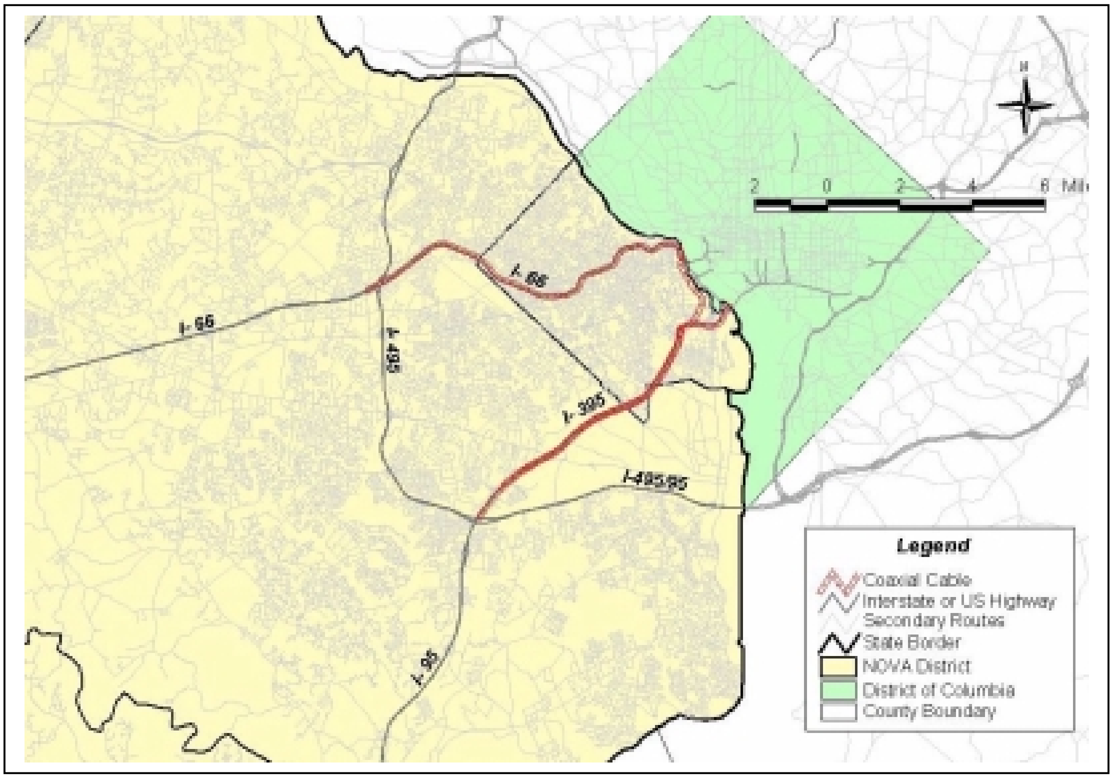

Figure 6 – VDOT NOVA Coaxial Cable Locations

There is single mode fiber (SONET and distribution) installed on I-66 from the STC to just west of Route 234 and on I-395 south to I-95 up to Quantico. The SONET fiber has a maximum line rate of 622 Mbps (OC-12) and consists of 48 fibers, while the distribution fiber varies from 6 fibers to 24 fibers. The SONET fiber on I-95/I-395 has been rerouted to Backlick Road from the Newington Hub to minimize the impact of the work being completed at the Springfield Interchange. The distribution fiber and TWP cable on I-66 are also routed over the Theodore Roosevelt Bridge, just over the District line, in order to communicate with some VDOT cabinets located in the District of Columbia. The communications cables on I-66 also run along Route 110 as they head towards the STC.

On I-495/I-95 (between the Woodrow Wilson Bridge (WWB) and the Springfield Interchange), multi-mode fiber optic cable and TWP cable provide the interface to the controller cabinets. These cabinets communicate with the STC via dedicated single mode fiber that interfaces with the multi-mode fiber at the Van Dorn Street Hub. Some fiber strands from the multi-mode fiber extends to the Maryland side of the WWB to interface with controller cabinets and facilitate the sharing of video between the Maryland State Highway Administration (MDSHA) and the NOVA STC. The available bandwidth in this existing fiber system has been used as part of the WWB replacement project. See Figure 7 for location of VDOT NOVA fiber optic cables.

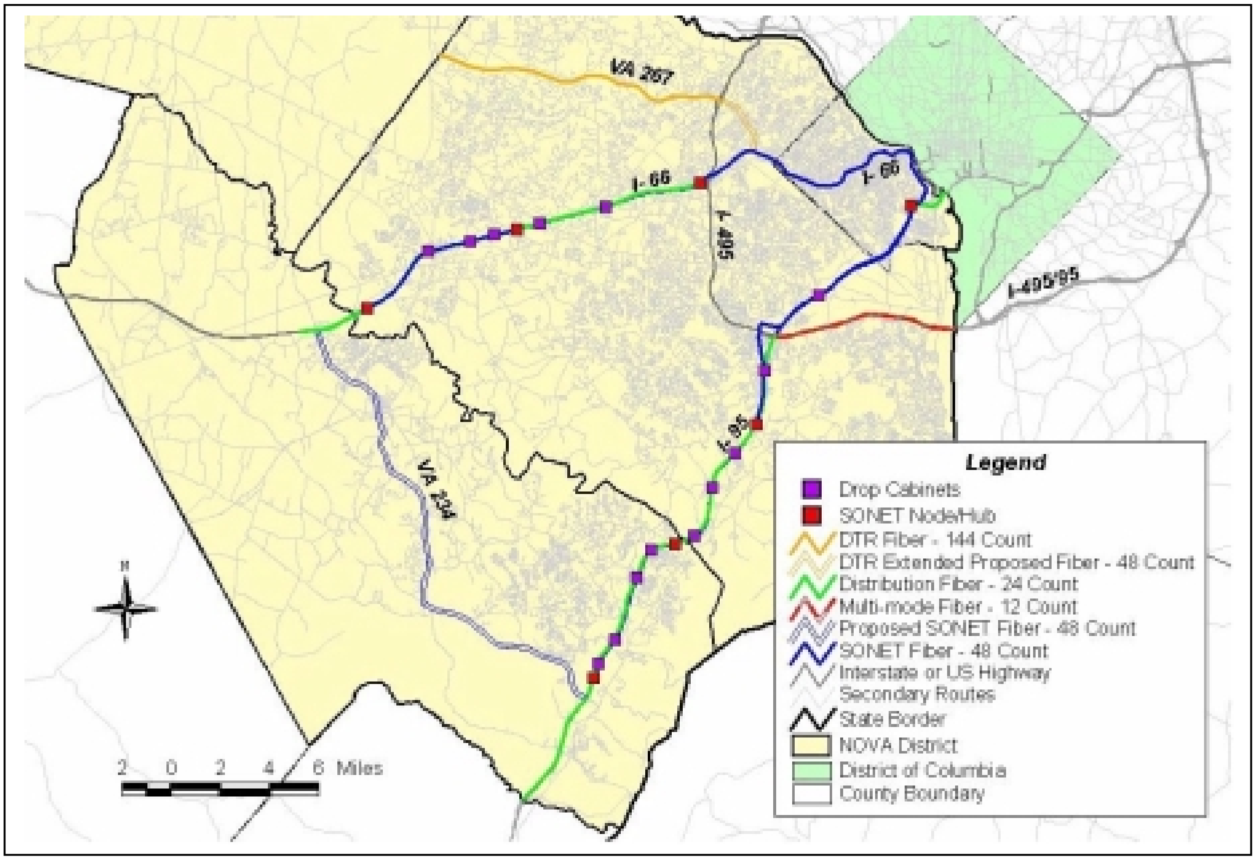

Figure 7 – VDOT NOVA Fiber Optic Cable Locations

VDOT has also obtained FCC licenses in order to install and operate Highway Advisory Radio (HAR) transmitters along their roadway network. At the present time, the only one that is operational is located on I-95 at Route 145 in Aquia (Aquia). The other planned HAR transmitter locations include I-495 at Route 1 (WWB), I-95 at Lorton Road (Lorton), and at the Van Dorn Area headquarters (Van Dorn).

4.2 INCIDENT AND EMERGENCY MANAGEMENT

4.2.1 VDOT NOVA SAFETY SERVICE PATROL (SSP)

VDOT's snowplow and Safety Service Patrol (SSP) fleets utilize time-based cellular digital packet data (CDPD) technology as a communications channel for their Automatic Vehicle Location (AVL) system. The fleet vehicles are equipped with on-board equipment including a CDPD modem with a unique IP address. The modems are able to communicate with Central spontaneously, at specific intervals, or they can be polled for Central. Communications between VDOT and the fleet vehicles occurs over the Verizon Wireless network.

4.2.2 PRINCE WILLIAM COUNTY POLICE / FIRE

The infrastructure utilized by PWC Police and Fire is County owned and consists of fiber optic cable, twisted wire pair cable, and some microwave components installed at pre-determined locations. The communication technology used includes Asynchronous Transfer Mode (ATM), Microwave, and Ethernet topologies. The bandwidth utilized by these topologies can range from 1 Mbps (megabit per second) to 100 Mbps depending on the location of the medium and the traffic being transmitted. The communication lines are presently being used to transmit data and voice feeds, but may possibly be used to transmit video sometime in the future.

4.2.3 FAIRFAX COUNTY FIRE AND RESCUE

The Fairfax County Fire and Rescue Department utilizes unshielded twisted wire pair (UTP) Category 5 100BASE-T cabling in all buildings where department business is conducted daily. In areas where signal degradation may be an issue, fiber optic cabling is used, with the interface being via Ethernet/Fiber Transceivers to Cisco Switches. There are still some UTP cable and network interface cards (NIC) in use on some floors of the Massey Building.

Most of the current wide area network (WAN) connections are via leased lines over T1 and Fractional T3, which provides a maximum bandwidth of 256 kbps (kilobit per second), and transmit only data traffic. The lines are leased from Verizon Networks along with some internal infrastructure from the Fairfax County Department of Information Technology (DIF).

The Fire and Rescue units currently communicate with the dispatch center via an eight-site, twenty (20) channel Motorola 800 MHz Digital Trunked radio system. As part of a complete upgrade Communications network, seamless mutual aid communications with neighboring jurisdictions including Arlington County, the City of Alexandria, Loundon, Montgomery, and Prince William County has been achieved. This has been accomplished in the first eight zones with all radios, in all jurisdictions, being programmed identically.

4.2.4 ARLINGTON COUNTY POLICE / FIRE

The Arlington County Fire and Police departments are currently interconnected via the County owned Institutional Network (I-Net). I-Net is a full duplex fiber optic network intended to interconnect governmental, educational, and non-commercial County sites, as needed, to receive fully interactive video, data, and voice signals.

The network consists of two control centers and hub locations. One center and hub is dedicated to public school sites while the other is being utilized for non-school locations. A single mode fiber optic cable line connects the two hub locations. Each I-Net location is linked to the I-Net control center via a 6-fiber single mode cable. Overall, I-Net links together thirty-nine (39) County Sites (Fire Stations, Police, and Public libraries), forty (40) school sites, and the WETA broadcast station.

The fiber plant is being maintained by SBC Media Ventures L.P.

4.2.5 CITY OF ALEXANDRIA POLICE

The City of Alexandria Police Department utilizes fiber optic cabling for transmissions between its facilities throughout the City and a mix of fiber optic cabling and Category 5e twisted wire pair cabling inside its facilities. The fiber connecting the facilities is located throughout the Comcast Fiber network within City limits. The communications media are used to transmit data, voice, and video feeds.

The infrastructure is owned and maintained by the City and upgrade plans are in the works that will increase the bandwidth capacity of the current network. The existing network operates at the Optical Carrier Level 3 (OC-3) line rate, which provides a maximum bandwidth of 155 Mbps.

4.2.6 CITY OF FALLS CHURCH POLICE

There are various communications mediums used within the City of Falls Church. Standard POTS (plain old telephone service) lines for Internet accesses are available throughout the city. Emergency phones are hooked up to a Verizon Centric. For connection to the Virginia State Police, frame relay is used at a bandwidth of 64kbps. T1s are present throughout the city for Internet access and are tied to a 100Mbps switch. Three (3) ISDN lines are available for the video magistrate.

Fiber optic cable is run to each floor of City Hall. The Police Dept. has both single mode and multi-mode fiber installed and running at 100Mbps. The internal phone system is hooked up to a NEC Private Branch Exchange (PBX) system. Star Power and Cox Communications has installed fiber optic cables in the city streets but not in City Hall. "Nestor" has fiber as well at T1 lines for video red light violations. Nestor Server is not part of the Police network.

4.3 TRAFFIC OPERATIONS

4.3.1 VDOT NOVA SMART TRAFFIC SIGNAL SYSTEM (STSS)

The VDOT NOVA STSS handles the communications link with approximately 1000 traffic signals via communications lines leased from Verizon. A fiber optic cable backbone provides a link from the Camp 30 facility in Fairfax to key node locations in the field. From that point, twisted wire pair cables provide the link to the separate field devices (traffic signal controllers).

The fiber backbone originates from the STC in Arlington and runs along I-66 to the VDOT Camp 30 facility in Fairfax. Currently, data is the only information being transmitted. The transmission rate for the signal system is 2.4 kbps for all locations except for Reston Parkway, which has a transmission rate of 9.6 kbps.

4.3.2 ARLINGTON COUNTY

Arlington County owns and maintains twenty-five (25) square miles of 19 AWG (American Wire Gauge) twisted wire pair (TWP) copper communications cable. This cable provides the medium of communication for the County’s two separate traffic control signal systems; the MONARC (Master Office Network Adaptive Real-time Control) system and the SCOOT (Split Cycle Offset Optimization Technique) system.

The County is also planning to upgrade its copper backbone to a T1 carrier network. This will facilitate communications with soon to be deployed Closed Circuit Television Cameras (CCTVs) and Variable Message Signs (VMSs). At present, Cox Communications is upgrading their cable television service in the County by installing a fiber optic backbone. There is a resource sharing agreement in place that will give the County access to two fibers for their use.

4.3.3 CITY OF ALEXANDRIA

The City of Alexandria owns and maintains approximately five (5) miles of twisted wire pair communications cable. The cable is currently being utilized as the medium for transmitting data to and from traffic signals within City limits. Due to the bandwidth limitations of fiber optic cable, the City is considering replacing the copper plant with fiber optic cable in the future. This will facilitate bringing an additional sixty intersections “on-line” as well as implementing video sharing capabilities with VDOT’s Northern Virginia (NOVA) Smart Traffic Center (STC) in the future.

4.3.4 CITY OF FALLS CHURCH

Refer to 4.2.5.

4.3.5 DULLES TOLL ROAD

The Dulles Toll Road (DTR), or Route 267, infrastructure includes twelve (12) miles of fiber optic cable on the main line (between Spring Hill Road and Route 28 East) and approximately four miles of cable on the Dulles Access Road (from I-66 to Spring Hill Road). The cabling includes a 144-strand fiber optic cable between the DTR Administration Building located on westbound Route 267 and the Spring Hill Road Interchange as well as a 180-strand fiber optic cable between the Administration Building and Route 28 East (Sully Road). All of the fibers are currently in use and facilitate the communications between the Administration Building and the ten (10) toll plazas locations (one on each side) with the exception of the Main Toll Plaza, which connects to the Administration Building via coaxial cable. These fibers have no extra capacity and phone lines are in place for use as backup to the fiber optic cabling.

There is also a 48-strand fiber optic cable on the Dulles Access Road that is currently dark. Nonetheless, handholes have been located along the route to facilitate the integration of future components. Refer to Figure 7 (Section 4.1.1) for locations of DTR fibers.

Lightwave Spectrum International, Inc (LSI) of Chantilly, VA, currently has a resource sharing agreement with VDOT that provides VDOT with 24 fibers out of the 144 fibers running along the DTR (between Spring Hill Road and Route 28). The agreement also specifies the installation of fiber optic cable on Route 234 between I-66 and I-95.

At the present time, VDOT and LSI are drafting resource sharing agreement that would enable VDOT to increase its available fiber capacity by having LSI install a 30-strand fiber optic cable along the DTR. When / If the new cable plant is installed, LSI would maintain the use of 24 fibers, two (2) fibers would be used as transmit and receive channels between the toll plazas, and 10 fibers will be dedicated for future use. The current 144-strand fiber optic cable along the DTR would be dark and also available for future use by VDOT.

As part of the agreement, an optical Ethernet network with new electronics will be installed in the Administration Building and each toll plaza. At each toll plaza, the two (2) fibers will go form the north toll plaza to the south toll plaza, then daisy chain to the adjacent toll plaza. The capacity for this network will be 8 Gbs (gigabit per second). The increase in fiber capacity would facilitate the addition of ITS components that cannot be addressed with the existing design.

The fiber plant is used to transmit data information for toll collection only. It is owned by VDOT, with LSI providing the Miss Utility locates, and Transcore providing network maintenance.

4.3.6 DULLES GREENWAY

The Dulles Greenway maintains three separate Windows NT domains. There are two in the Administration Building, one for Autostrade Administration, the operators of the road, and one for TRIP II (Toll Road Investors Partnership II). The two domains share a Category 5 twisted pair wire cable plant and utilize a 144 kbps Symmetric Digital Subscriber Line (SDSL), which supports the same data rates for upstream and downstream data. There is one Windows NT domain in the Operations building for Autostrade Operations.

The Automatic Revenue Collection System (ARCS) toll collection system consists of a VAX cluster operating on a 10 Mbps coaxial cable backbone. This connection is utilized by the fourteen (14) lanes at the main toll plaza. The ten (10) remote plaza locations communicate to the host via a point-to-point 9600 baud rate leased line with multiplexed serial connections. Eight lines are leased from MCI and two lines are leased from GTE/Verizon. The Dulles Greenway is operated and maintained by Autostrade International of Virginia.

4.3.7 MARYLAND STATE HIGHWAY ADMINISTRATION (MDSHA) COORDINATED HIGHWAYS ACTION RESPONSE TEAM (CHART)

The MDSHA has 48-fiber optic strands that run down I-83 from the Pennsylvania border to I-695, around the west side of I-695, then down I-95 to I-495, where it terminates in a communications hub facility in College Park. The fibers were obtained through a resource sharing agreement with MCI and has been utilized to build the CHART network backbone which connects five MDSHA facilities via asynchronous transfer mode (ATM) technology over an OC-3 Synchronous Optical Network (SONET).

Fiber will become available in conjunction with the Net.Work.Maryland effort, an initiative for the design and deployment of a statewide, high-speed fiber optic network. Additional resource sharing fibers will also be obtained from Level 3 Communications along I-68 from the west to I-70, down I-270, then along I-495 to a communications hub in McLean, Virginia. Another leg will leave this hub, go through the District of Columbia, and enter Maryland along the US-50 corridor to I-97. From here it will head up I-97 to I-695, to I-95, and will extend to the Delaware border along I-95. A third leg will come up US-301 from the Nice Bridge in southern Maryland, connecting with the leg along US-50 west of Annapolis. Communications over this fiber are expected to be ATM over OC-192 SONET. In the long term, the CHART backbone will be integrated into Net.Work.Maryland with 12 strands of the fiber will be reserved for ITS and SHA networking. Refer to Figure 8 for locations of Maryland Regional Fibers.

MDSHA uses various wireline services to communicate with facilities and devices across the state. T-1 lines for camera sites and CHART backbone connectivity have already been mentioned. MD SHA's enterprise backbone makes extensive use of frame relay with ISDN backup, particularly outside the densely developed center of the state. There are a number of plain old telephone service (POTS) lines providing communications to some field devices (Dynamic Message Signs (DMS), Traffic Advisory Radio (TAR), detectors, and Road Weather Information Systems (RWIS)). Integrated Services Digital Network (ISDN) is being phased in for the DMS communications as part of CHART II, a new initiative that will support access to field devices from a number of MDSHA facilities. Leased ATM services may also be employed to reach future hub sites on the CHART backbone.

MDSHA also maintains a statewide radio system to communicate to its maintenance fleet.

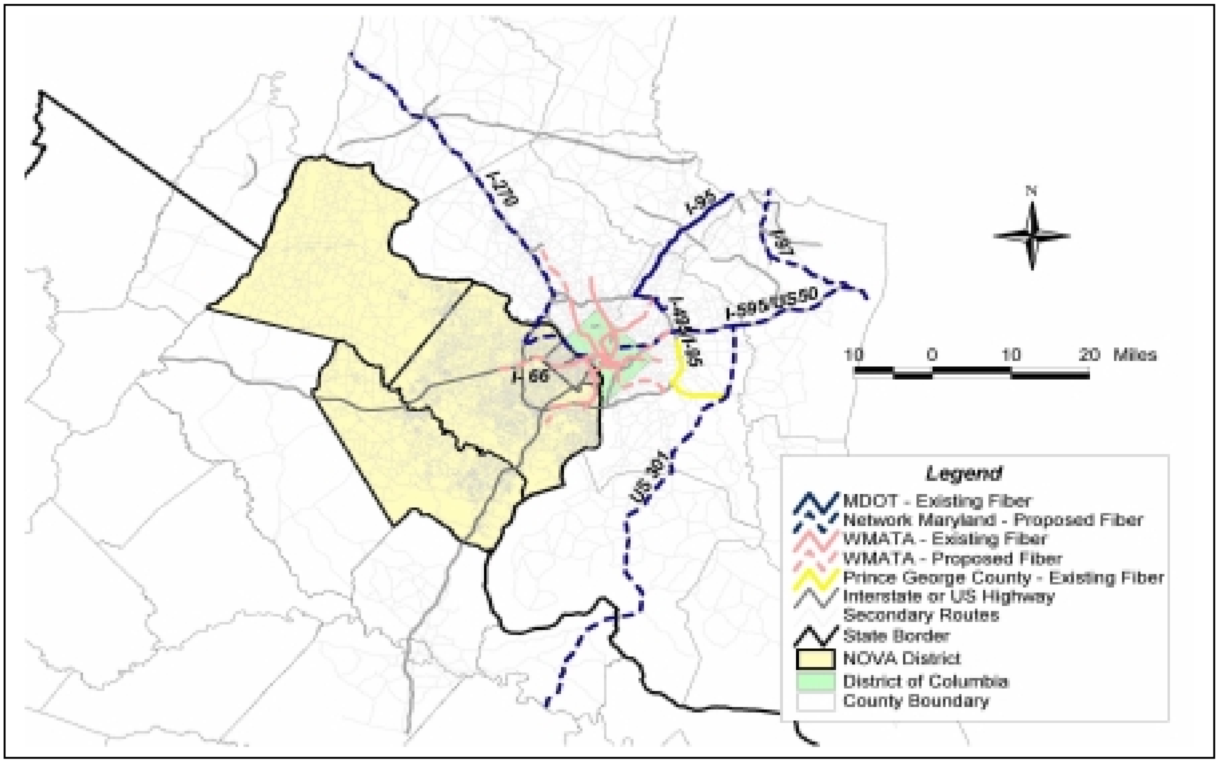

Figure 8 – Maryland / DC Fiber Optic Cable Locations

CHART hosts a web site for dissemination of traveler information to the public. A visitor to the site can view live video from the cameras, observe a roadway conditions map, obtain weather reports from SCAN, and view the most recently reported data from the RWIS.

4.3.8 DISTRICT OF COLUMBIA DEPARTMENT OF PUBLIC WORKS (DCDPW)

The existing DCDPW infrastructure consists of fiber optic cabling between the DC Traffic Management Center (TMC), the Department Heads' office, and the Snow Room, all located in the Reeves Building. Twisted wire pair copper cable facilitates communications between the TMC and all field devices and some field device locations are radio linked via microwave. Closed Circuit Television (CCTV) devices transmit on coaxial cable from device to data converters then link to the TMC via the TWP backbone. The communication links transmit data, voice, and video feeds.

The TWP cabling is located in the PEPCO duct system. DCDPW allows PEPCO to dig City streets, as needed for their use, in return for the use of one duct in their underground system. PEPCO owns the ducts and the City owns the cabling. The ducts are maintained by PEPCO or by DCDPW personnel with PEPCO permission.

The current TWP system will be upgraded to the fiber optic cable in the near future which will facilitate the support of existing and any proposed field devices, as well as the exchange of information with neighboring stakeholders.

4.3.9 NATIONAL PARK SERVICE

The National Park Service maintains a frame relay data network from their National Capital Region location in SW, DC, to their park headquarters located at Turkey Run on the George Washington Memorial Parkway. Verizon provides the data circuits.

4.4 PLANNING

4.4.1 METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS (MWCOG)

MWCOG currently has a single administrative LAN employing both NT and UNIX servers. A single T-1 line supports both Internet access and e-mail requirements.

4.4.3 FEDERAL HIGHWAY ADMINISTRATION – REGIONAL RESOURCE CENTER

There is no data infrastructure in place or planned for the future

4.4.4 FEDERAL HIGHWAY ADMINISTRATION – VIRGINIA OFFICE

There is no data infrastructure in place or planned for the future

4.5 TRANSIT

4.5.1 WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY (WMATA)

WMATA operates and maintains the Metrorail and Metrobus systems in the Washington Metropolitan Area. The Metrorail system employs fiber optic cabling and copper cabling installed in WMATA right-of-way, as the communications media to its field locations. (See Figure 8 (Section 4.3.7)). Some remote Metrorail facilities are connected to the system via leased T-1 lines or microwave communications.

Real-time train operations are continuously monitored from the WMATA Operations Center in downtown Washington. The Operations Center is not hardwired or connected to any outside agency transportation facilities and provides the main hub for the fiber optic cabling plant.

Currently, WMATA has 250 Metrobuses equipped with a global positioning satellite (GPS) system with static bus schedule information being made available via the web. A new digital trunked radio system (490MHz) will be deployed in the early 21st century to replace the current radio communications systems used by the Operations Center staff to communicate with the Metrobus fleet. The deployment of the new radio system will facilitate WMATA’s deployment of automated vehicle location (AVL) technology within its Metrobus fleet.

WMATA is in the process of identifying its future fiber optic cable needs for the next 5-10 years. Enhancements may include analyzing the existing fiber optic cabling system, replacing the remaining copper plant with fiber optic cables, and setting aside a number of fibers for as regional sharing purposes

4.5.2 POTOMAC AND RAPPAHANNOCK TRANSPORTATION COMMISSION (PRTC)

The PRTC operates OmniLink, a local bus service throughout Prince William County and, OmniRide, a commuter bus service serving the Arlington and Washington areas. OmniRide also provides local bus service on buses that employ global positioning satellite (GPS) technology, with automated vehicle location (AVL) to track its vehicles. When fully operational, bus drivers will confirm trip completions via a Mobile Data Terminal (MDT) by transmitting to the central tracking system.

PRTC uses basic two-way radio systems to communicate with the bus fleet operators and dispatchers. PRTC does not make use of wireline mediums to communicate with its bus fleet.

4.6 ELECTRONIC PAYMENT

4.6.1 DULLES TOLL ROAD

Refer to 4.3.5.

4.6.2 DULLES GREENWAY

Refer to 4.3.6.

4.6.3 METROPOLITAN WASHINGTON AIRPORT AUTHORITY (MWAA)

The MWAA operates the Washington Dulles International Airport (IAD) and the Ronald Reagan Washington National Airport (DCA). Both airport facilities have an extensive, intelligent infrastructure in place with approximately 3,200 fiber optic cables deployed at DCA and about 5,000 fiber optic cables deployed at IAD. Each airport campus has a dual ring backbone running SONET OC-3. The fiber plant at each airport is approximately 10% single mode and 90% multi-mode.
There is an 800MHz trunk radio system employed for radio communications between the two airports with some channels assigned for communications to the maintenance vehicle fleets serving each airport.

Both airports utilize individual operations centers. A collocation study was conducted in 2000 to examine the potential for combining both centers with the a centralized operations center being located at DCA. DCA also operates a highway advisory radio (HAR) system at the 530 AM dial setting.

MWAA is currently studying the feasibility to build new fiber optic cable connecting both Airports along the Dulles Toll Road – I-66 path. Right-of-way is an issue in the Crystal City and Arlington areas. SONET OC-48 technology is envisioned.

5 CANDIDATE TECHNOLOGIES

This section will present the various communications technologies and services currently available and projected to be available within the timeframe of the Comm. Plan. This section will be organized consistent with the "Sausage Diagram" (as discussed in the NOVA ITS Architecture section) and define technologies according to the following subsection structure.

5.1 WIRELINE COMMUNICATIONS

5.1.1 FIBER OPTIC CABLE

Fiber optic (FO) cable is a medium used to transmit information over long distances using pulses of light. It has a cylindrical shape and consists of three main parts. The inner most part is the core, which contains extremely thin strands of glass or plastic designed to transmit light signals. The amount of light capable of being transmitted by the fiber is dependent on the size of the core. The core is surrounded by cladding, a glass or plastic coating which has different optical properties from the core, to facilitate the reflection of the light traveling through the core. The outer most part of the optical fiber called the coating or jacket is made of plastic or other materials. The jacket provides protection for the fiber and prevents environmental destruction such as cuts. (See Figure 9.)

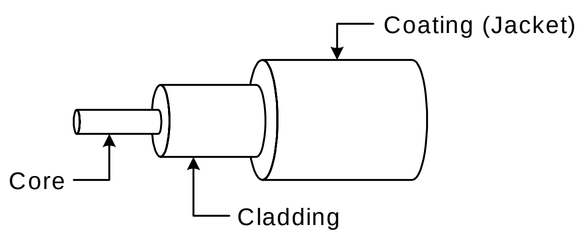

Figure 9 – Fiber Optic Cable

At one end of the fiber optic cable is an optical transmitter with a light source, typically a light-emitting diode (LED) or laser diode (LD). On the other end is an optical receiver with a light sensitive receptor, typically a PIN (Positive, Intrinsic, Negative) or Avalanche type photodiode (APD). In a typical system, the transmitter processes the input data and emits an optical signal that is carried along the optical fiber. The optical signal travels along the fiber until the receiver decodes it and the original data is restored.

There are several types of optical fiber in use today, each with individual characteristics and benefits depending on its intended use. These include multimode fiber, single-mode fiber, silica fiber, plastic fiber and ribbon fiber. Plastic fibers and silica fibers are not suitable for data communications and will not be discussed here. Multimode fiber has a large core diameter enabling a number of modes to be dispersed throughout its core. This results in the modes reaching the end of the fiber at separate times. Multimode fiber can further be categorized as step-index or graded index fiber with graded-index fiber providing less dispersion. Single-mode fiber has a much smaller core thereby limiting the different paths light can travel through it.

Figure 10 below illustrates the path light rays travel through multimode fiber and single-mode fiber.

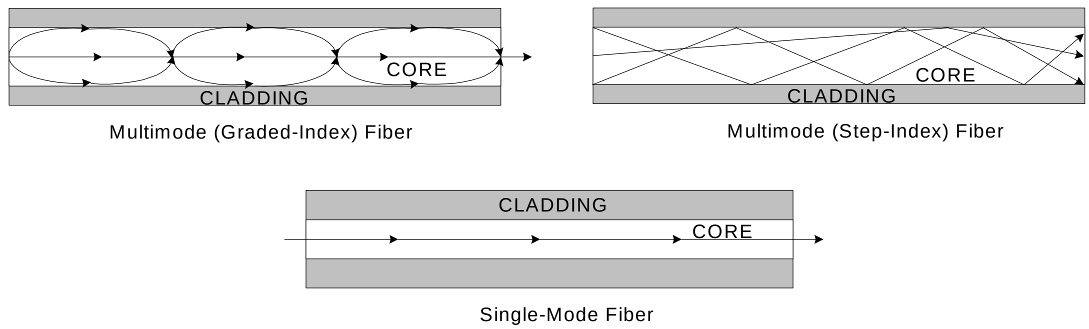

Figure 10 – Light Dispersion in Optical Fiber

The most common operating wavelengths of fiber optic cable are 850 and 1300 nanometers (nm) for multimode cable and 1300 nm and 1550 nm for single-mode cable. There are a number factors that affect the transmission capabilities of fiber optic cable. These factors are losses that occur as the light travels through the fiber's core. There are losses due to attenuation (loss in signal strength associated with the transmission process along the distance of the cable) caused by the scattering and/or absorption of the light as it passes through the cable. Scattering can be defined as a property of glass that causes light to deflect from the fiber, while absorption is the loss of light caused from impurities in the glass. Other losses are caused by the excessive bending of the cable beyond its designed allowable bending radius and by splices (method of joining ends of cable) along the cable.

The bandwidth of optical fiber is determined by its ability to disperse light as it is transmitted through the core region of the optical fiber, also known as dispersion. The path that the light ray travels (mode) is dependent on the angle the light ray entered the core and the core diameter. That is, a core with a large diameter has a larger number of modes being transmitted through the core. When light rays pass through the larger diameter core, they are dispersed thereby limiting the bandwidth of the fiber.
The bandwidth limitations of optical fiber also alter its performance, as it determines the maximum rate at which data can be transmitted. Single mode fiber can handle a higher bandwidth and has smaller attenuation losses when compared to multi-mode fiber. The low attenuation rates of optical fiber facilitate longer cable runs without the use of repeaters to regenerate the signal.

Overall, fiber optic cable transmits much more information over much longer distances than coaxial cable and twisted pair cable, and at much greater data rates. This makes fiber ideal for applications where video, data and/or voice are being transmitted. The cable is completely immune to any form of electronic, magnetic or radio frequency interference and emits no radiation.

5.1.2 TWISTED PAIR CABLE

Twisted pair cable is composed of two copper wires that are separately covered by plastic or some other similar material. The two insulated wires are twisted together to form a communications line with one wire carrying the signal while the other wire is grounded and absorbs signal interference. Twisting the wires together also reduces the effects of cross-talk from adjacent cables. It is widely used in telephone communications and local area network (LAN) installations and can be combined into a cable that may consist of two, four, fifty, or hundreds of pairs.

The two types of twisted pair cable available are shielded twisted pair (STP) or unshielded twisted pair (UTP). UTP cable is inexpensive, flexible, more readily available, and most of the local telephone networks in operation today. STP cable increases the cables' immunity to electromagnetic interference allowing it to transmit data over longer distances and making it suitable for environments with electrical interference, but only if the shield is properly grounded.

The Electronics Industries Association/Telecommunications Industries Association (EIA/TIA) has defined categories of unshielded twisted pair cable as listed below:

- Category 1 - Traditional telephone cable.
- Category 2 - Cable certified for data transmission up to 4 megabits per second (Mbps). Mainly used in token ring networks.
- Category 3 - The most common type of previously installed cable found in corporate wiring schemes and is certified for data transmission up to 10 Mbps. Used by 10BASE-T (Institute of Electrical Engineers (IEEE) 802.3 standard for Ethernet signaling) and 100BASE-T4 (IEEE standard for Fast Ethernet signaling) installations.
- Category 4 - This grade of UTP is not common and is certified for data transmission up to 16 Mbps. Used by 10BASE-T, 100BASE-T4 and token ring network installations
- Category 5 - The most popular cable used in new installations today and is certified for data transmission up to 100 Mbps. Used by 10BASE-T, 100BASE-T4 and 100BASE-TX (Fast Ethernet) installations.
- Category 6 - Used for super fast broadband applications.

The rate of attenuation that occurs in twisted pair cable is a result of its signal frequency, cable length, conductor size and the number of cable splices and connections along the cable. As the diameter decreases and operating frequency and cable length increase, attenuation in the cable increases.

5.1.3 COAXIAL CABLE

Coaxial cable consists of two conductors that are insulated from one another. The inner conductor is covered by a dielectric (nonconductor) with the outer conductor surrounding it and providing a shield. The outer shield protects the inner conductor from outside electrical signals. The distance between the inner and outer conductor and the type of material used for insulating the conductor determines the cable properties or impedance. Typical impedances for coaxial cables are 75 ohms for Cable TV and 50 ohms for Ethernet Thinnet (thin coaxial cable) and Thicknet (thick coaxial cable). The ability to control the impedance characteristics of the cable allow higher data rates to be transferred than with twisted pair cable. An insulating protective coating or jacket covers the outer conductor.

There are many applications for coaxial cable including cable television broadcast, local networking, short-length runs for computer networking and long- distance telephone transmissions. In local networking, coaxial cable supports different types of traffic and data communication including a single building or a complex facility. In the transmission of data between different computers, coaxial cable can serve high-speed input and output channels for computer systems. Coaxial cable can carry more than 10,000 channels at the same time by using Frequency Division Multiplexing (FDM), a method in which a number of signals are combined for transmission on one communications channel, by being assigned a different frequency within the main channel. The use of strategically located repeaters in coaxial cable runs enables the cable to carry information for great distances. Coaxial cable has a higher bandwidth than twisted pair cable, thereby supporting higher data rates.

5.1.4 HYBRID FIBER COAX (HFC)

Hybrid fiber-coax (HFC) is a technology that combines optical fiber with coaxial cable to provide video, data and voice services to residential users and businesses. Evolved from the coaxial cable distribution systems used in the CATV industry, the HFC architecture uses fiber optic cables as a backbone to carry video and telephony from a distribution center to a node (hub) serving a group of subscribers as small as 200 to 500 homes. At the node, the optical signal is converted to an electrical signal and transmitted via coaxial cables to the subscribers' homes or businesses. This technology provides users with high bandwidth two-way communications and minimal signal degradation from the head-end to the node.

The three areas or elements of an HFC system are:

- Network Elements: Service specific devices that connect the operator to service origination points and other equipment that places the service onto the network,
- HFC Infrastructure: Includes the fiber and coaxial cables, fiber transmitters, optical nodes and other components used to transmit from the head-end to the hub to the subscriber.
- Subscriber Access: Access equipment including set-top terminals, cable modems, and units used to integrate telephony services.

Figure 11 below depicts the typical HFC architecture.

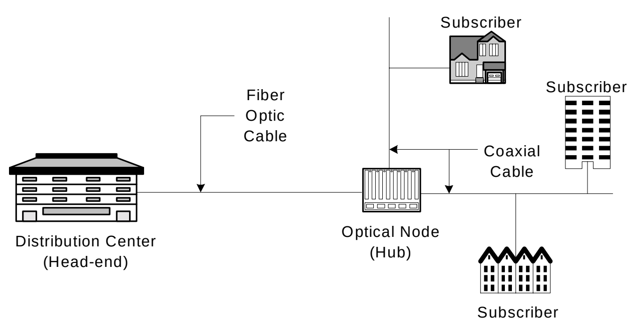

Figure 11 – HFC Architecture

Utilizing HFC technology increases bandwidth capacity, but that capacity must be divided into a downstream bandwidth (to the home) and an upstream bandwidth (to the hub). The downstream bandwidth typically occupies 50-750 MHz, while the upstream bandwidth occupies from 5-40 MHz

The use of fiber optic (FO) cable increases the bandwidth available for transmission since a wider range of frequencies can be used over FO cable. Signals also travel longer distances over the FO cable without the need for amplification. HFC supports simultaneous analog and digital transmission and, all current and emerging transmission technologies, including asynchronous transfer mode (ATM), synchronous optical network (SONET), frame relay and switched multi-megabit data service (SMDS).

5.1.5 POWER LINE CARRIER (PLC)

Power line carrier (PLC) communications refers to communications over the existing power cables that are prevalent in all homes and offices. Specifically, power line or "carrier-current" systems employ existing AC or DC power lines to transfer information that would normally require additional hardwire installation, thereby saving on costs associated with such installations.

PLC systems are attractive because they use existing electrical connections within a building. Typical applications include remote control, security systems, and low speed data networking. For the most part, the devices which employ power lines for data communication are intended for use in a single building and are restricted to fairly low speed information. This is primarily because power lines encounter very large inductances at the main transformers. This phenomenon tends to attenuate all but very low frequencies.

5.1.6 HIGH SPEED DIGITAL (T1 LINE)

A T1 line is a dedicated point-to-point digital telephone communications circuit used to transmit data and/or digitized voice. These lines are available in copper (shielded twisted pair) or fiber optic cables and consists of 24 individual digitized voice channels, each capable of supporting 64 kilobits per second (kbps), and an overall user data rate of 1.544 megabits per second (Mbps). A transmission rate of 64 kbps is the bandwidth normally used for one telephone voice channel and is also referred to as the Digital Signal 0 (DS0) transmission rate. Information is transmitted over T1 lines using Pulse Code Modulation (PCM), a digital scheme for transmitting analog data and Time Division Multiplexing (TDM), a method where multiple signals are combined (multiplexed) for transmission on a single communication channel.

When referring to T1 lines, the corresponding data stream is a DS1 signal, which is equivalent to 24 DS0 signals at 64 kbps. If more transmission capacity is required, a larger communications circuit needs to be used. This is accomplished by multiplexing digital signals together. For example, a DS2 (T2) signal is four DS1 signals (96 DS0s) multiplexed together to provide a desired user data rate. Figure 12 below provides an example of how the DS0s are multiplexed to provide more user capacity and Table 9 illustrates the relationship between the digital signals. The E1 carrier is a similar service being utilized in Europe.

The use of a T-carrier requires a Channel Service Unit / Data Service Unit (CSU / DSU), a device that connects to both ends of the carrier system (typically T1 and T3) to provide diagnostic capabilities, loopback functionality and access to a digital line. These devices can be sold separately, but are typically packaged as a single unit

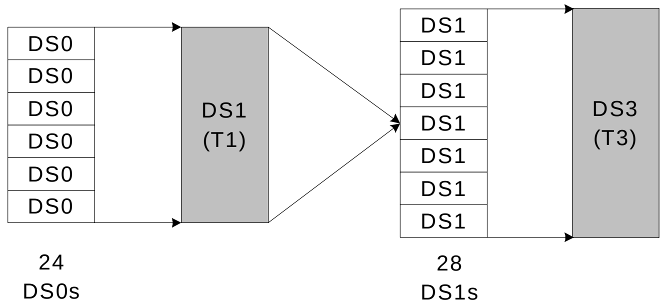

Figure 12 – Digital Grooming Scheme

Table 9 – Digital Signal Designators

Digital Signal	Carrier Name	Data Rate	Number of Channels
DS0	-	64 kbps	1
DS1	T1	1.544 Mbps	24
-	E1	2.048 Mbps	32
DS1C	T1C	3.152 Mbps	48 (2 T1s)
DS2	T2	6.312 Mbps	96 (4 T1s)
-	E2	8.448 Mbps	128 (28 T1s)
-	E3	34.368 Mbps	512
DS3	T3	44.736 Mbps	672 (28 T1s)
DS4	-	274.176 Mbps	4032 (168 T1s)

5.1.7 DIGITAL SUBSCRIBER LINE (DSL)

DSL is a telecommunications technology that utilizes existing twisted pair telephone lines to transmit high-bandwidth information to service subscribers with minimal change to the existing telephone infrastructure. The technology utilizes the unused bandwidth available on your home phone line to achieve higher data transfer rates. DSL service is always on – users don't need to dial a connection to gain access to the Internet – and some services even allow users to use the same line for voice and data traffic.

The equipment used to provide DSL services includes a DSL transceiver (DSL modem), which connects the user's computer to the DSL line; a DSL Access Multiplexer (DSLAM) at the service provider's location, that allows numerous users to use a single high-capacity connection to the Internet; and, telephone splitters used when the DSL service has to provide for simultaneous use of the Internet and the telephone.

As long as your home or business is close enough to your service providers' central office (a local office with switching equipment that connects everyone in a certain area to the companies network), you'll be able to subscribe to DSL service. As the connection length increases, the signal quality decreases and the connection speed goes down. Typical connections allow users to receive data at 1.5 Mbps and send data at approximately 256 kbps, though actual speed is determined by the proximity to the providers' central office.

The term *x*DSL refers to various forms of DSL technologies in use, depending on the specific needs of the subscriber and its availability from the service provider. All DSL variations fall into two categories: asymmetric DSL (ADSL) or symmetric DSL (SDSL). Some of the DSL technologies are described below:

- Asymmetric DSL (ADSL): Assumes Internet users download more information than they upload and provide more downstream (to subscriber) bandwidth than upstream bandwidth. Allows simultaneous phone use while on the Internet. Better suited for Internet users and users of remote LANs.
- Symmetric DSL (SDSL): Doesn't allow phone use while on the Internet. Speeds for receiving and sending information are the same. Better suited for web servers, corporate networks, or any organization that transmits large amounts of data.
- Very high bit-rate DSL (VDSL): An adaptation of ADSL used to transmit at very high rates, but only over short distances-typically between 1,000 and 4,500feet.
- High Bit Rate DSL (HDSL): An adaptation of SDSL providing data rates of 1.544 Mbps over TWP cable. It currently is the most widely used xDSL technology and is often utilized as an alternative to T1 connections.

DSL technology provides users with higher connection speeds compared to a regular modem, requires minimal upgrades to existing infrastructure and facilitates the use of a phone line for voice calls while the Internet connection is still active. However, the service may not be available everywhere and the connection speed may suffer depending on a subscriber's distance in relation to a provider's location.

5.1.8 OPEN SYSTEMS INTERCONNECTION (OSI)

OSI is a reference model developed by the International Organization for Standardization (ISO) in 1984 to describe how information should be transmitted between two points in a telecommunication network. The functions and protocols associated with the OSI reference model enable any computer system to connect to another computer system, regardless of the manufacturer.

The OSI model is composed of seven layers, with each specifying particular network functions. Figure 13 illustrates the layers of the OSI reference model.

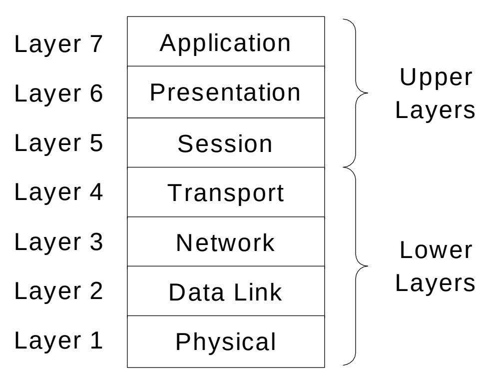

Figure 13 – OSI Reference Model

The seven layers of the OSI model can be separated into two categories. The upper layers are used whenever messages pass from or to a user. The lower layers are utilized when messages pass through the host computer. The interaction between OSI layers is such that any given OSI layer communicates with three other OSI layers. That is, a given layer typically communicates with the layer directly above it, the layer directly below it and its peer layer in the other networked computer systems.

A brief description of the seven OSI layers is provided below.

- **Layer 1: Physical Layer** – Defines the physical and electrical characteristics of the network. Layer connections can be point-to-point or multi-point with operations capable in simplex, half-duplex or full-duplex mode.

- **Layer 2: Data Link Layer** – Establishes a protocol interface across Layer 1 on behalf of the Network layer (Layer 3). Its data link control functions establish a peer-to-peer relationship to provide for the reliable transit of data across a physical network link. The entities in this layer exchange clearly delimited data units called frames.

- **Layer 3: Network Layer** – Provides reliable, in-sequence delivery of protocol data between Transport layer entities. Supports connection-oriented and connectionless service from higher-layer protocols and may also perform end-to-end flow control and the segmentation and re-assembly of data. The Internet Protocol (IP) resides in this layer.

- **Layer 4: Transport Layer** – Manages end-to-end flow control (ensuring all data packets are delivered) and some error checking functions. Its main purpose is to implement reliable inter-network data transport services and interconnect Session layer (Layer 5) entities. The Internet Transmission Control Protocol resides in this layer.

- **Layer 5: Session Layer** – Provides for two communicating presentation entities to exchange data with each other via connections between a user, such as a terminal or LAN workstation, and a central processor or host. Some examples of this layer include terminal-to- mainframe log-on procedures and the transfer of user information.

- **Layer 6: Presentation Layer** – Determines how data is presented to the user by providing a variety of coding and conversion functions that are applied to Application layer (Layer 7) data. Some examples of protocols in this layer include video and text display formats such as MPEG, JPEG and GIF.

- **Layer 7: Application Layer** – Provides the actual interface to the end user and manages the program or device generating the data to the network. Examples of application layer implementations are TCP/IP protocols such as Telnet, File Transfer Protocol (FTP).

Information being transmitted from a software application in one computer system to a software application in another system must pass through each of the OSI layers. That is, the information flows down from the Application layer (Layer 7) of the originating system to the Physical layer (Layer 1). At that point, the information is placed on the physical network and transmitted across the interconnecting physical medium to the destination system. Upon arrival of the information at the destination system, the information flows up from Layer 1 to Layer 7, where the application program completes the communication process.

SWITCHING TECHNOLOGY

5.1.9 FRAME RELAY (FR)

Frame Relay is a high-speed telecommunication service, utilizing packet switching technology to transmit information over a Wide Area Network (WAN). Packet switching refers to the protocols in which messages to be sent are broken up in to small packets prior to transmission. Each packet is embedded with information related to its source, destination and other unique identifiers. This facilitates the reassembling of the original message at the receiving end as the packets are transmitted separately and can follow different paths to the destination. Typical frame relay connections range from 56Kbps to 2Mbps. Frame relay is similar to packet switching X.25, but is more streamlined giving higher performance and greater efficiency.

Frame Relay operates at layers 1 and 2 of the Open Systems Interconnection (OSI) model. Layer 1 is the Physical layer dealing with the signaling of the message and the interface between the sender or receiver and the medium. Layer 2 is the Data Link layer and describes the representation of bits on the physical medium and the format of messages on the medium. The Data Link layer also provides for some error correction but does not guarantee message delivery.

The components included in a frame relay network can be separated into two categories: data terminal equipment (DTE), which consists of the network terminating equipment such as terminals, PCs, bridges and routers; and, data circuit-terminating equipment (DCE) which actually transmit data through the WAN, such as packet switches.

In order to provide a connection among DTE devices, a “logical” connection is created by using a uniquely identified virtual circuit. Virtual circuits can be classified as permanent virtual circuits (PVCs) or switched virtual circuits (SVCs), and provide a bi-directional communications path between DTE devices. SVCs are temporary connections established by the network on a call-by-call basis. Once transmission is completed, the network connection is dismantled. PVCs are permanently established connections that are available for use at all times. Most frame relay networks utilize PVCs rather than SVCs partly because PVCs were the original service offered. A data-link connection identifier (DLCI) uniquely identifies PVC on a frame relay network. Each DLCI has a permanently configured switching path to a destination allowing a system with several configured DLCIs to simultaneously communicate with a number of sites.

The structure and organization of a frame is defined by the frame relay frame format shown in Figure 14. Descriptions of the frame format fields are also included.

Flags	Address	Information (Payload)	FCS	Flags

Figure 14 – Frame Relay Frame Format

- Flags: Indicates the beginning and the end of the frame.
- Address (Frame Relay Header): Contains information related to the following:
    - DLCI bits: Identifies a virtual circuit on the Frame Relay Network
    - Extended Address (EA) bits: Enables the expansion of the DLCI addressing structure to handle more addresses.
    - Command/Response (C/R) bit: Currently not used by the protocol.
    - Congestion Control: These include the Forward-explicit congestion notification (FECN), the Backward-explicit congestion notification (BECN) and the Discard Eligibility (DE) bits. These bits determine the network response to congestion. The BECN bit controls traffic at the source, while the FECN bit initiate flow

control at the destination. The DE bit sets the priority for frames to be discarded during congestion periods on the network.

- Information (Payload): Contains the actual user data.
- Frame-Check Sequence (FCS): Ensures the integrity of the frame. Damaged frames are discarded and not transmitted.

Frame relay implements multiple virtual circuits over a single connection, but does so using statistical multiplexing techniques which yields a much more flexible and efficient use of the available bandwidth. FR includes a cyclic redundancy check (CRC) for detecting corrupted data, but does not include any mechanism for correcting corrupted data.

Many higher level protocols include their own flow control algorithms. Frame Relay implements a simple congestion notification mechanism to notify the user when the network is nearing saturation, thereby offering higher performance and greater transmission efficiency. The packet switching technology utilized can dynamically allocate bandwidth during data transfers.

5.1.10 ASYNCHRONOUS TRANSFER MODE (ATM)

ATM is also a set of international interface and signaling standards defined by the International Telecommunication Union-Telecommunications Standardization Sector (ITU-T) for cell relay, which employs small, fixed-sized cells to transport information at high speeds. ATM is also a communications networking technology that combines the benefits of circuit switching (minimum routing delays) with those of packet switching (efficient for bursty traffic) and utilizes a fixed sized cell (packet) structure to carry different types of traffic. ATM transmits data by separating them into small fixed size cells of 53 bytes each with the first 5 bytes containing the cell header information and the remaining 48 bytes carrying the payload or user information, typically voice, data or video. The fixed cell size ensures that time critical information is not affected by long packets.

The components of an ATM network include ATM switches and ATM endpoints. The ATM endpoints are components that contain an ATM network interface adapter, i.e., routers, workstations and LAN switches. The ATM switches route the cells through the ATM network based on cell header information. The switches support two types of interfaces: a user-network interface (UNI) which connects ATM endpoints to an ATM switch and a network-node interface (NNI) which connects two ATM switches.

The ATM cell header will be in either UNI or NNI format depending on its intended route. The ATM cell formats and the UNI and NNI cell header formats are shown below in Figure 15. A description of the cell header fields also follows.

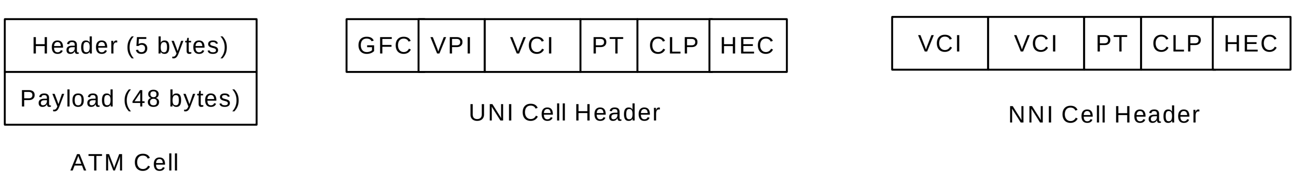

Figure 15 – ATM Cell, UNI Cell Header and NNI Cell Header

- Generic Flow Control (GFC) – Permits transmissions of several endpoints to be multiplexed on the same ATM interface. Only used in UNI cell headers.
- Virtual Path Identifier (VPI) / Virtual Circuit Identifier (VCI) – Identifies the next destination of a cell it passes through a series of ATM switches on the way to its destination.
- Payload Type (PT) – indicates if a cell contains user data or control data.
- Congestion Loss Priority (CLP) – Provides some buffer management based on the value of the bit. If set to zero, the cell cannot be discarded. If set to one, it may be discarded depending on network conditions.
- Header Error Control (HEC) – Used to detect and correct errors in the header.

ATM is a connection-oriented technology whose services exist on permanent virtual circuits (PVC), switched virtual circuits (SVC) or connectionless service. The building blocks of ATM networking are a virtual circuit or channel (VC), a virtual path (VP) and a physical transmission circuit. The physical circuit supports on or more virtual paths, which in turn support numerous virtual channels. The VPI and the VCI identify the virtual channel and virtual path, which only has local significance across an ATM link, as they are remapped as need at each switch. Figure 16 depicts the relationship between the VC, VP and transmission circuit.

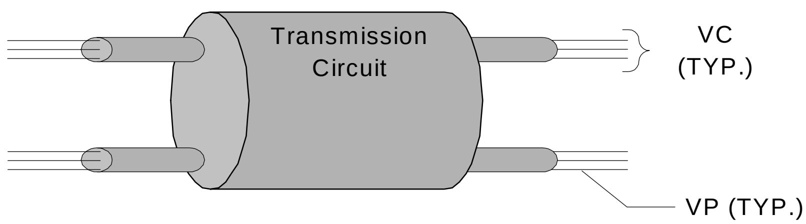

Figure 16 – ATM Virtual Connections

The ATM reference model relates to the first two layers of the OSI model (Physical Layer and Data Link Layer).

ATM is designed for handling large amounts of data across long distances using a high-speed backbone approach. Rather than allocating a dedicated virtual circuit for the duration of each call, data is assembled into small packets and statistically multiplexed according to their traffic characteristics. ATM dynamically allocates bandwidth for traffic on demand. This means greater utilization of bandwidth and better capacity to handle heavy load situations. ATM provides no error detection, error correction, or retransmission services. While earlier networking protocols have/do provide these, it has been determined that today's networking equipment is quite reliable and therefore these services are no longer needed. Replacing earlier administrative functions with much simpler ones helps to support the multi-megabit transfer rates associated with ATM.

When an ATM connection is requested, details concerning the connection are specified which allow decisions to be made related to the route and handling of the data. Typical details are the type of traffic, destination, peak and average bandwidth requirements, and cost factor. The connection oriented service classes available via ATM are listed below:

- Constant Bit Rate (CBR) – Cell rate throughput is constant with time and data is sent in a steady stream.

- Variable Bit Rate-Real Time (VBR-rt) – Cell throughput is bursty but delay of cell data is critical, as the cells are sensitive to delay and loss.
- Variable Bit Rate- Non-Real time (VBR-nrt) – Cell throughput is bursty with less severe delay requirements.
- Unspecified Bit Rate (UBR) – Supports connections where no throughput levels are guaranteed for the cells. It's widely used for TCP/IP.
- Available Bit Rate (ABR) – A minimum cell rate is guaranteed, but data may be sent in a bursty manner at higher rates when the network bandwidth becomes available.

The Coordinated Highways Action Response Team (CHART) program deployed by the Maryland State Highway Administration (SHA), uses ATM technology as the interface to distribute video images from closed circuit television (CCTV) cameras to numerous satellite facilities within the State of Maryland. Refer to the Section 4 of this document for more information on the CHART Program.

5.1.11 FIBER DISTRIBUTED DATA INTERFACE (FDDI)

Fiber Distributed Data Interface (FDDI) is a standard for dual-ring Local Area Networks (LANs) utilizing the token ring protocol. Originally developed by the American National Standards Institute (ANSI) X3T9.5 standards committee in the mid-80s, FDDI was implemented to support LAN workstations and their new distributed applications. Utilizing fiber optic cable as its transmission medium, FDDI employs a dual-counter rotating ring architecture (see Figure 5-9) whereby a primary ring and secondary ring can be used to transmit data in opposite directions as needed. Single-mode fiber optic cable is the preferred medium as it is capable of achieving a higher performance bandwidth and communicates over longer distances. When using multi-mode fiber optic cable, FDDI only allows a maximum distance of 2 kilometers (1.24 miles) between stations (or nodes). This distance is increased to 20 kilometers (12.42 miles) with single-mode fiber optic cable.

Data normally travels on the primary ring (anti-clockwise) unless a fault occurs, at which point the working stations "wrap" (doubles back onto itself) onto the secondary ring (clockwise) to maintain the network. The upstream neighbor of a particular station is the one that is sending data to this station on the primary ring. The downstream neighbor is the one relieving data from this station on the primary ring. The primary ring provides up to 100 Mbps capacity and can support 500 stations on a single network. Employing the dual ring architecture improves upon the reliability and robustness of the network.

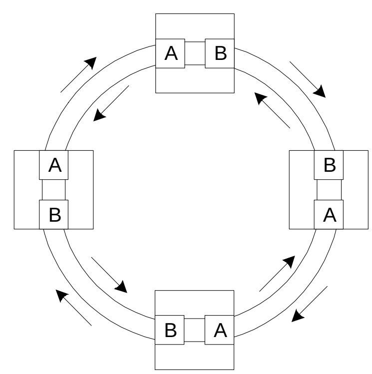

Figure 17 – FDDI Dual Ring

The FDDI specification defines the use of OSI Layers 1 (Physical layer) and 2 (Data Link layer), with each layer being further separated into sublayers. The Physical layer can be separated into sublayers for the Physical Layer Medium Dependent (PMD) layer and the Physical Layer Protocol (PHY). The Data Link layer can be divided into sublayers for Media Access Control (MAC) and Logical Link Control (LLC). The FDDI Station Management standard provides the control needed at the station to manage the processes under way in the FDDI layers. A depiction of the interaction between layers as well as a description of each standard is shown below in Figure 18.

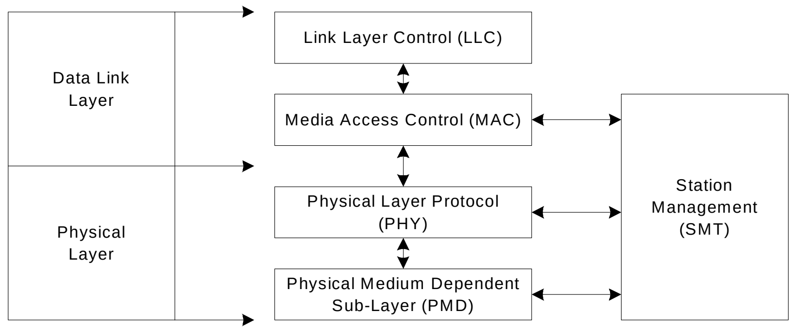

Figure 18 – FDDI Standards Mapped to OSI Model

- Physical Layer Medium Dependent (PMD): The lower sublayer of OSI Layer 1 (Physical Layer). Defines the characteristics of the transmission medium including links, components and connectors.
- Physical Layer Protocol: The upper sublayer of OSI Layer 1. Defines data encoding/decoding procedures and clocking requirements
- Media Access Control (MAC): The lower sublayer of OSI Layer 2 (Data Link Layer). Defines how the medium is accessed, including frame format and addressing conventions.
- Logical-Link Control (LLC): The upper sublayer of OSI Layer 2. Establishes and maintains the data communication link.

FDDI-II is a superset of FDDI that defines additional protocols to support circuit switched (dedicated circuit for duration of transmission) services in addition to the packet switched (messages divided into packets prior to transmission) service currently provided by FDDI. This will enable FDDI-II to support voice, video and data transmissions.

5.1.12 DISTRIBUTED QUEUE DUAL BUS (DQDB)

Distributed Queue Dual Bus (DQDB) is the Institute of Electrical and Electronics Engineers' (IEEE) standard for Metropolitan Area Networks (MAN) which utilizes a communication protocol based on the Data Link layer of the OSI model (see OSI section of this document). A MAN can be defined as a geographical area of diameter less than 150 km (90 miles). It was developed based on the IEEE 802.6 standard for Local Area Networks (LAN), thereby providing immediate benefits including high fault tolerance, speeds of about 150 Mbps and a length of up to 100 km (62 miles) when implemented with optical fiber. DQDB is a high-speed connectionless, public, packet switching service requiring no connection between origin and destination points. All transmitted data has addressing information within its frame to direct it as needed. It is also the protocol used in Switched Multi-megabit Data Services (SMDS).

A DQDB system is based on dual bus topology, with two unidirectional data buses connecting all nodes or stations along the buses, via an access unit. A typical system can have as many as 512 stations. Since the buses support communications in opposite directions, full duplex communications is facilitated between the network nodes. The head of each bus contains a head node called "head-of-bus" (HOB) that generates fixed length cells (slots) of 53 octets at a steady rate. Figure 19 below depicts the typical DQDB dual bus architecture.

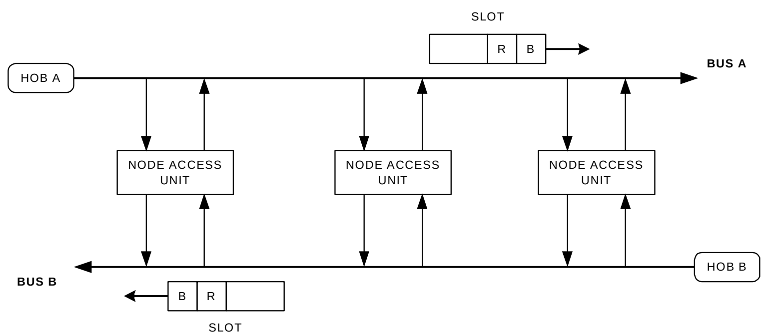

Figure 19 – DQDB Architecture

DQDB enables the nodes to gain access to the dual bus via two different modes: queued arbitrated (QA) access and pre-arbitrated (PA) access. The QA access uses QA cells and is controlled by the distributed queuing protocol. There are distance limitations with the QA access method so it is usually allocated to non-isochronous or intermittent services that can handle longer delays, i.e., data. The PA access uses PA cells and supports isochronous (constant bit-rate) services such as voice and video because it enables the service provider to allocate the bandwidth for those services.

The cell generated in DQDB is almost identical to that of an ATM cell, minus differences in the header and payload. The header of a DQDB cell contains no virtual path identifier (VPI), but instead has an access control field (ACF). Figure 20 below depicts the structure of a DQDB cell followed by cell field descriptions. The structure of a PA cell is similar to that of a QA cell, but with different values in the ACF.

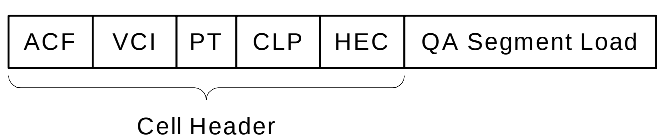

Figure 20 – DQDB Cell Structure

- Access Control Field (ACF) – Contains the REQUEST and BUSY bits. The BUSY bit indicates a slot in use while the REQUEST bit is set in a slot by a node that is waiting to transmit.
- Virtual Channel Identifier (VCI) – Helps identifying to which virtual channel the segment belongs. It is not available for PA transmissions.
- Payload Type (PT) – Indicates the nature of the data to be transferred (same as ATM).
- Cell Loss Priority (CLP) – Provides buffer management based on the value of the bits (same as ATM).
- Header Error Control (HEC) – Provides for the detection of single bit errors in the header.

DQDB has been implemented as the access mechanism for Switched Multi-megabit Data Services (SMDS). The network capacity of DQDB is 150 Mbps in each direction.

5.1.13 SWITCHED MULTIMEGABIT DATA SERVICES (SMDS)

Switched Multimegabit Data Services (SMDS) is a high-speed, connectionless, packet-switching service designed to provide local area network (LAN) like service in a metropolitan area. The service is a subset of Distributed Queue Dual Bus (DQDB, see prior section) technology AND can be utilized to interconnect LANs together over a large geographical area. As such, the SMDS data increments, which can be in increments of 9,188 octets, are divided into 53-octet cells prior to transmission (same size as DQDB cells).

The components of an SMDS network include customer premises equipment (CPE), which are customer owned end devices (computers, routers, modems, etc.); carrier equipment, which typically are Wide Area Network (WAN) switches conforming to the system specs, and; the subscriber network interface (SNI), which is the point at which the customer and carrier networks meet. The protocol used for communications between the CPE and carrier equipment is the SMDS Interface Protocol (SIP), which provides a connectionless service over the SNI.

The SIP has three levels to control the customer's network access. SIP Level 3 operates at the Media Access Control (MAC) sublayer of the data link layer of the OSI reference model and receives and transports frames of the upper layer protocol information. The frame created is referred to as a protocol data unit (PDU). SIP Level 2 is based on the IEEE 802.6 DQDB standard, operates at the MAC sublayer of the data link layer, and controls access to the physical medium. SIP Level 2 is where the 9,188 octet long datagrams (Level 3 PDUs) are segmented into fixed-length 53 octet cells, referred to as Level 2 PDUs. SIP Level 1 operates at the physical layer of the OSI reference model and specifies the physical connectivity that enables transmission. Figure 21 illustrates the relationship between SMDS and the OSI reference model.

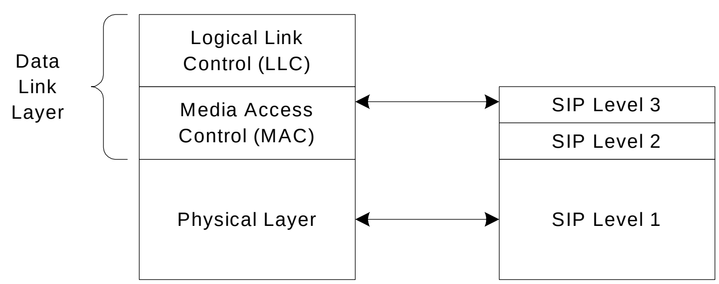

Figure 21 – SMDS Standards Mapped to OSI Model

SMDS offers six network access classes, which can be defined as speeds at which data travels from the customer site to the network switch. These classes control the rate at which data can be transferred by establishing a maximum transfer rate and a maximum degree of "burstiness". They include 1.2 Mbps for T1 (DS1) lines and 4,10,16,25 or 34 Mbps for T3 (DS3) lines.

NETWORKS

5.1.14 INTEGRATED SERVICES DIGITAL NETWORK (ISDN)

Integrated Services Digital Network (ISDN) is a set of communication standards for digital phone connections and transmissions that provide greater speed and bandwidth than a regular phone line. ISDN uses a standard phone line in a home or office and converts it from a single analog circuit into multiple high-speed digital circuits capable of transmitting audio, still images, motion video, and text data simultaneously.

Standard telephone service requires a separate phone line for each device to be used simultaneously. Not only can multiple lines be expensive, but also the amount of information that can be transmitted is limited with analog service as current technology allows 56 kilobits per second (kbps). ISDN, however, provides multiple digital channels that can operate concurrently on the same pair of wires, and each channel is capable of transmitting at 64 kbps. Additionally, digital transmissions allow for reduced noise and interference on the carrier channels.

As with most technologies and/or services, the components and network configurations are unique to that technology or service. The components of and ISDN network include the following:

- Terminal Equipment Type 1 (TE1) – This is a specialized ISDN terminal used to connect to an ISDN phone line. This could be an ISDN telephone, computer or an ISDN fax machine.
- Terminal Equipment Type 2 (TE2) – These are non-ISDN terminals that are connected to an analog line, i.e., analog telephone, fax machine, etc.
- Terminal Adapter (TA) – Facilitates communications between a TE2 device and the ISDN network.
- Network Termination Type 1 (NT1) – Customer owned end devices (computers, routers, modems, etc.).
- Network Termination Type 2 (NT2) – Device in digital private branch exchanges (PBXs) to perform ISDN functions. They are typically found in companies with their own private telephone system.

ISDN also specifies reference points or interfaces to the ISDN network. These reference points are defined below.

- R – Point between non-ISDN equipment and a TA.
- S – Point between user terminals and the NT2.
- T – Point between NT1 and NT2 devices.
- U – Point between NT1 devices and line termination equipment in the carrier network.

Figure 22 below illustrates the relationship between ISDN components and their corresponding reference points.

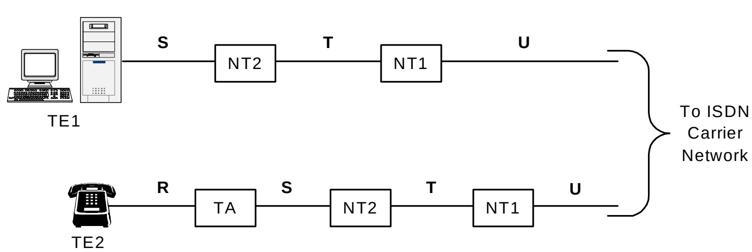

Figure 22 – ISDN Components and Reference Point Relationship

ISDN provides two types of services: the Basic Rate Interface (BRI) for the home or small enterprise, and the Primary Rate Interface (PRI) for larger businesses. The BRI service provides two B (bearer) channels at 64 kbps and one D (data) at 16 kbps for a total of 144 kbps, while the PRI service provides 23 B channels and one D channel at 64 kbps for a total of 1536 kbps. The B channels carry data, voice and other services, while the D channel carries control and signaling information. With PRI service, several B channels can be combined to form a larger capacity H channel.

Broadband ISDN (BISDN) is a standard for transmitting voice, video, and data at the same time over fiber optic telephone lines. It can support data rates of 1.5 Mbps, and is being widely implemented due to its ability to support greater rates. Some of the services applicable via BISDN include interactive services (video conferencing, messaging and retrieval services) and distribution services, i.e., TV program distribution.

ISDN operates on the bottom three layers of the OSI reference model with each layer using a different specification.

5.1.15 NATIONAL INFORMATION INFRASTRUCTURE (NII)

The National Information Infrastructure (NII) or “information superhighway”, as it is sometimes called, is an all encompassing interconnection and integration of telecommunications applications, services, and physical infrastructure (bitways). The components that have a role in the NII includes but is no limited to, transmission media (optical fiber, coaxial cable, satellite, cable TV), physical equipment (consumer electronics, fax machines, modems), personnel (vendors, operators, service providers, software developers), and physical facilities (schools, libraries, businesses, hospitals).

Some information technology areas are already using and benefiting from the NII. They include education and life-long learning, electronic commerce, libraries, health care, and manufacturing facilities. Some of the benefits gained in these areas are listed below.

Electronic Commerce:
Wal-Mart Stores, Inc. invested a large sum of money in equipment (bar code systems, scanners, computer and satellite communications network) linking each point-of sale terminal to its distribution centers and headquarters. This allowed individual stores to order directly from suppliers thereby reducing inventory restocking time. The ability to track every sale allowed stores to see what was selling, which in turn, enabled Wal-Mart to maintain well stocked inventories.

Education:
Distance Learning: Many colleges and universities now offer courses via one and two way video and two way audio communications, which provides added benefit for students who are not local or who cannot make it in to class. It also allows schools to go after better-qualified instructors who may not be local to the school. Persons with disabilities can also participate in class instruction without being physically present. Employers are also able to keep their staff up-to-date on policy changes and procedures, including training for new processes.

Information Collection: Teachers, students, and employees have access to a number of digital libraries and databases via desktop computers in the workplace or school. Students can receive their assignments, teachers can retrieve lesson plans and latest information on school topics, and employees

Health Care:
Surgeons can now participate in virtual reality learning, whereby a surgical procedure can be performed in a virtual environment. This environment allows the surgeon to experience the surgical procedure prior to operating on a real patient. Surgeons can use a scalpel, feel the sensation of cutting into a patient, the texture of a patient's skin, and all this while, using an electronic model of the patient with clinical measurement readings from the actual patient who will undergo the procedure.

Libraries:
As the volume of material (i.e, recordings, films, books) in libraries and demand for access to these materials continues to increase, there is a need to get that information out to those who request it quickly and concisely. As such, libraries have started converting materials to digital format to facilitate archival and access by the public. The role of librarians also has changed as their functionality within the library system has changed. Librarians are now looked upon as system administrators and network administrators.

Manufacturing Facilities:
John Deere & Co. made significant investments in advanced manufacturing equipment and techniques and provided its employees intensive education and training programs. This has led to reduced design time production costs while improving product quality and productivity.

Intel Corporation implemented computer–based concurrent engineering practices and improved communications among design teams, which provided for consistency and the sharing of data among the concurrent work teams. These reduced the time from design to sample product in half, even though the complexity of the product doubled. The Institute for Defense Analyses (IDA) defines concurrent engineering as, the systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support. This approach is intended to cause the developers to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.

Interactive Television (ITV):
Interactive television (ITV) combines traditional TV viewing with the interactivity of the Internet and a PC. This interactivity may include retrieving video programming, accessing sports scores, stock quotes and weather information. It is a subset of Digital television that would allow viewers to gain more information than they would by simply watching a television program.

ITV capabilities include:

- Home banking
- Home shopping
- E-mail
- Instant Shopping
- Answer trivia questions in real time during a TV show
- Interactive Sports
- Local/regional/national weather and traffic

To be able to provide the above services, many different components have to work in conjunction with one another. Those components are listed and described below:

- **Content** – The data (information) that constitute what appears on the user's screen. It can be composed of text, audio, video, photos, etc. and any necessary ITV functions.
- **Compression Capabilities** – Converts analog signals to digital format for storage.
- **Storage Hierarchy** – Provides the digital storage space needed to store large files of compressed video.
- **Control System** – Services the requests coming into the system.
- **Transmission System** – The high speed links needed to deliver the data in a timely manner.
- **Return Path** – A two-way communications link between the user and the content provider that enables the user to send, request, or demand information from the content provider.
- **Set-Top Box** – An addressable communications box that can provide a variety of ITV functions including, decoding signals at they arrive at the user's television and decompressing the digital signal.
- **Remote Control and Navigation System** – The remote provides an easy to understand user interface while the navigation system provides a means for the user to communicate with the control system.
- **Subscriber Management System** – Sophisticated systems for administration, billing and encryption required to ensure that users pay for the services they use and that copyrights are preserved.

Current examples of ITV programming are the electronic programming guides that are available on Digital Broadcast Satellite (DBS) and digital cable systems. By pressing a "Guide" or "Menu" button on the remote, viewers can display the electronic programming guide to navigate through selected channels in search of programming. Programming can be determined by time, theme (sports, children's show, movie, etc.) and/or by channel, among other search criteria. When a show is selected, viewers can see a summary of the program, search for all available viewing times or set a reminder where the system alerts them automatically prior to a program starting.

5.1.16 HIGH DEFINITION TELEVISION (HDTV)

High Definition Television (HDTV) is a subset of Digital Television (DTV) and refers to a digital standard for television sets that provides wider images with higher picture resolution and CD quality sound to the viewer. It is the most advanced form of digital television available today.

HDTV advantages include (discussed further below):

- **Higher resolution:** Regular analog TV is made up of 480 active lines (525 total lines of resolution) while HDTV stations have several formats from which to choose. They include:
    - 720p, where the picture displayed is composed of 1280H x 720V pixels, and
    - 1080i, where the picture displayed is composed of 1920H x 1080V pixels.

  The "p" and "i" designations refer to the scanning system used to update the picture. The "p" designation implies "progressive" scanning whereby the lines on the screen are updated every sixtieth of a second, while the "i" designation implies interlaced scanning whereby the lines on the screen are updated in alternative frames. That is, the odd numbered lines are updated first followed by the even numbered lines.

- **Aspect Ratio:** Analog TV has an aspect ratio of 4:3 (width to height), while HDTV provides an aspect ratio of 16:9. This ratio is closer to that used in theatrical movies.

- **CD Quality Sound:** HDTV broadcasts are encoded in Dolby Digital (AC-3), also known as Dolby Digital 5.1. For the home viewer, this implies that there are five main speakers in the playback system (left, center, right, left surround and right surround) plus a subwoofer that reproduces a low-frequency effects (LFE) bass channel. These features provide realistic surround sound.

- **Digital Compression:** HDTV makes use of the MPEG-2 encoding and compression system to fit more information (increased resolution and sound) onto the same 6 MHz bandwidth channel used by analog TV. Already a standard for DVD videos, MPEG-2 records an image and exploits the redundancy in video information by only updating changes in a frame rather than the whole frame. This facilitates the handling of high quality video but at a limited transmission rate.

- **Additional Data:** Utilizing any left over bandwidth, broadcasters can transmit data such as web content, stock reports or electronic coupons over the air.

There are several current options for watching HDTV quality programming. Viewers can purchase HDTV sets (i.e., plasma screen, front or rear projection) that have HDTV receivers/decoders built in. HD-capable or HD-ready television sets can also be used, but they require the use of a separately purchased external receiver/decoder (set-top box) to view HDTV broadcasts. Analog television sets require the purchase of an external HDTV converter. However, for analog TV sets, this option provides DVD quality images, but not HDTV quality images.

There are some obstacles hindering more widespread HDTV usage. These include the high cost of HDTV sets, which can vary from as low as $1200 to as high as $10,000; the delay associated with broadcasting stations upgrading to HDTV hardware, who now have until 2006 to provide HDTV broadcast to viewers pending some preset thresholds by the Federal Communications Commission (FCC); and, concerns by the television industry regarding copy protection.

5.1.17 SYNCHRONOUS OPTICAL NETWORK (SONET)

SONET is the American National Institute of Standards (ANSI) standard for high-speed synchronous data communications over fiber optic cable. The basic building block of SONET is the Synchronous Transport Signal Level (STS), which is the electrical specification for the various levels of SONET hierarchy. The base signal for SONET is STS-1, which provides a base rate of 51.84 Mbps. The optical counterpart of this electrical signal is the Optical Carrier Level 1 (OC-1) line rate. Higher level signals (STS-*n)* are integer multiples of the base rate. For example, an STS-3 designation is equivalent to an OC-3 designation and provides a transmission rate of 155.52 Mpbs, which is equal to (51.84 Mbps * 3). Table 10 provides information on SONET optical line rates.

The components or network elements (NE) of a SONET network include path terminating equipment (PTE), line terminating equipment (LTE), and section terminating equipment (STE). PTEs are network elements that multiplex/demultiplex the STS payload, i.e., a SONET Terminal or Switch. LTEs originate and/or terminate the line signal, i.e., Add/Drop multiplexers or Digital

Cross-Connect Systems, while STEs are any two adjacent SONET network elements (regenerators, line terminating equipment).

Table 10 – SONET Line Rates

Signal Designation	Line Rate (Mbps)	Capacity
STS-1, OC-1	51.84	28 DS1s/1 DS3s
STS-3, OC-3	155.52	84 DS1s/3 DS3s
STS-12, OC-12	622.08	336 DS1s/12 DS3s
STS-24, OC-24	1244.16	672 DS1s/24DS3s
STS-48, OC-48	2488.32	1344 DS1s/48DS3s
STS-192, OC-192	9953.28	5376 DS1s/192 DS3s

The SONET frame is a 9-row by 90-column that can be separated into two main parts as indicated below:

- **Transport Overhead (TOH)**
  - Section Overhead (SOH): Terminated by STEs and contains error information between adjacent nodes in a network.
  - Line Overhead (LOH): performed by LTEs and contains error information between major nodes in the network. Used for the STS-*n* signal between STS-*n* multiplexers.

- **Synchronous Payload Envelope (SPE)**
  - STS Path Overhead (POH): Provides end-to-end monitoring of the payload between the point of creation of an STS SPE and its point of disassembly.
  - Payload: the actual information being transmitted.

The layering scheme utilized by SONET divides the responsibilities for transmitting the payload throughout the network. The overhead information facilitates Operations, Administration, Maintenance and Provisioning (OAM&P) in the network to further reduce the cost of transmissions.

The SONET protocol stack consists of four layers, with each layer being able to communicate with adjacent layers as well as its counterpart on the opposite end of the network. Layers are illustrated in Figure 23 and defined below:

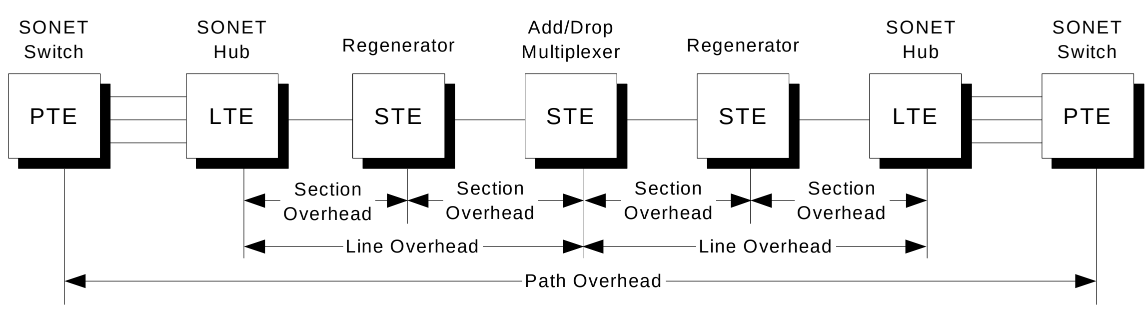

Figure 23 – SONET Overhead Layers

1. Photonic Layer – converts the electrical signals into optical light pulses for transmission over FO cable, with the process being reversed at the other end.
2. Section Layer – deals with the transport of STS-*n* frames across the physical medium.
3. Line Layer – Handles numerous path layer functions such as synchronization and multiplexing.
4. Path Layer – Maps services such as DS-3 or T1into the SONET frame and handles all end-to-end communications (between PTEs), maintenance, and control.

Virtual tributaries (VTs) are used to transport signals that are lower than STS-1 signals (less capacity than a DS3 signal). VTs come in four different sizes with each designed to accommodate a certain size of digital signals. Table 11 below provides information on VT signals as well as their corresponding digital signals

Table 11 – Virtual Tributary Signal Comparison

SONET Signal Designation	Digital Signal
VT – 1.5 (1.728 Mbps)	DS1 (1.544 Mbps)
VT – 2 (2.304 Mbps)	CEPT-1 [2](2.048 Mbps)
VT – 3 (3.456 Mpbs)	DS1C (3.152 Mbps)
VT – 6 (6.912 Mbps)	DS2 (6.312 Mbps)

One benefit of a SONET network is the ability of synchronous transmissions to support bandwidth (or circuit) provisioning allowing providers to have control over individual digital signal (DS) channels thereby enabling the provider to add more channels to meet traffic demand and remove them when they are no longer necessary. Synchronous transmissions also allow customers to do real time routing around nodes experiencing a lot of traffic without having to end other sessions.

SONET defines interface standards at the Physical layer (Layer 1) of the seven-layer OSI model thereby providing the physical connectivity between locations. It supports point-to-point, point-to-multipoint, hub network, and ring architecture as network configurations. Its high speed and high quality makes it a good transmission medium for telecommunication services such as ATM, DQDB, and FDDI.

The NOVA STC utilizes a single mode fiber optic cable SONET backbone (48 fibers) capable of achieving an OC-12 data rate (622 Mbps) as a trunk communications to field devices. This SONET backbone is discussed further in Section 4 of this document.

5.2 WIDE AREA WIRELESS COMMUNICATIONS

5.2.1 UHF/VHF BEACONS – RADIO FREQUENCY IDENTIFICATION (RFID)

Radio Frequency IDentification (RFID) is a wireless communication application where electronic chips are used to control, detect and track a variety of items using FM transmission methods. A typical RFID system consists of a transponder (RF tag), a reader or interrogator (transceiver with decoder, antenna), and some kind of processing system to process the data read from the tag.

[2] CEPT is the European E-1 equivalent of the T1.

There are two types of RFID tags: active tags, which include a battery and, passive tags, which don't. Active tags have a longer read range and offer read/write functionality. Their life span is limited from 2 to 10 years, depending upon usage. Passive tags obtain operating power from electromagnetic field generated by the reader. They have a shorter reading range and they require more power from the reader. They also have a nearly infinite lifetime, are often smaller and lighter than active tags, and are less expensive.

In a typical application, the reader emits radio waves to activate the tag. When an RFID tag passes through the electromagnetic zone, it detects the reader's activation signal, the reader decodes the data encoded in the tag's integrated circuit and the data is passed to the host computer for processing.

The components and interactions between typical RFID components are shown below in Figure 24. The range of the radio waves emitted by the tag can vary from one inch to more than 100 feet or more, depending on its power output, various environmental conditions, the kind of antenna used, and the radio frequency used.

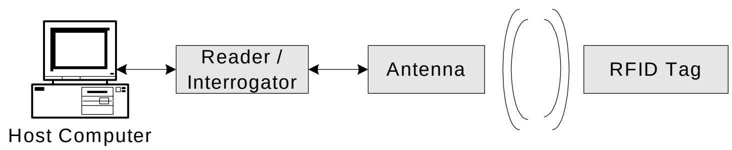

Figure 24 – RFID System Diagram

RFID systems have distinct advantages including:

- No line-of-sight required between the transponder and the reader,
- Works effectively in hostile environments (dirt, inclement weather, dust, poor visibility), and
- Read/write capability (depending on application)

Some disadvantages of RFID systems are:

- No standards commonality (RFID equipment from different manufacturers may be incompatible)
- Readers may have more than one tag in the inquiry zone and must be able to cope with all of them. Reading data from more than one transponder may confuse the reader.

RFID technology is applicable to many applications, including:

- Easy Pay - RFID tags are used to communicate with fuel pumps at gas stations. When used by a customer the tags identify the customer, links to his/her preferred credit card and turns on the pump.
- Automatic Vehicle Identification (AVI) - RFID tags (i.e., E-Z Pass, SmartTag) mounted on the windshield of cars are used to calculate the toll at a number of toll plazas. The reader identifies the vehicle at tollbooths, the toll plaza number is encoded onto the tag and read again when the car leaves the tollbooth to calculate the toll deducted from the account.

Frequency ranges can vary from low frequency (30 kHz-500 kHz), intermediate frequency (6 MHz-15 MHz), and high frequency (850 MHz-950 MHz as well as 2.4 GHz-5.8 GHz). The data transfer rate and reading speeds are primarily a function of the frequency; the higher the frequency, the higher the data rate transfer that can be achieved. Higher frequency RFID systems also incur higher system costs.

5.2.2 TWO-WAY WIDE AREA RADIO (SPECIALIZED MOBILE RADIO [SMR])

Specialized Mobile Radio (SMR) is a radio technology consisting of any two-way radio system where two or more mobile/portable wireless transceivers are linked by a single repeater. A typical SMR system includes one or more base station transmitters (repeaters), one or more antennas, and end user radio equipment (mobile radio unit). The transmitters are located above average terrain to maximize the areas of coverage. Each transceiver has a transmit frequency and receive frequency that are in the same band, but differ by a fixed amount, known as the offset. The transmit frequencies and receive frequencies of the mobile/portable receivers in a system are identical.

SMR systems communicate via half-duplex communication and a push-to-talk (PTT) mode. This allows messages to be transmitted in both directions, but not at the same time. SMR end users can operate in two modes, “interconnected” mode or “dispatch” mode. In interconnected mode, the mobile radio units are linked with the local public switched telephone network (PSTN). When an end user transmits a message to the base station with a mobile radio, the call is routed to the local PSTN, and the mobile radio then functions as a mobile telephone. In dispatch mode, two-way, over the air conversations between two or more mobile units or mobile and fixed units can be accomplished.

SMR systems can be either conventional or trunked systems. A conventional system provides the end user with use of only one channel. If that channel is in use when needed, the end user must wait for it to become available. A trunked system combines channels and contains the intelligence to automatically search for an open channel. This method allows more users to be served at one time and maximizes the network bandwidth efficiency.

Some current SMR technology systems include 1) ARDIS, which is owned and operated by Motorola and provides cellular packet-switched radio services in the U.S with data transmission rates at 4.8 Kbps and 19.2 Kbps (in larger centers), and 2) RAM Mobile Data, a company jointly owned by RAM Broadcasting, Inc., Ericsson and BellSouth Corp, that provides a cellular-radio-based packet data service called Mobitex. Data transmission rates are 8.0 Kbps and 19.2 Kbps in some larger cities.

In 1991, Nextel was granted permission by the FCC to build an enhanced SMR system entitled Enhanced Specialized Mobile Radio (ESMR). ESMR functions similarly to SMR with a few exceptions; the mobile/portable transceivers are linked to a network of repeaters with a range of 5 to 10 miles, it can operate in full-duplex mode allowing both parties to listen and talk simultaneously and it utilizes digital radio transmission which provides for faster connection speeds.

Some ESMR systems currently deployed include 1) Ericsson’s Enhanced Digital Access Communications System (EDACS), 2) the Nextel System, and 3) Motorola’s Integrated Dispatch Enhanced Network (iDEN). All these systems offer wireless analog voice, digital voice and data communications in both point-to-point and point-to-multipoint modes.

Operating frequencies for traditional SMR systems are in the very high frequency (VHF) range (30 MHz-300 MHz) or the ultra high frequency (UHF) range (300 MHz-3 GHz). Currently, fourteen MHz of spectrum is available in the 800 MHz SMR band while five are available in the 900 MHz band. The 800 MHz systems operate on two 25 kHz channels paired, while the 900 MHz systems operate on two 12.5 kHz channels paired. Due to the different bandwidth allocations for the 800 MHz and 900 MHz systems, the radio equipment used for one is not compatible with the other. ESMR systems have operate in the UHF range with the working band near 900 MHz

SMR technology provides for instant connectivity with the touch of a button, users can communicate with many people simultaneously and radios can operate independent of the network. The technology has been utilized to provide voice communications by taxi dispatchers, fire and police departments and parcel services, among others, including the Fairfax County Fire and Rescue Department which currently operate a 800 MHz system.

5.2.3 CELLULAR (DIGITAL/ANALOG) – CELLULAR DIGITAL PACKET DATA (CDPD)

Developed by a consortium of leading wireless carriers, CDPD is a fee based two-way digital packet switching technology that allows carriers to transmit packetized data over the existing analog cellular network, commonly referred to as AMPS (Advance Mobile Phone System). The packet switching technology used by CDPD encodes the data into digital packets for transmission. Each packet is transmitted separately to its destination when there are no voice calls on cellular network. Once at the destination, the packets are recompiled to recreate the original message. CDPD is also based on TCP/IP, enabling it to work seamlessly with Internet-based applications. Users can send and receive data from anywhere in the cellular coverage area at any time, quickly and efficiently at rates up to 19.2 Kbps.

There are two types of CDPD networks: dedicated channel and channel hopping. In a dedicated channel network, certain channels are set aside solely for use by the CDPD network. In a channel hopping network, channels are shared by the CDPD network and the cellular telephone network with cellular calls having priority over CDPD calls. If a cellular user wanted to make a call over a channel that's in use by CDPD, the CDPD call will be taken off that channel to allow the cellular user's call to be processed. The CDPD call then moves or "hops" to another available channel to continue the session. If no channel is available, the CDPD call is dropped.

For the mobile end user, CDPDs packet-switching capabilities mean that a persistent link isn't needed. This is beneficial for users who send information that is both "short" and "bursty". It also uses less power since the information is transmitted in short bursts.

In a typical system, the Mobile Data Base Station (MDBS) receives CDPD packets from the Mobile End System (MES), a mobile computing device equipped with a CDPD modem. The MDBS receives the CDPD packets and routes them to the Mobile Data Intermediate System (MDIS) which forwards them to the CDPD network. A Fixed End System (FES), i.e., a stationary computing device and an Intermediate System (IS), i.e., an off-the-shelf CDPD compatible routers are also components in some CDPD networks

There is also a circuit-switched version of CDPD, called CS-CDPD, that can transmit CDPD traffic over the AMPS network when a packet connection is not available. This enables carriers

to extend their CDPD coverage to anywhere cellular phone service is available. In order to initiate a CS-CDPD call, the MDIS and the MES components of the network must be equipped with the protocol stack for circuit-switched service and circuit-switched capable modems.
To process a CS-CDPD call, the MES accesses a voice channel. The modems convert the message to binary form and connect to a circuit-switched capable MDIS (CMDIS). The software and the MES can then select packet CDPD or CS-CDPD as the connection options based on the available coverage area and the least expensive method of transmission. The need for CS-CDPD to establish a call and synchronize modems adds some delay to a connection. This delay is typically 15 to 30 seconds.

CDPD can be used in a number of applications including fleet management (AVL), weather and traffic advisories, home office applications (checking e-mail, accessing databases, etc.), transportation/package delivery and tracking, and point of sale. CDPD supports both the Internet Protocol (IP) and the ISO Connectionless Network Protocol (CLNP). It also supports IP multicast (one-to-many).

CDPD operates in the 800 MHz band, which is the same as the existing cellular network. This facilitates the deployment of CDPD networks. CDPD service providers in the U.S. include AT&T Wireless, Verizon, and Comcast Cellular Communications. Unfortunately, there is no single nationwide CDPD service provider. The Virginia Department of Transportation (VDOT) employs CDPD technology as the communications medium for the Automatic Vehicle Location (AVL) system utilized by the Safety Service Patrol (SSP) and snowplows deployed in the Northern Virginia region.

5.2.4 MOBILE SATELLITE SYSTEMS

Mobile Satellite systems offer a combination of wireless phone, data, fax and paging services worldwide via various satellite technologies. These systems include Geosynchronous (GSO) and (Geostationary) Equatorial Orbit (GEO), Low Earth Orbit (LEO), and Medium Earth Orbit (MEO) satellites. All of these satellites operate in the same manner; signals are transmitted from ground stations to the satellites (uplink), the satellite amplifies the signals, shifts it to a lower frequency and returns them to earth (downlink). The satellites are powered by relay signals from earth that employ low power microwave, solar panels or onboard nuclear reactors.

Geostationary satellites (GEOs) are satellites with circular orbits orientated in the plane of the earth's equator at an altitude of 22,300 miles. As such, they always appear to remain in a stationary position relative to the Earth. Geosynchronous satellites (GSOs) make one orbit every 24 hours so that it's synchronized with the rotation period of the earth. In general, all geostationary satellites are geosynchronous, but to be a geostationary satellite, the geosynchronous satellite must be in orbit in earth's equatorial plane. In essence, geostationary is a small subset of orbits that are geosynchronous. Figure 25 illustrates the difference in orbital position between the two satellites.

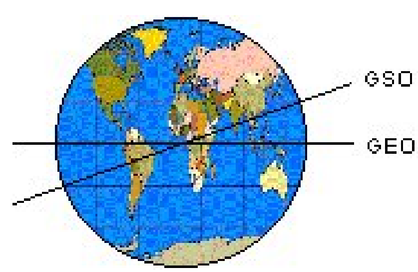

Figure 25 – Geostationary and Geosynchronous Orbits

The service area of GEOs covers almost 1/3 of the earth's surface, so that near-global coverage can be achieved with a minimum of three satellites in orbit. Most of the existing

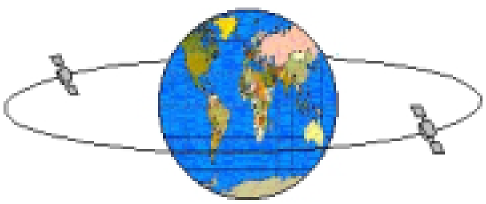

Figure 26 – Geostationary Satellite (GEO) Orbital Ring

telecommunications and broadcasting satellites in orbit are GEOs. This is beneficial because the satellites can provide transmission from a single uplink reception to a regional downlink pattern (point-to-multipoint distribution). These satellite systems offer great signal clarity and can handle large amounts of data, but they do suffer from transmission delays that can affect voice communications. A signal takes approximately one-quarter of a second to go from a ground station, to a GEO and back to a ground station.

At present, the number of positions available for GEOs in space is limited due to their size and orbiting altitude. Also, due to the orbiting distance of these satellites from earth, it's costlier to launch a GEO satellite into space and fairly large ground stations are required to facilitate communicating with the satellites as compared to other types of satellites. Figure 26 depicts the typical orbital ring for GEOs.

The Inmarsat satellite system (Comsat) uses four GEOs to provide global communications services to users including direct dial-up voice, fax capabilities, duplex data transfer, e-mail, compressed video and still video pictures. Other GEO systems include Spaceway deployed by Hughes Network Systems (12 satellites providing voice, data, video and broadband services) and Thuraya (2 satellites providing video, voice, paging and data services).

MEO satellites (MEOs) are located at 1,300 to 6,250 miles from the Earth and also suffer from some sort of latency regarding voice communications. The amount of time it takes to transmit and return a signal to a MEOs from a ground station is around 50 to 150 milliseconds. These satellite systems require a modest number of satellites in 2 to 3 orbital planes to achieve global coverage. (See Figure 27).

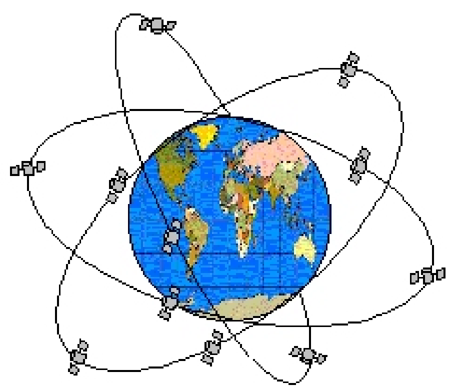

Figure 27 – Medium Earth Orbit (MEO) Satellite Orbital Ring

Some examples of MEO satellite systems include the United States Navistar Global Positioning System (GPS), which contains 24 satellites in 6 orbital planes. These satellites allow land, sea and airborne users to determine their three-dimensional position, velocity, and time, 24 hours a day, anywhere in the world, regardless of weather conditions. ICO Global Communications has 10 satellites (2 spares) in two orbital planes providing voice, data, paging and fax services.

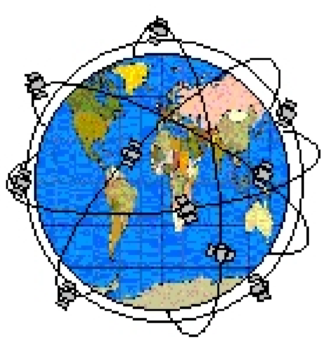

Figure 28 – Low Earth Orbit (LEO) Satellite Orbital Ring

LEO satellites (LEOs) orbit the earth at distances of 300 to 1,500 miles, thus eliminating long transmission delays when compared to other satellites. They are either in elliptical or circular orbits and take approximately 20 to 40 milliseconds to transmit and return a signal to a ground station. (See Figure 28) These satellites can further be separated into

"Big LEOs" and "Little LEOs". Big LEOs are used for technology applications such as high-speed, high-bandwidth data communications and video conferencing. Little LEOs are used for data communications, such as pager, cellular telephone and location services and weigh around 100 kg.

LEOs are closer to the earth's surface so less power is needed to communicate with a ground station, which helps reduce terminal size and price. They are also cheaper to build and to launch than GEOs. Telephone calls are also possible from handheld mobile units anywhere on earth. Due to their proximity to earth, more satellites are needed to cover the earth's surface, which can become costly. A complete global coverage systems using LEOs requires a large number of satellites, in multiple orbital planes, in varied inclined orbits.

The Iridium System (Motorola) uses 66 Big LEO satellites (plus 6 spares) in six orbital planes to provide voice, data, fax and paging services. Globalstar (Qualcomm) has 48 Big LEOs (plus 4 spares) in orbit providing voice, data, fax, paging and GPS services. The Teledesic (backed by Bill Gates and Craig McCaw) system utilizes 288 LEO satellites (4 spares per orbit) in 21 circular orbits to provide two-way broadband services.

Global Mobile Personal Communications by Satellite (GMPCS) systems refer to systems that utilize MEO and/or LEO satellites to provide seamless telecommunications services worldwide (global roaming), with Big LEOs being the most utilized technology. Users are able to communicate to and from any point on the Earth's surface using a small, highly portable handset and utilize any of the services provided by the system providers.

All communication satellites have to occupy a portion of the electromagnetic spectrum to send signals back and forth. These systems look for space in one of three areas of the spectrum; the L-band (1.53-2.7 GHz), Ku-band (10.7-14.5 GHz), or the Ka-band (18-31 GHz). New satellite broadband corporations will mostly operate in the Ka-band spectrum for transmissions.

5.2.5 HIGH FREQUENCY (HF) RADIO

The ionosphere is the outermost layer of earth's atmosphere located at a height of 50 km (31 miles) to over 500 km (310 miles). One of its most important features is its ability to refract radio waves within a certain frequency range to facilitate radio communications. In this region, some of the molecules are ionized by incoming solar radiation from the sun to produce an ionized gas. Ionization is the process by which solar radiation is absorbed by an atom or molecule, producing a free electron and a positively charged ion.

The ionosphere can be separated in to four regions called the D, E, F1 and F2 regions, with the D region being the closes to earth (50-90 km (31-56 miles)) and the F2 region being the furthest (over 210 km (131 miles)) away. The F2 region is most conducive to HF radio propagation because it is present 24 hours a day, it usually refracts the highest HF frequencies and its high altitude provides a longer communication path.

There are several types of propagation modes associated with HF radio communications. These are described below and shown in Figure 29.

- **Ground Wave:** Transmits over shorter distances (about 100 km (62 miles) over land and 300 km (186 miles) over sea). The range of the wave depends on a variety of conditions including the terrain or sea conditions, frequency and antenna height. Varies daily and with the seasons.

- **Direct (Line-of-Sight) Wave:** Interacts with earth-reflected wave depending on frequency and polarization

- **Sky Wave:** Refracted by the ionosphere, these waves transmit over all distances. At night, the transmit range increases considerably. Frequency, time-of-day and atmospheric conditions can cause signal to bounce several times before reaching a receiver.

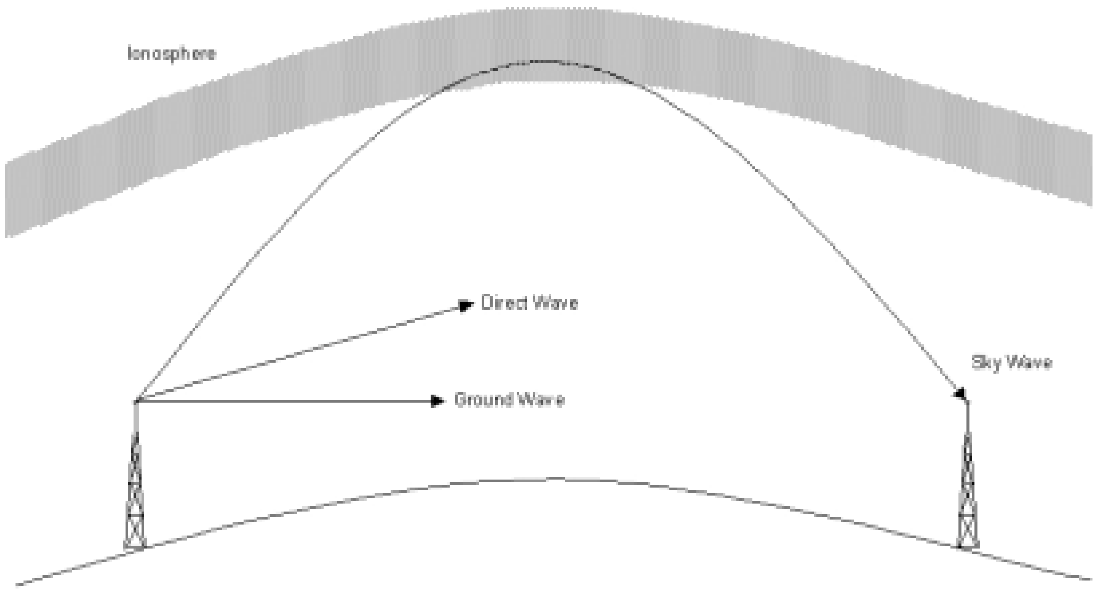

Figure 29 – HF Radio Propagation Modes

Due to the instability of the ionosphere, the distance a HF signal travels is dependent on the frequency, transmitter power, take-off angle relative to the ground and the state of the ionosphere through which it is traveling. For any given distance and time, there is a range of HF frequencies that will most likely increase the chances of successful communications. The highest frequency, which may be used for reliable HF communications under given ionospheric conditions, is referred to as the Maximum Usable Frequency (MUF). Frequencies higher than the MUF can penetrate the ionosphere and continue into space. Those lower than the MUF can be refracted back to earth. The frequency at which an HF signal is completely absorbed by the ionosphere is called the Lowest Usable Frequency (LUF). The best frequencies for HF communications fall between the MUF and LUF. HF Radio frequencies fall into the 3 to 30 MHz ranges.

There are also some atmospheric disturbances that can degrade HF communications. Short-Wave fadeouts are disturbances in which solar activity results in the absorption of lower frequency HF signals. Ionospheric storms create large scale changes in the chemical composition of the ionosphere resulting in changes to the MUF, which restricts the frequencies available for use over a given distance. Variations in the ionosphere related to the solar cycle, seasons and levels of absorption also affect communications.

5.2.6 PERSONAL COMMUNICATIONS SERVICES (PCS)

- **Narrowband PCS**

Narrowband PCS can be defined as a family of mobile or portable radio services that may be used to provide services to individuals and businesses, and which may be integrated with a variety of competing networks. Services provided include wireless telephony, data messaging, and advanced voice paging and messaging.

The Federal Communications Commission (FCC) has allocated three MHz of spectrum for narrowband PCS in the 900MHz band of the electromagnetic spectrum. These are the 901-902, 930-931 and 940-941 MHz bands.

Refer to Broadband PCS Section for a listing of PCS technologies.

- **Broadband PCS**

The FCC defines broadband PCS as "radio communications that encompass mobile and ancillary fixed communication services that provide services to individuals and business and can be integrated with a variety of competing networks." Broadband PCS provides two-way voice, data and video communications. These systems will enable people to communicate anytime and virtually anywhere.

The spectrum allocation for broadband PCS is in the 1850 to 1990 MHz range with 20 MHz in that block (1910-1930 MHz) reserved for unlicensed applications.

Some key technologies being deployed in the PCS (1900 MHz) bands in the United States are defined below:

- Time Division Multiple Access (TDMA) (IS-136 or D-AMPS) - Users are assigned a slice of the RF spectrum, but share the slot with multiple users on a time slot basis to make more efficient use of the available bandwidth and avoid interference.

- Code Division Multiple Access (CDMA) (IS-95) - This technology is based on EIA/TIA Interim Standard 95 (IS-95) technology which uses a multiple access spectrum spreading technique called Direct Sequence (DS). The spread spectrum technology separates users by assigning them digital codes (DS code) within the same broad spectrum. The code is a signal generated by linear modulation with wideband Pseudorandom Noise (PN) sequences. This generates a wider signal, which reduces interference and provides a higher user capacity.

- Global System for Mobile Communication (GSM) 1900 - Utilizes technology similar to TDMA where frequency bands are divided into time slots, with each user having access to one time slot at regular intervals. GSM is the only technology that provides data services (i.e., fax, internet access and e-mail) in the U.S. and is also the only technology that permits roaming between North American, European and Asian countries.

5.2.7 DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) USING AN AUGMENTED UNITED STATES COAST GUARD (USCG) LF/MF BEACON SYSTEM

DGPS is a radio navigation system that receives satellite-generated positioning information for the Global Positioning System (GPS) and adds "differential" correction information to improve overall accuracy of the basic GPS. DGPS enables end users to determine their position to an accuracy of 10 meters (32 feet) or better, as opposed to 100 meters (328 feet) or better with traditional GPS.

The accuracy is achieved by installing navigation equipment at precisely known locations. The equipment receives the GPS signal and compares the position solution from the received signal to its known location. The result of this comparison is then generated in the form of a correction message and sent to local users via radio beacon broadcast. The received correction is applied by the user's GPS equipment to reduce the system position error, thereby improving the user's absolute accuracy.

The components of the USCG DGPS service include:

- Reference Station – Precisely located GPS receiving equipment that calculates satellite range corrections based on a comparison of the satellite navigation message to its known location.
- Integrity Monitor – Precisely located GPS receiver and MSK (minimum shift keying) radio beacon receiver that apply differential corrections. Verifies the accuracy of the corrections generated by the Reference Station.
- Broadcast Site – A marine radio beacon transmitting correction data in the 285 to 325 kHz bands.
- Control Station – Site for human centralized control of DGPS service elements. Also location where DGPS performance data processing and archiving occurs. An X.25 packet-switched service provides connectivity between broadcast sites and control stations.
- DGPS User Equipment – Includes two interfaced receivers with a display; a radio beacon receiver for MSK demodulation and a GPS receiver capable of applying differential corrections.

THE USCG is part of a seven-agency partnership for the Department of Transportation's (DOT) Nationwide DGPS (NDGPS) initiative to provide DGPS signals for public safety services.

5.2.8 SPREAD SPECTRUM COMMUNICATIONS

Spread spectrum is a technique that takes a narrow band signal (conventional radio signal) and spreads it over a broader (wider) portion of the radio frequency band for transmission. These signals use special fast codes (Pseudorandum Noise (PN) Code) that run many times the information bandwidth or data rate. These codes add noise to the spread spectrum signals, thereby making them harder to detect, intercept, demodulate or interfered (jammed) with.

In performing spread spectrum, a low-power transmitter takes the input data and spreads it in a predefined method. Each receiver must understand this predefined method and despread the signal before it can be interpreted. Two of the more popular techniques that can be used to perform the spreading are Frequency Hopping (FH) and Direct Sequencing (DS). There are also Hybrid systems (a combination of FH and DS), "Time Hopped" and "Pulsed FM (Chirp)" systems in existence.

For FH systems, the wide band is generated by transmitting at different frequencies, "hopping" from one frequency to another according to the code sequence. The specific order in which frequencies are occupied is a function of a code sequence, and the rate of hopping from one frequency to another is a function of the information rate. There are two basic kinds of FH techniques: Slow Frequency Hopping (SFH), where one or more data bits are transferred within one frequency and Fast Frequency Hopping (FFH), where one data bit is divided over more frequency hops. With SFH, coherent data detection is possible, but if one frequency hop channel is jammed, one or more data bits are lost so error-correcting codes must be used. When using FFH, error-correcting codes are not needed. FH systems provide the greatest amount of spreading along with shorter acquisition times.

DS systems are the best known and most widely used spread spectrum systems. Direct sequencing spreads the signal by expanding the signal over a broad portion of the radio band. This is done by taking the data and modulating it by adding a PN code sequence known only by the transmitter and receiver. The PN code is then subtracted on the receiving end to recreate the original message. This method of spreading the signal enable parallel communications to exist as each message can be discerned by its unique PN code. DS systems are the most difficult to intercept and provide the best noise and anti-jam performance. They do however, require larger bandwidth channels and longer acquisition times due to long PN codes.

Hybrid systems combine the techniques utilized by frequency hopping and direct sequence. One data bit is divided over the frequency hop channels (carrier frequencies). In each carrier frequency, a complete PN code is added to the data signal. Pulsed FM systems (Chirp) are characterized by a pulse RF signal whose frequency varies in some known way during each pulse period. For Time Hopping systems, the carrier is on/off keyed by the PN sequence resulting in a very low duty cycle. The speed of keying determines the amount of signal spreading.

For transmissions under 1 Watt of power, the FCC allows the use of radio bands in the 902-908 MHz, 2.4-2.4835 GHz and 5.725-5.850 GHz spectrum. Transmitting under these conditions requires no FCC license and the power limit prevents interference within the band over long distances.

5.2.9 METEOR BURST COMMUNICATIONS

Everyday, billions of small meteors enter the earth's atmosphere and quickly vaporize. The vaporized meteors leave a trail of ionized particles that have the ability to reflect or re-radiate radio signals to establish long-range radio communications. Meteor burst communications refers to the reflection of radio waves off the ionized trails left by meteors as they enter the earth's atmosphere and disintegrate.

A typical meteor burst network consist of one Master Station and many Remote Stations. The Master Station continuously transmits a probe signal at a selected frequency. The operating frequency of most meteor burst systems lies between 40 to 60 MHz. When a suitable meteor (appropriate size and trajectory) enters the atmosphere, the signal is reflected to a Remote Station. The Remote Station decodes the signal and transmits a burst of data back to the Master Station via the same path. This exchange can continue until the trail has diffused to a point too low to sustain reflection. The meteor is best used when traveling between an altitude of 120 km (75 miles) and 80 km (50 miles).

The maximum length of a single link is around 1600 km (995 miles). This is determined by the height of the meteor trail and the curvature of the earth. The performance of a communication link is determined by the “wait time”, the time required to transfer a message between two stations at a specified reliability.

Although billions of meteors enter the atmosphere, only a small number are suitable for communications purposes because of a number of factors, including; (1) the trails diffuse fairly quickly (typically in 0.3 seconds or less), (2) the trails must produce an ionized trail with an acceptable reflection loss, (3) the trails must be within a common volume that is within the line-of-sight of the master and remote stations, and (4) the trail must be tangent to the surface of an ellipse of which the two stations are the foci.

Compared to other wireless alternatives for distances beyond 100 km (62 miles); HF systems and mobile satellite systems, meteor burst communications may be the most reliable. Communications for satellites and HF systems are received over a larger area making them susceptible to being intercepted and/or disrupted. Satellite communications is also very expensive.

Some current users of meteor burst technology include 1) The Natural Resources Conservation Service (NCRS), who operates and maintains SNOTEL (SNOwpack TELemetry), an automated system used to collect snowdrift depths and related climatic data for sites in 11 western states. This system has 600 SNOTEL sites that are polled by two master stations as needed, typically every 15 minutes; and, 2) StarCom, a wireless solutions provider, that utilizes this technology to offer its customers a means of tracking fleet vehicles, security and remote site monitoring and supervisory control and data acquisition (SCADA) applications.

5.2.10 HIGHWAY ADVISORY RADIO (HAR)

Highway Advisory Radio (HAR) systems provide travel information to motorist via the AM broadcast band on their car radios. The information provided by these systems include current traffic conditions, travel restrictions, notices of events and general safety information. HAR systems can be stationary, meaning they are permanently installed at fixed locations; or portable, that is, they are mounted on trucks and travel to different locations to broadcast on an as needed basis.

A typical HAR system contains a transmission system (broadcast antenna, grounding system, roadside transmitter, a voice recorder and a communications link to a Traffic Control Center) and a system of Changeable Message Signs (CMS) or static signs with beacons advising motorists to tune to their HAR station. Portable HAR systems also include a photovoltaic (solar) battery storage system mounted on a towable trailer.

The broadcast antenna could be a vertical monopole antenna or an induction cable antenna. Vertical monopole antennas provide a circular transmission zone and can generate clear signals for 3 to 8 miles. Several vertical antennas could also be used to create a directional array that transmits signals in a non-circular shape. Induction cable antennas (radiating or leaky) are buried along the roadway and produce a strong signal within a short lateral distance from the cable that can broadcast multilane highways. Radiating cable antennas are restricted to 1.86-mile runs over which a broadcast message is heard. Leaky cable antennas radiate a signal strong enough to be detected over the length of the cable, with no restrictions on cable length. Cable antennas are better served in areas that receive significantly weak monopole antenna transmission (tunnels). However, there must be some cost considerations for the maintenance and installation of cable antennas.

Two different transmitters could be used to broadcast HAR messages, a 10-watt transmitter or a 0.1-watt transmitter. 10-watt transmitters have a broadcast radius of 3 to 6 miles, provide a radial zone of influence, and require a FCC license. The FCC allows HAR broadcast between the 453 kHz and 1710 kHz frequencies, with most systems operating at 530 kHz or 1610 kHz. Licenses are provided at frequencies that ensure no interference with existing AM stations. Low power 0.1-watt transmitters can be broadcast over any unused commercial radio frequency and does not require any FCC licensing. The transmitters are interconnected and synchronized to form a zone of coverage. They can also be arranged in a customized zone configuration to allow unique messages to be broadcast in each zone.

The NOVA STC operates or plans on operating fixed and portable HAR systems at frequencies of 1610 and 1620 kHz. Refer to the Section 4 of this document for more information on the NOVA HAR system.

5.2.11 BROADCAST TV – VERTICAL BLANKING INTERVAL (VBI), SECONDARY OR SEPARATE AUDIO PROGRAM (SAP)

- **VBI**

Vertical blanking Interval (VBI) refers to the first 21 lines of the television signal which is comprised of 525 lines on standard television sets. Lines 1 to 9 of the signal are used by the VBI for timing set-up, but lines 10 to 20 carry no audio or video. As such, Lines 10 to 21 are available to carry other information including closed-captioning information and stock market data. Line 21 of the VBI has been used for many years to provide closed-caption text to the hearing impaired, via a decoder unit, anywhere a signal is received. VBI data can also be transmitted to all carrier media including VHF, UHF, satellite and cable (analog and wireless). VBI data in a cable providers' signal can be transmitted to a PC's RS-232C port via a special receiver. The VBI has the capacity to transmit data at around 150 kbps, after accounting for the forward error correction (FEC) algorithms used to guarantee data integrity in the transmission.

VBI advantages include point-to-multipoint capabilities (networks generate a signal transmitted via satellite to network affiliates who then broadcast it over the air at the channels allocated frequency); the ability to receive data in a timely manner; the added flexibility of being able to address data streams to specific users by simply reconfiguring user group addresses on the receiver at the receiving site; and, the reliability of broadcast networks being up and running near 100% of the time.

- **SAP**

SAP refers to the Secondary or Separate Audio Programming channel carried alongside a television channel as an alternative to the standard audio that accompanies the video portion of a program. It is a feature available in most stereo television sets and video cassette recorders (VCRs) sold after 1990, as these sets are usually equipped with internal SAP decoders. For televisions manufactured prior to 1990, a stand-alone audio SAP receiver can be purchased. SAP is not available on televisions equipped with mono sound only.

The SAP feature allows the audio portion of programs to be heard in another language. ABC currently provides audio programming in Spanish for “Monday Night Football” and other sporting events and specials. The SAP feature can also be used to provide weather information or Descriptive Video Services (DVS) for the visually impaired. This service enables the listener to hear a narrator describe the action of a scene during pauses in dialogue.

The FCC recently adopted video description rules requiring local affiliates for ABC, CBS, NBC and Fox networks to provide a minimum of 50 hours of SAP programming per calendar quarter. These rules will be in effect the calendar quarter April to June 2002 and equate to approximately four hours per week. The FCC is also looking into applying video description rules to all video programming distributors including all wireless cable operators, home satellite dish providers, direct broadcast satellite operators, cable operators and TV stations.

5.2.12 BROADCAST FM RADIO – RADIO DATA BROADCAST SYSTEM (RDBS), SECONDARY CARRIER (OR SUBSIDIARY COMMUNICATIONS) AUTHORIZATION (SCA) AND DIGITAL AUDIO BROADCAST (DAB)

- **SCA**

SCA is a provision of the FCC rules that allows a FM radio station to transmit multiple channels of audio or data using the same frequency. It is commonly referred to as a “subcarrier” because a subcarrier is used to transmit the information.

There are 100 FM channels (stations) allocated from 88.1 to 107.9 MHz, in 200 kHz increments. Each station is allocated 100 kHz of bandwidth for audio transmissions. Because FM audio is generally restricted to 15 kHz, a large amount of the spectrum went unused. When the FCC added to the capabilities of FM radio by implementing a standard for FM stereo broadcasting, more of the allocated bandwidth was utilized but it still left a lot of the spectrum unused. This unused portion is the portion allocated to subcarriers to transmit audio or data.

SCA broadcast are transmitted in the 67 kHz and 92 kHz frequency, with 67 kHz being the most common because its signals are received with more clarity and less interference. The 71 kHz frequency is sometimes used for data transmissions. Subcarriers are used for many purposes, including, data transmissions (stock market reports, sports results, etc.), radio reading services (news, books, etc for the hearing impaired), foreign language services (music and news in various languages), radio broadcast data systems (RDBS) and background music (Muzak). In order to receive SCA transmissions, a listener must be equipped with a FM receiver, as well as a receiver that demodulates the subcarrier signal.

- **RDBS**

Originally developed in Europe in 1976, the Radio Data System (RDS), RDBS in the U.S., was used as a method of sending data to radio pagers. It was adopted as a standard in the U.S. in 1993 and is used by low-speed FM subcarriers to verbally deliver breaking news, weather and traffic reports. The digital RDBS signal is modulated at a subcarrier frequency of 57 kHz. There are a number of RDBS broadcasters in the U.S. and numerous suppliers of RDBS receivers for the home, car or PC, including Cadillac, Kenwood and Audiovox.

- **DAB**

DAB is a digital method of transmitting CD quality audio signals to radio receivers. It can be operated at any frequency from 30 MHz to 3 GHz for mobile reception. These systems will in no way disrupt existing services, as a 'smart' digital receiver must be used to obtain the digital sound quality offered. DAB systems designed for FM bands will provide CD quality audio via existing FM stations, while those designed for the AM band will provide near CD quality audio. While some subcarriers are already transmitting data, DAB systems will allow a larger volume of data to be transmitted with higher reliability (station call letter and names, song titles, etc.). DAB systems also enable the transmission of data in the AM band, which was not available before. At present, there are no DAB systems in operation in the U.S.

One of the concerns associated with radio reception is the phenomenon known as multipath propagation. Propagation refers to the scattering of the transmitted radio waves from the surfaces of buildings and by diffraction over and/or around them. Multipath refers to the different paths taken by the waves to one location (receiver). That is, the waves arrive from different directions with different time delays. Multipath propagation can create a problem with SCA subcarriers because if reflected waves collide with the primary signal, the subcarrier could be lost or the stereo signal is significantly degraded (interference).

Interference with SCA subcarriers can be minimized by properly locating the receiving antenna. Digital radio is virtually immune to interference because DAB systems are designed to minimize the effects of multipath in the FM band in a variety of ways. The first is Orthogonal Frequency Division Multiplex (OFDM), which is a digital modulation scheme that applies each bit to a frequency-time window to minimize distortion of the waveform when transmitted. The second method is the use of interleaving and forward error correction (FEC). FEC is capable of correcting errors and interleaving is used to distribute the errors so as to optimize the effectiveness of FEC. The third method is the use of time diversity, that is, if the FM channel is delayed in time, the chances of an outage due to multipath is reduced. These methods are all handled by the "smart' receiver used with digital radio, which includes a tiny computer to sort through the various distorted transmissions and create a solid signal.

5.3 VEHICLE-TO-VEHICLE COMMUNICATIONS

Vehicle-to-vehicle communications systems are dedicated wireless systems requiring the handling of high and "bursty" data rates, low probabilities of error, and line of sight transmissions with high reliability between vehicles to enable inter-vehicle communications. No standards have been developed for this type of technology as yet. This type of communications is associated with Advanced Vehicle Safety Systems (AVSS) and the Automated Highway System (AHS). AVSS provides various forms of collision avoidance and safety precautions (longitudinal, intersection, and lateral collision avoidance) for vehicles. The AHS refers to a dedicated highway lane in which vehicles are automatically controlled; that is, the vehicles' steering, braking and throttle are controlled by the system, not the driver. Advanced vehicle services may use this vehicle-to-vehicle communication link in the future to support advanced collision avoidance implementations, road condition information sharing, and active coordination to advanced control systems.

5.4 DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)

DSRC is a short to medium range radio frequency (RF) communications service that supports both Public Safety and Private operations in roadside-to-vehicle and vehicle-to-vehicle communication environments. It is meant to complement cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication small communication zones are important.

The current DSRC system used today in North America operates in the 915 MHz band and is proprietary. The new DSRC standards developments will be based on the 5.9 GHz radio spectrum allocated to DSRC by the Federal Communication Commission (FCC). These standards will focus on North America and facilitate a new level of communications that will enable the U.S., Canadian, and Mexican ITS programs to evolve a new class of communications and applications to support future transportation systems by ensuring full interoperability.

The five basic classes of applications for DSRC are Public Safety, Traffic Management, Traveler Information/Support, Freight/Cargo Transport, and Transit. To obtain any information on current DSRC status, refer to the following web site:

http://www.leearmstrong.com/DSRC%20Home/DSRC%20Home%20set.htm

6 STANDARDS

This section will provide a thorough review of the National Transportation Communications for ITS Protocol (NTCIP) along with consideration of its application to NOVA ITS. It will also address the center-to-center and center-to-field standards considered for the VDOT NOVA ITS Architecture.

6.1 STANDARDS

One of the most important issues in Intelligent Transportation System (ITS), transportation and traffic community is lack of widely recognized and accepted communication standards, which results in lack of interchangeability and interoperability. Historically, traffic device and controller vendors adopted different, proprietary data communication protocols under different system platforms. It created a handful problems for both equipment and systems owners, as well as systems integrators. Typical systems integration and interoperability problems, include:[3]

- different types of devices are unable to operate on the same communication channel,
- systems software requires modifications if new traffic devices are incorporated into the systems, and
- systems are unable to communicate with other systems owned by adjacent agencies.

These problems usually result in higher systems design, maintenance, and operational cost with lower efficiency for systems owners. For systems integrators, developing or upgrading systems comprised of new and legacy devices that are purchased from mixed vendors using proprietary protocols require extensive efforts on hardware and software integration. In addition, these integrators experience technical difficulties when dealing with proprietary information.

6.2 NTCIP COMMUNICATIONS PROTOCOL

6.2.1 NTCIP BACKGROUND

In the early 1990s, the Federal Highway Administration (FHWA), the American Association of State and Highway Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE) and the National Electrical Manufacturers Association (NEMA) proposed and sponsored the National Transportation Communication for ITS Protocol (NTCIP).. NTCIP offers increased flexibility and choices for operating transportation management systems, enables interagency coordination, removes proprietary information barriers, and allows different types of devices from different vendors to be mixed on the same system with minimum efforts of integration. As such, it has been rapidly and widely embraced and specified in many new ITS deployment systems.

6.2.2 NTCIP FRAMEWORK

A communication protocol is a set of rules of how messages are defined, coded, and transmitted between electronic devices. NTCIP is comprised of a family of general-purpose communication protocols, based on the Open Systems Interconnection (OSI) seven-layer

[3] "The NTCIP Guide", Joint Committee on the NTCIP, December, 1999

structure. It not only supports data transmission between microcomputers and control devices used in ITS, but also provides users, manufacturers, and system integrators a standards base to build new systems and/or to integrate new system into existing infrastructure with systems interchangeability and interoperability ensured.

ITS data communication applications can be divided into two fundamentally different types. The first type is between a management center and multiple field devices. This is referred as "Center-to-Field" (C2F) communications, in which a computer system in management center issues commands and/or polls real-time data routinely to and from field devices. For example, a traffic management system controls Closed Circuit Television (CCTV) cameras, Variable Message Signs (VMS) and regularly polls data from detectors. The second type of communication occurs between two or more traffic management systems. This is referred as "Center-to-Center" (C2C) communications, which enables information attained from one resource to be shared by others. Primary areas that require such communications are traffic coordination (signal status exchange at jurisdiction boundaries), event notification (incident notifications), data sharing (CCTV images), and regional commands distribution (regional traffic diversion)[4], and NTCIP supports data communication for both center-to-field and center-to-center applications for a variety of ITS management systems, such as traffic management, emergency management and transit management. The role of NTCIP in the NOVA ITS Architecture is illustrated in Figure 30.

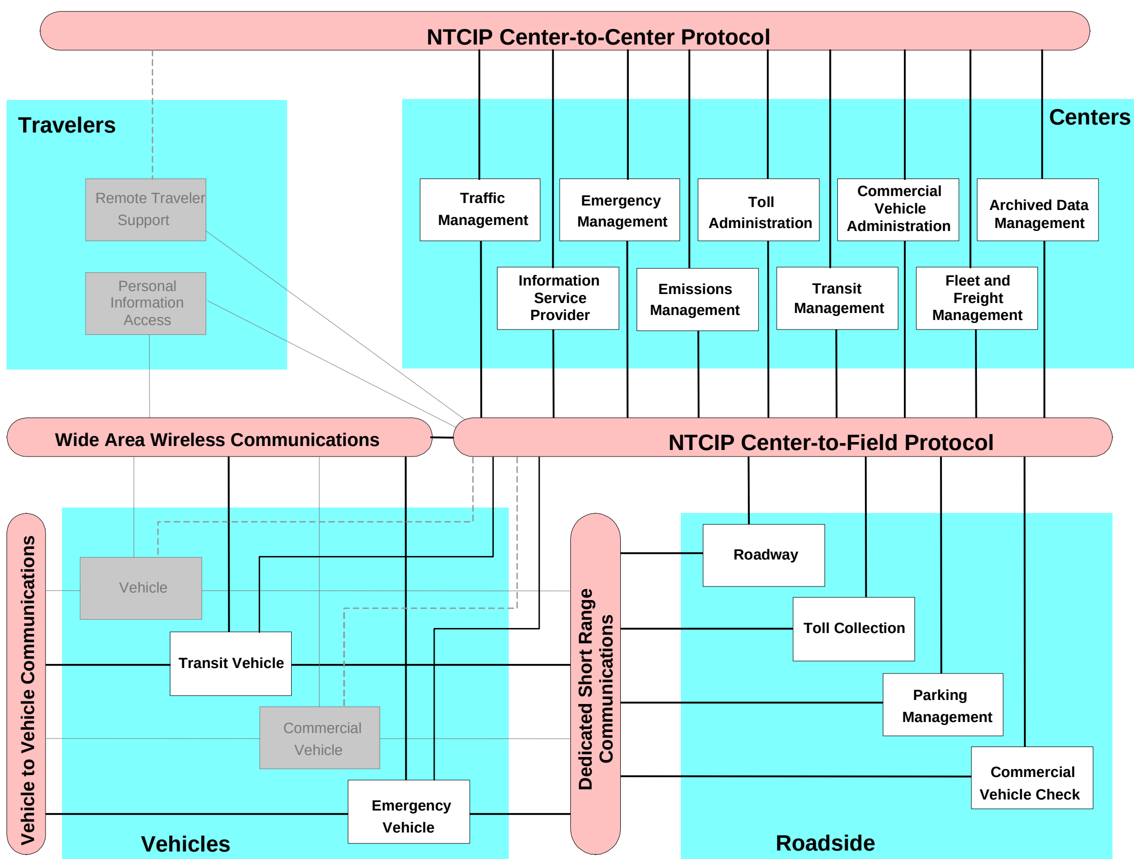

Figure 30 – NCTIP and the NOVA ITS Architecture

[4] "NTCIP White Paper: Center-to-Center Communications", G Mosley; R Ristow, November, 1996

As mentioned earlier, NTCIP adopted a layered structure based on International Standard Organization's (ISO) seven-layer OSI reference model. Slightly different than the OSI model, the NTCIP communication stack framework is comprised of five primary layers, which include:

- Information Layer - provides standards for data elements, objects, and messages,
- Application Layer - provides standards for data packet structure and session management,
- Transport Layer - provides standards for data packet subdivision, packet re-assembly and routing when needed,
- Sub-network Layer - combines data link and physical layers in OSI model and provides standards for physical interface and data packet transmission method, and,
- Plant Layer. - indicates data transmission media used for communications.

Most efforts devoted to NTCIP developments are focusing on standards, data, and object definitions, at the Information Layer, which is unique to transportation community. Standards such as NTCIP 1203, NTCIP 1205, and NTCIP 1209 define data structure and objects used between Traffic Management Center and Dynamic Message Signs (DMS), CCTV, and Transportation Sensor Systems (TSS), respectively. In addition, common data elements and message sets transmitted between management centers are developed and initiated by Traffic Management Data Dictionary (TMDD) and Messages Sets for External Traffic Management Center Communications (MS/ETMCC) activities.

As of now, six application layer protocols have been proposed and standardized by NTCIP. There are Common Object Request Broker Architecture (CORBA), DATa EXchange in Abstract Syntax Notation One (DATEX-ASN), Simple Network Management Protocol (SNMP), Simple Transportation Management Protocol (STMP), File Transfer Protocol (FTP) and Trivial File Transfer Protocol (TFTP). DATEX-ASN and CORBA are protocols suitable for center-to-center communications. SNMP and STMP, on the other hand, are protocols appropriate for center-to-field communications. FTP and TFTP could be used to retrieve files stored on server when client receives a DATEX-ASN file publication message or any file transfer requests. With the exception of STMP, all application protocols are existing and widely accepted industrial standard application layer protocols.

As for the Transport and Sub-network layers, NTCIP adopts a number of existing standards used by computers and communication industries, especially for the Internet. Transmission Control Protocol and Internet Protocol (TCP/IP) provide transport routing and addressing services for connection-oriented networks. User Datagram Protocol/IP (UDP/IP), in contrast, provides transport delivery services to connectionless networks. Transport service is not required if intermediate routing is unnecessary. The Sub-network layer protocols adopted in NTCIP provide a wide range of options for data packet formatting and data link control, from Asynchronous Transfer Mode (ATM), Fiber Distributed Data Interface (FDDI), Ethernet, to Point-to-Point Protocol (PPP) and Point-to-Multiple-Point Protocol (PMPP) protocols. The Plant layer simply defines communication media, such as Fiber, coaxial cable, twisted pair copper line, telephone line and wireless communications.

Figure 31 below represents the NTCIP framework. Shaded blocks indicate areas where NTCIP devoted most of its efforts. The series of communication standards used in data transmission is called "communication stack." As indicated in the figure, each NTCIP "stack" involves NTCIP specific protocols in the upper layers and existing industrial standards in the lower layers. The reference model shown above the CORBA protocol is the model of how the object is referenced in Object Request Broker (ORB). Details of CORBA will be discussed in the later sections.

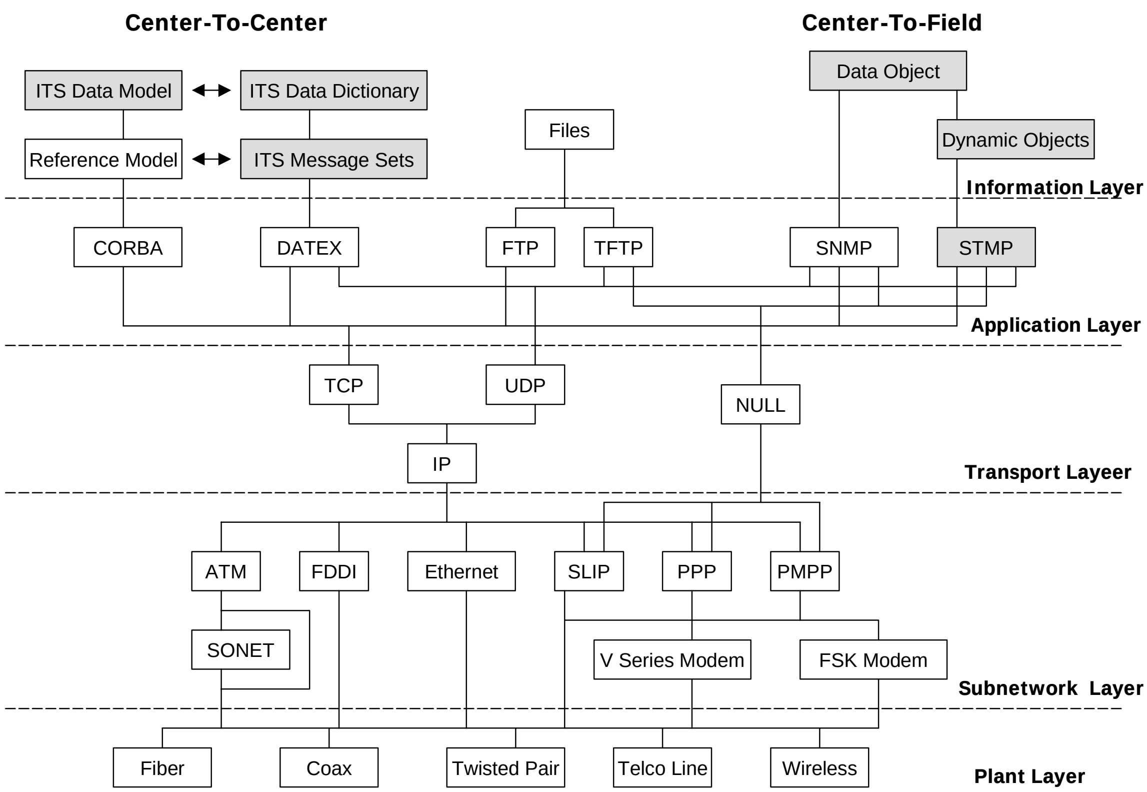

Figure 31 – NTCIP Framework

6.2.3 CENTER-FIELD (C2F) COMMUNICATION STACKS

In ITS systems, central computers consistently communicate with field devices for system monitoring, data collecting and equipment control. Under NTCIP framework, Center-to-Field (C2F) stacks are defined for data exchanging between management center and field equipment with considerations of interoperability and interchangeability. The stacks include both well-developed and newly defined protocols. Figure 32 illustrates two samples of C2F stacks from the Information layer down to the Plant layer. The blue designation in this sample stack reflects data transmissions from the central computer to field devices utilizes SNMP protocol at the Application layer, and PMPP protocol and Frequency Shift Keying (FSK) modem at the Sub-network layer via twisted-pair copper media. Since the central computer is a type of peer-to-peer connections, routing is not required. Thus, a "null" is indicated at the Transport layer. Data objects used in this stack are defined at the Information layer. This sample stack is known as "Class B" profile.

Another sample stack (shown in red) illustrates data transmissions that require routing using TCP/IP and Fiber Distributed Data Interface protocols over a fiber network. This stack uses STMP instead of SNMP protocol at the Application layer. SNMP and STMP are two application layer protocols for C2F communications. SNMP is based on the existing Internet protocol, which provides simple but bandwidth inefficient services and is suitable for networks with high bandwidth or low volumes of messages. STMP is a new protocol developed by the NTCIP Committee and Working Groups. It uses more efficient data encoding rules, known as Octect Encoding Rules (OER), to reduce packet overhead and supports several dynamic objects at the Information layer. Thus, although STMP is an extension of SNMP, it is able to transmit C2F messages with higher efficiency. However, the C2F message sets supported by STMP is limited to thirteen (13) message sets so far. STMP is suitable for networks with low bandwidth and high volumes of messages, such as traffic signal systems.

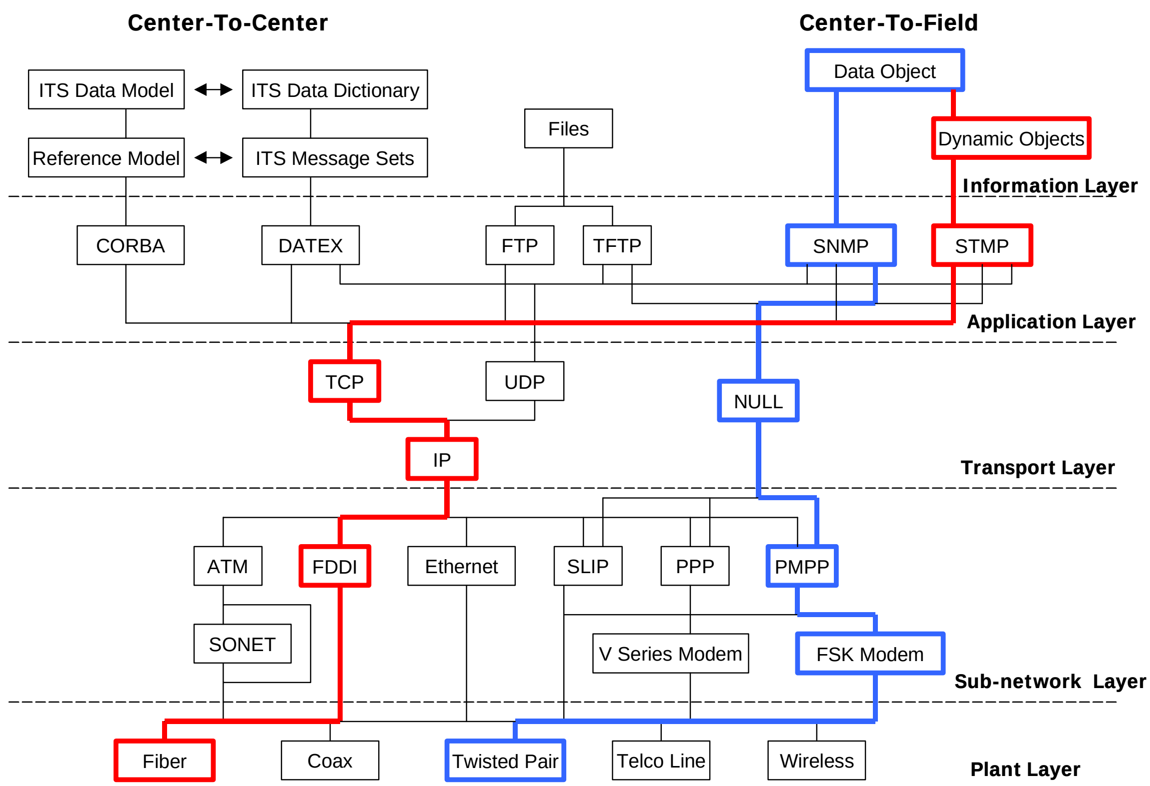

Figure 32 – Example C2F NTCIP Stack

To implement C2F communication stacks, an "agent" has to reside at the central computer in the management center and in the controller that controls field devices. "Agent" is a piece of software that is able to interface with operating systems and end applications to retrieve and deliver data from specific communication port. When a command is issued from an end application in the management center to a field device, the central agent should, at first, be able to verify whether the data/object associated with the command is valid. To do so, the central agent verifies data/object definitions by checking device's Management Information Base (MIB), a compiled file that is generated from a text file and contains data and object definitions in a specific format known as Abstract Syntax Notation One (ASN.1). If the data/object is verified as a valid item, the central agent starts to "wrap" the data/object from top layer to bottom layer, starting from to either SNMP or STMP message, based on a communication stack specified by the end application. Each communication data message is composed of a message header and a message body. The message header is prefixed to message body to comprise the Protocol Data Unit (PDU). Depending upon the types of protocols selected in the stack, message is wrapped according to fields defined in the protocol to form the layer-based message. Different data encoding rules then are applied for converting message to bit-stream data. Central agent interfaces with operating system to transmit the bit-stream via designated communication port over a certain media. Field agent, on the other side of the communication channel, has to coordinate with the controller's operating system to receive incoming data bit-stream, "unwrap" the message layer-by-layer, and attain the transmitted data/object. Like central side operations, the data/object is verified against the field MIB. If the verification is successful, field agent implements the command associated with the data/object to the controller's memory. Figure 33 presents NTCIP C2F communication implementation concepts.

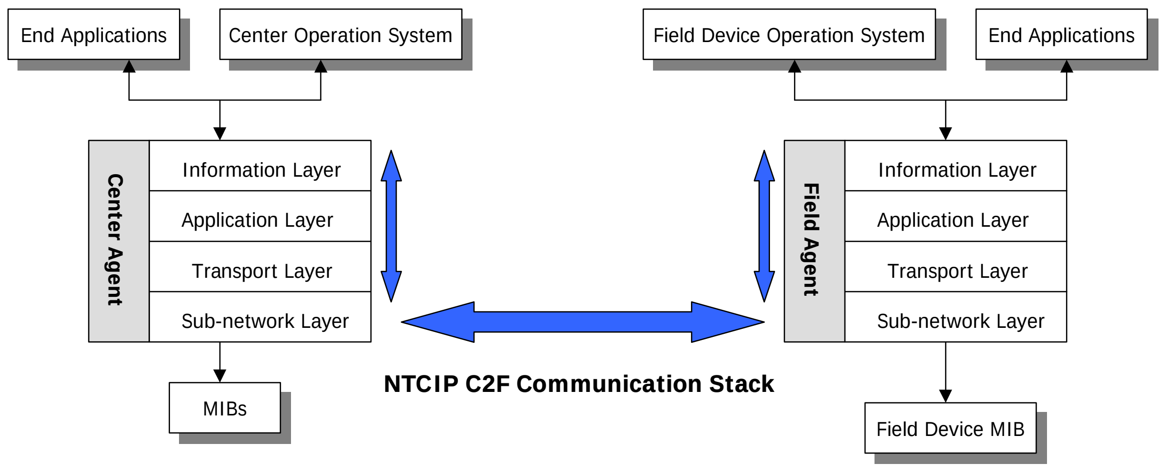

Figure 33 – C2F Communication Implementation Concepts

Several transportation agencies have embraced and installed NTCIP C2F compliant devices in their jurisdictions. The Illinois State Toll Highway Authority (ISTHA) and Delaware Department of Transportation (Del DOT) installed the NTCIP compliant full matrix, walk-in variable message signs on Chicago's East-West Tollway and Interstate 95 in 1999. Recently, the cities of Phoenix, Arizona and Lakewood, Colorado announced the successful integration efforts on their traffic signal management system with NEMA TS-2 signal controllers by applying NTCIP. It is claimed that the system implemented in Phoenix and Lakewood supports low-speed and high-speed communication, which provides flexibility to public agencies to use existing low-speed lines to reduce costs. The Phoenix/Lakewood system is the first multiple vendors NTCIP implementation. All message exchanges between center and field use STMP and SNMP with customized MIBs.

6.2.4 CENTER-TO-CENTER (C2C) COMMUNICATION STACKS

As discussed in former sections, inter-center communications are mainly for four requirements, traffic coordination, event notification, data sharing and regional command distributed. Traffic coordination may include time synchronization, background signal cycle coordination, signal plan coordination, and adaptive-signal control data exchange. Event notification may include notifications on hardware status, communication link status, incident detection, incident management, and special events. Data sharing may include real-time data sharing such as detector data, CCTV video images, device status at jurisdiction boundaries, coordination details, and static data sharing such as event and detector historical information. Regional command distribution may include regional traffic diversion plan and emergency response plan coordination.

Similar to center-to-field communication stacks, Center-to-Center (C2C) communication stacks are comprised of sets of protocols from Information Layer to Plant Layer. An example of C2C stack is shown in Figure 34.

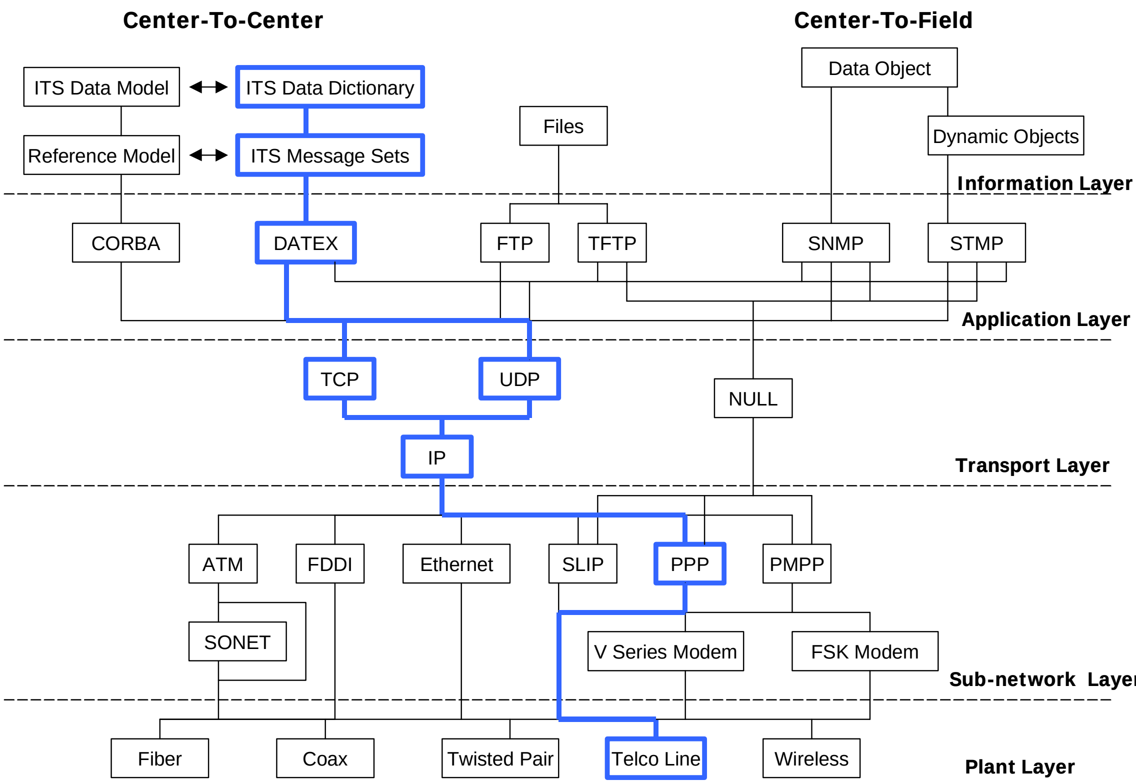

Figure 34 – Example C2C NTCIP Stack

As depicted in Figure 34, the communication messages are constructed based on data definitions and message sets defined in ITS Data Dictionary and ITS Message Sets, known as Traffic Management Data Dictionary (TMDD) and Message Sets for External Traffic Management Center Communications (MS/ETMCC). These messages are wrapped using DATEX standard. Depending on whether the network is connection or connectionless, TCP/IP or UDP/IP is used. Data packets and transmission frames are constructed using PPP standard at the Sub-network layer. The data stream is then transmitted over a leased wire-line to the subject center. In addition to DATEX, CORBA is the other C2C application layer protocol adopted by NTCIP. DATEX and CORBA are for low-end and high-end systems, respectively.

6.3 DATA EXCHANGE IN ABSTRACT SYNTAX NOTATION ONE (DATEX-ASN)

DATEX was developed in Europe in early the 1990s due to the increasing need for integrating nearby transportation systems to provide required services. The DATEX Task Force produced a set of basic tools to meet existing needs including a common data dictionary, a common set of Electronic Data Interchange for Administration Commerce and Transport (EDIFACT) messages, and a common geographical location referencing system. The initial solution provided a common interface, which satisfied the basic requirements of existing systems and was named the Data Exchange Network (DATEX-Net) specifications for interoperability. During the initial efforts to deploy this standard, there was a growing sense that the message structure should be better organized and should be defined using widely accepted Abstract Syntax Notation One (ASN.1) rather than EDIFACT[5]. ASN.1 provides a standard notation for data types and values definition. Data types and values can be converted into byte-stream based on standardized encoding rules. In 1997, the U.S. developed the initial draft of the DATEX-ASN, which has been adopted as one of the two NTCIP application layer C2C standards.

DATEX-ASN is based on the client-server architecture. Data elements are exchanged between a client, i.e., a customer, and a server, i.e., an information supplier. Any management center requesting information from other centers is defined as a client and any management center that is being requested to provide information is defined as the server. A management center can act like as a client, a server, or both client and server at the same time, which means multiple application sessions may exist simultaneously.

Similar to the typical client-server system, requests and responses can be generated by either client subsystem or server subsystem. Request can be either scheduled or event-driven. To establish a session, the server may issue an "initiate" request to the client asking to set up a connection or the client may initiate the login request. Upon receiving a login data packet, a server shall determine if the domain names, user-name, password and other associated data are valid for the request. Depending upon the results, the server shall accept or reject the request. Requests and responses for logging-out from the server are similar to login procedures. To maintain a session, a "Friendly Exchange of Data" (FrED) data packet has to be sent back and forth between client and server to ensure smooth data transmission without facing time-out situation.

If the server accepts the login information, the client station may issue an "subscription" data packet to server "subscribing" to specific information. If the subscription message is accepted, the server will prepare "publication information" according to publication type specified in client's request. For datagram publication, publication data is embedded into publication data packet and transmitted back to the client. In the case of the resulting datagram being over the pre-defined maximum datagram size, the publication data will be stored in a file and the publication data packet will indicate the path and the filename of the file that stores the publication data. Once the client receives the publication data packet, it can activate the file transfer mechanism, such as File Transfer Protocol (FTP), to retrieve the publication data from the server. Figure 35 shows DATEX-ASN client-server architecture, request and response messages and their operating sequences.

DATEX-ASN provides a simple, general-purpose C2C data exchange stack for basic data exchange needs. It is a cost-effective solution for systems that request fast data transfer and high data volumes, but with limited bandwidth. DATEX-ASN is not designed for and cannot take advantages of highly object-oriented systems.

Recently, the Texas Department of Transportation (TxDOT) successfully implemented DATEX-ASN application protocol to subscript incident data from the Dallas / Fort Worth System. The central computer acts like a data clearinghouse for the incident information of the region. TxDOT plans to expand the system to include data from all major regional centers in Texas.

[5] "Transportation Information and Control Systems: Data Interfaces Between Centers, Part II", ISO-14827-2, February, 2000

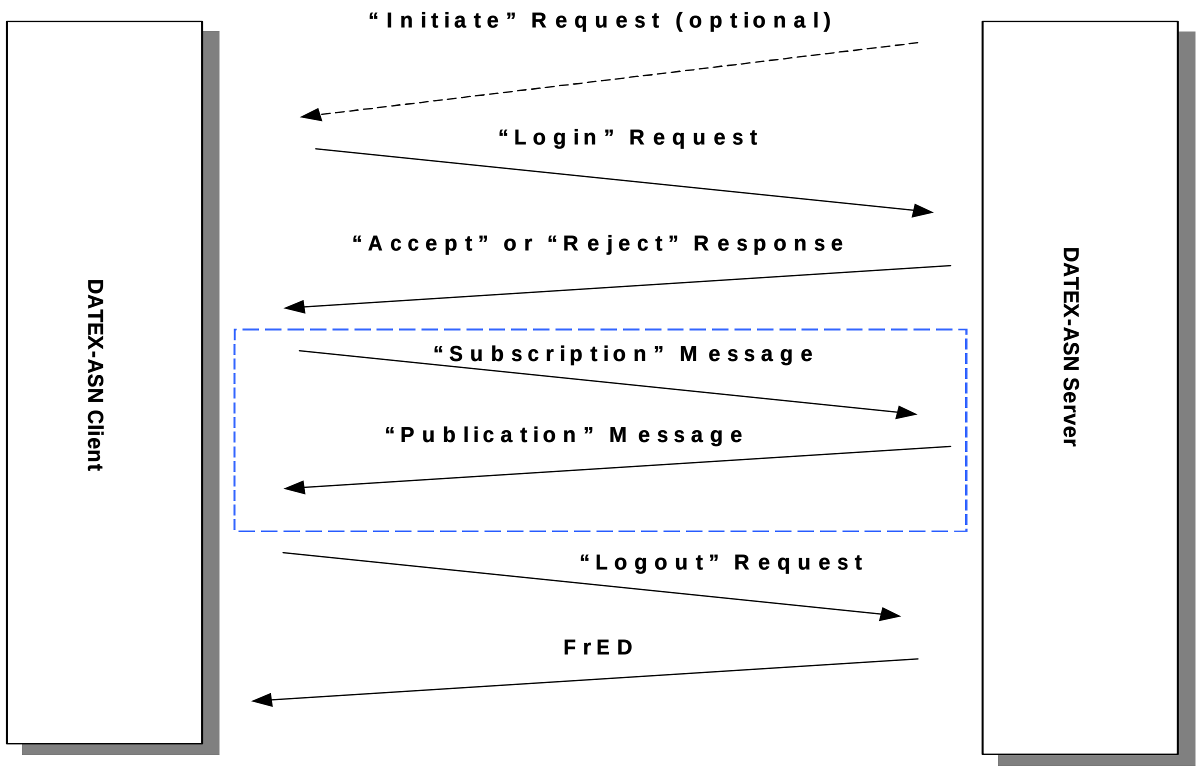

Figure 35 – DATEX-ASN Client-Server Architecture

6.4 COMMON OBJECT REQUEST BROKER ARCHITECTURE (CORBA)

CORBA is one of the two standards adopted by NTCIP C2C communications. As the popularity grows for the design of distributed systems today, CORBA is able to provide a truly open, vendor-independent architecture for distributed object computing. It has also been standardized by Object Management Group (OMG), a non-profit consortium created in 1989 for promoting theory and practice of object technology in distributed computing systems. Using the standards Internet ORB Protocol (IIOP), a CORBA-based program, independent to computer, platform, programming language and network, can operate with any other CORBA-based program resided on computer in the network. It provides interoperability between objects in a heterogeneous distributed environment and in a way transparent to the programmer.

CORBA is based on OMG Object Model, which defines common object semantics for specifying the externally visible characteristics of objects in a standard and implementation-independent manner. In this model, clients request services from servers through a strong-type defined interface, which is specified using Interface Definition Language (IDL). When a client intends to access an object, it issues a request to the object. The request is composed of object reference of the service provider and required parameters associated with the services. The central piece of CORBA is the Object Request broker (ORB), also known as Object Reference Model. It encompasses the entire communication infrastructure required for identifying and locating objects, managing connection and delivering data. Figure 36 shows CORBA ORB architecture.

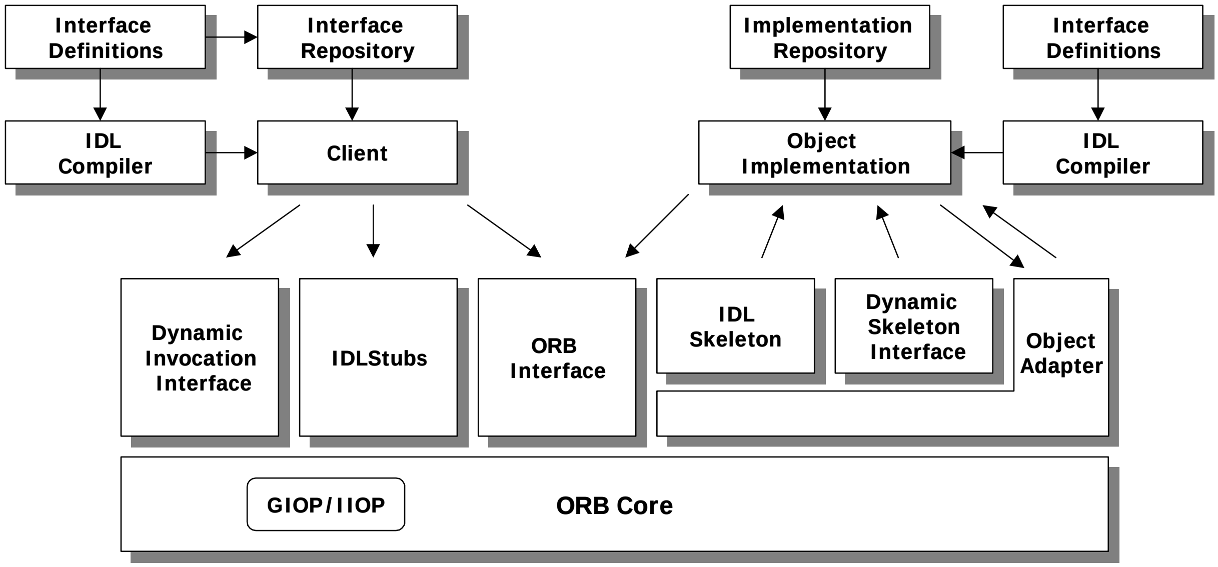

Figure 36 – CORBA ORB Architecture

ORB is responsible for transferring requests from clients to the object implementations on which they are invoked. Clients can communicate with the ORB via the IDL stub or the Dynamic Invocation Interface (DII) and make requests. The ORB then transfers the requests to the object implementation, which receives the requests as up-calls via IDL skeleton or Dynamic Skeleton Interface (DSI). Requested services are provided and results are sent back to clients via ORB. The communications between the object implementation and the ORB core is performed by the Object Adapter. It provides services such as generation and interpretation of object references, method invocation, security of interactions, object implementation activation and deactivation, and object references mapping.

The IDL stub represents the mapping between the language of implementation of the client and the ORB core. Thus, the client can be written in any language as long as the implementation of the ORB supports that mapping. DII allows clients to specify requests to objects whose definitions and interface are unknown at client's compile time. DII is implemented by using Interface Depository, a database that provides object interface definitions. Using DSI on the server side offers ORB the access to an object implementation that does not exist at compile-time.

Since the ORB is independent to its implementation, currently there are many different ORB products. To ensure proper ORB-to-ORB interaction, special transfer syntax is specified and fulfilled by General Inter-ORB Protocol (GIOP). Using popular transport layer TCP/IP protocol, OMG defined the Internet Inter-ORB Protocol (IIOP) for "bridging" gap between ORBs, which enhances CORBA's interoperability.

CORBA provides a full-scale architecture for object-oriented distributed system. Object-oriented software implemented in traffic management centers can take full advantages of CORBA technology that traditional software can not offer. However, due to the complicity CORBA has, it requires significant resources for implementations in the areas of programmer knowledge, hardware requirements and funds. In short, CORBA is a good candidate for high-end system with plenty of resources.

6.5 DATEX-ASN AND CORBA COMPARISON

NTCIP offer DATEX-ASN and CORBA application layer protocols for C2C communications. DATEX-ASN is based on client-server architecture in which a transportation center can subscribe to information from other central systems with a relatively simple procedure. Implementation of DATEX-ASN is a cost-effective solution to low bandwidth and small systems. Conversely, CORBA not only enables systems to retrieve data from other systems, but also enable systems to remotely activate methods embedded in objects. It provides full-scale features for data exchange between systems. As expected, CORBA requires significant resources for implementation and is more suitable for major transportation management centers with high communication bandwidth. A DATEX-ASN and CORBA comparison table is provided in Table 12 shown below:

Table 12 – DATEX-ASN and CORBA Standards

	DATEX-ASN	CORBA
Systems		
• Size	Small	Large
• Connection	Peer-to-Peer or Dial-Up	Peer-to-Peer
• Bandwidth Requirement	Limited	High
Access	Data only	Object (data and method)
Implementation		
• Required Resources	Limited	Significant
• Complexity	Low	High
Object-Oriented	No	Yes
Services Provided	Limited	Full-Scale

6.6 TMDD AND MS/ETMCC[6]

Traditionally, transportation professionals and agencies use unique data definitions to build up applications and implementations. This creates communication barriers and limits interoperability when data has to be exchanged between a variety of systems. For example, links and nodes used to define roadway geometry could be interpreted differently between a traffic management center and a transit authority. To reduce data element ambiguity and improve system interoperability, standardization of data elements, messages, and message sets is essential. ITS community realized such needs and devoted efforts to initiated Traffic Management Data Dictionary (TMDD) and Message Sets for External Transportation Management Center Communications (MS/ETMCC) standards for data exchanged between centers. TMDD standardizes common data definitions using certain formats and templates in four separated sections in the areas of traffic network, events, incidents and notification alarms.
Message sets defined in the MS/EMTCC standard are based on the data elements defined in TMDD. These message sets are grouped according to the application needs and are organized

[6] "TMDD" AND MS/ETMCC Guide, Version 1.0", TMDD Steering Committee, October 2000

to provide uniform information and interpretation throughout ITS deployment. Six message groups have been developed so far to offer standardized messages between centers in the following areas:

- Roadway-Network
- Network-State
- Network Events
- Traffic Requests
- Traffic-Device-Status,
- Traffic-Control.

As for C2C communication stacks that select DATEX-ASN as their application protocol, subscription and publication messages are formed based on data elements defined in TMDD and message sets defined in MS/ETMCC. For those C2C stacks that select CORBA as their application protocol, TMDD and MS/ETMCC serve as the foundation for construction of Interface Definition, as well as the design and implementation of Object Request Broker (ORB).

6.7 NOVA ITS ARCHITECTURE AND NTCIP

The NOVA ITS architecture defines interconnects and architecture information flows between stakeholders within the Virginia Department of Transportation (VDOT), regional agencies, and private sectors. Interconnections and information flows between stakeholders have been extensively discussed in a series of outreach meetings and finalized. The NOVA ITS Communication Plan evaluates the available communication technologies and is aimed at providing the "glue" to all stakeholders in the Architecture with the best suitable technical solutions.

NTCIP C2F communication stacks using SNMP or STMP as application layer protocols, will be used between transportation/information centers and transit vehicles, emergency vehicles, roadway traffic devices, and devices for toll collection, parking management and commercial vehicle operations. NTCIP C2C communication stacks, using CORBA and DATEX-ASN as application layer protocols, will be used between transportation management centers, information centers, and toll administration centers.

NOVA ITS stakeholders who have specific roles in the NOVA ITS architecture have been categorized into several groups based on the nature of the services their provided. These groups are:

- VDOT Smart Traffic Centers
- Incident and Emergency Management Group
- Traffic Operations Group
- Transit Group
- Planning Group
- Electronic Payment Group
- VDOT Internal Group

Interconnections and information flows developed from group-specific outreach meeting focused only on C2C data communications occurring at inter and intra-group levels. For example, the NOVA Smart Traffic Center (NVSTC) has heavy data flows between its management center and hundreds of field devices. However, the NOVA ITS architecture does not provide the definitions of information flows within the NVSTC. Instead, it defines information flows that are exchanged with other stakeholders' systems, such as Smart Traffic Signal Systems (STSS), Virginia State Police Centers, VDOT NOVA Dulles Toll Road, and Smart Travel Laboratory (STL).

Selection of NTCIP C2C communication stacks to fulfill data transmission needs among transportation centers may be determined by the following factors:

- Systems own by stakeholders – system complexity, hardware configuration, hardware/software integration
- Volumes of single or routinely exchange data
- Frequency of data exchange
- Whether or not the transmitted data is time-sensitive.

Deciding which C2C protocol to use for stakeholders' systems may vary according to the aforementioned factors. The rule of thumb is that for small systems with limited resources, DATEX-ASN may be the more suitable choice. NVSTC to/from Smart Tag Center is an example of this category. For stakeholder systems that function as data clearinghouses, in which real-time exchange is not required, DATEX-ASN could be a better option as well. NVSTC to/from STL or NVSTC to/from VDOT Data Warehouse are examples. CORBA fits into the systems with more functionality, resources and normally required real-time data exchange. NVSTC to/from STSS presents a good example for this category.

Some centers may require the implementation of both DATEX-ASN and CORBA protocols to fulfill the needs for data subscriptions from smaller systems that only deploy DATEX-ASN. For example, NVSTC may have to deploy DATEX-ASN server for STL, who may only have DATEX-ASN in its facility. In the meantime, CORBA may be heavily used for communicating with STSS or VDOT TEOC. . Table 13 below shows how DATEX-ASN or CORBA is selected based upon prior factors.

Table 13 – DATEX-ASN and CORBA Standards

Stakeholder	System Complexity	Data Volume	Data Frequency	Real-time Data	With DATEX Only Stakeholder	DATEX-ASN	CORBA
NOVA STC	High	High	High	Yes	Yes	✓	✓
NOVA STSS	Medium	High	Medium	Yes	Yes	✓	
STL	Low	Low	Low	No	Yes	✓	
VDOT TEOC	Low	Low	Low	No	Yes	✓	
VDOT Data Warehouse	Low	High	Low	No	Yes	✓	

7 EVALUATION CRITERIA & ALTERNATIVES ANALYSIS

This section will present the criteria used to evaluate the candidate technologies and potential system architectures.

7.1 EVALUATION CRITERIA

The evaluation criteria will augment the imposed stakeholder requirements and support the alternatives analysis. The evaluation criteria established includes:

- Application Performance - the ability to provide a certain quality of service for a defined application (stakeholder operation).
- Availability / Reliability - the ability to offer a certain level of robustness (even in the presence of individual component failures).
- Flexibility / Scalability - the ability to scale up or down in size, performance, or capacity.
- Security / Privacy - the ability to provide a certain level of inherent transmission integrity.
- Near-Term Deployment and Long-Term Viability
- Standards Conformance - the ability to conform to accepted industry standards and to support communications protocols.
- Operations & Maintenance - the ability to provide network management functions.

As part of the evaluation process, the more prevalent candidate technologies were evaluated based on the aforementioned criteria and given a rating of excellent, good, or poor. The results of the evaluation appear in Table 14.

7.2 CONCLUSIONS

As shown on Table 14, utilizing fiber optic cabling as the primary communications medium is the best option for VDOT NOVA for a number of reasons. VDOT NOVA staff and maintenance personnel are familiar with the technology, as it is deployed in a large portion of the regional backbone communication network and provides the interface to many field components. It is also clear, based on interviews with the stakeholders, that the demand for video images from CCTV cameras (VDOT and other local regions) has increased considerably. Fiber optic cables provide the best transportation medium for receiving and transmitting the requested video images. Limitations in the bandwidth of the fiber optic cable, as it relates to video feeds, could be resolved by employing specific compression algorithms.

Table 14 – Candidate Technologies Comparison

Evaluation Criteria	Application / Performance	Availability / Reliability	Flexibility / Scalability	Security / Privacy	Near-Term Deployment / Long –Term Viability	Standards Conformance	Operations & Maintenance
Candidate Technology							
Fiber Optic Cable	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Twisted Wire Pair	Good	Good	Good	Good	Good	Good	Excellent
Coaxial Cable	Good	Good	Poor	Good	Good	Poor	Excellent
Digital Subscriber Line (DSL)	Good	Good	Good	Good	Poor	Good	Poor
Cellular Digital Packet Data (CDPD)	Good	Poor	Poor	Good	Good	Good	Poor
Special Mobilized Radio	Good	Poor	Poor	Good	Poor	Poor	Good
Mobile Satellite Systems	Good	Poor	Poor	Good	Poor	Good	Poor
Spread Spectrum	Good	Good	Good	Excellent	Good	Good	Good

8 COMMUNICATIONS ARCHITECTURE

This section presents the logical and physical communications architectures to support the deployment of the NOVA ITS architecture. This section also reaffirms that the NOVA ITS Architecture is VDOT-centric and center-to-center oriented.

8.1 BACKGROUND

The NOVA ITS Architecture Project developed a high level interconnect diagram, shown in Figure 30 (in Section 6.2.2) that is customized based on the elements of the National ITS Architecture for supporting NOVA ITS needs. The unshaded boxes in the diagram highlight the National ITS Architecture subsystems that are applicable to the NOVA ITS Architecture.

This high-level interconnect concept forms the basis of the NOVA ITS Logical and Physical Architectures. The Logical Architecture defines existing and planned functions required by each stakeholder for providing specific user services. The Physical Architecture maps those defined logical functions into physical components, either systems or subsystems. The Physical Architecture also defines the information flows that connect systems or subsystems into an integrated system. The Communication Architecture defines communications system architecture to fulfill the communications needs for NOVA and support stakeholder requirements based upon the required communications bandwidth for accommodating existing and planned information flows, the characteristics of the information, and candidate communications technologies.

8.2 LOGICAL ARCHITECTURE

The logical architecture defines functions performed by each stakeholder for providing domain-specific services to users. Those functional services can be provided either by a single system or a number of subsystems that require information exchange with other system/subsystem owned by other stakeholders. Those “interconnects” between systems link elements of the logical architecture together.

As documented in the NOVA ITS Architecture report, a series of outreach meetings were held for investigating stakeholders’ expertise and interest. The stakeholders were grouped based on their domain-specific expertise in the Virginia/Maryland/DC region, including, transit management, traffic operations, incident and emergency management, VDOT district offices (internal and statewide), electronic payment, planning and the VDOT NOVA STC. Stakeholders existing and planned functional services and system interconnections were developed based on the input from each stakeholder in each domain-specific group. Appendix A and Appendix B of the NOVA ITS Architecture Report documents the functional analysis matrix among stakeholders and interconnections between the various systems of each stakeholder, respectively. Functional services and system interconnects form the foundation of the NOVA ITS logical architecture.

8.3 PHYSICAL ARCHITECTURE

Functional services and interconnects defined in the logical architecture were mapped into physical systems to form the physical architecture. The physical architecture is a high-level structure around the functional processes and interconnects that defines the subsystems that make up an intelligent transportation system and the information flows that connect the various subsystems into an integrated system. Information flows, existing or planned, in the physical architecture are defined at a much higher level of detail than interconnects in the logical architecture. Appendix C and Appendix D of the NOVA ITS Architecture Report document the details of information flows among subsystems along with their data flow directions.

8.4 COMMUNICATIONS ARCHITECTURE

A series of stakeholder phone interviews or email exchanges were conducted by the NOVA ITS Architecture team to investigate the details of the information flows related to each stakeholder. Questions included in the investigation referred to information flow status (planned or existing), time frame (near or long term), exchange format (voice, data, video) and frequency (per second, per minute or others), tolerated latency (real time or not), and supporting infrastructure (existing or planned). Findings from each stakeholder were collected and documented. Based on the detailed information flows, projected bandwidth requirements, available standards, and candidate technologies, a communications architecture that supports NOVA ITS Architecture and fulfills stakeholder needs along with regional considerations was created.

8.4.1 BANDWIDTH AND TECHNOLOGIES

The NOVA ITS Architecture is a VDOT-centric and center-to-center communications oriented architecture. Majority groups of stakeholders, internal of external to VDOT, expressed their interest in video image sharing, a data format that requires broad bandwidth for data transmission. Some of the stakeholders require such transmission in real-time for a variety of purposes, for example, incident management, security, and others.

Section 7 of this report evaluated both wireless and wireline candidate communications technologies in the areas of communications media, radio, cellular, microwave and satellites. Taking into considerations current communications assets owned by VDOT and from the perspective of cost/effectiveness along with viable technologies, it appears that fiber optic network could be the optimal solution for NOVA ITS center-to-center oriented data communications.

8.4.2 FIBER OPTIC SONET RING BACKBONE

Currently, VDOT-owned fiber covers majority areas along I-66, I-395, I-95 and a small portion of I-495. Table 15 shows locations, fiber types and fiber counts of the fiber optic network owned by VDOT in NOVA.

A majority of the network utilizes SONET as the standard fiber except portions on I-66, I-95 and Beltway. This VDOT NOVA fiber optic network forms the communications backbone to support most of the communications needs in NOVA District. Current network topology is a point-to-point type line structure, however VDOT is proposing to deploy SONET 48-count fiber along

Route 234 connecting fibers on I-66 and I-95 to form a ring structure. This will enable VDOT to construct a SONET ring topology and may provide redundancy to its communications structure.

Table 15 – Fiber Optic Network in NOVA

Fiber Network Location	Fiber Type	Fiber Count
I-66 Inside of Beltway	SONET Fiber	48 Count
I-66 outside Beltway till Route 234	Distribution Fiber SONET Fiber	24 Count 48 Count
I-395	SONET Fiber	48 Count
Springfield Area	SONET Fiber	48 Count
I-95 till NOVA District jurisdiction boundary	Distribution Fiber SONET Fiber	24 Count 48 Count
I-495 from I-95 to the Woodrow Wilson Bridge	Multi-mode Fiber	12 Count

8.4.3 REGIONAL DATA SHARING

Data sharing among multiple transportation jurisdictions in the Washington, DC region could improve operation efficiency and enhance area security. A regional ITS data communications sharing backbone may serve such need. The basis for a regional ITS backbone would be the interconnection of VDOT, MDSHA, WMATA fiber strands set aside for data sharing purposes.

As indicated in the NOVA ITS Architecture, a few VDOT agencies have existing or planned to exchange data with WMATA, the regional transit agency. The most likely place for a viable connection point between WMATA and VDOT fibers, under a separated multi-jurisdictional transportation communications study conducted by Maryland State Highway Administration (SHA) and Metropolitan Washington Council of Governments (MWCOG), is along I-66 or Virginia Route 110. Metro's Orange line in Virginia utilizes the median of I-66 for the majority of its route and Metro's Blue/Yellow Line parallels and is in close proximity to VA Route 110.

As identified in the same study mentioned above, a connection between VDOT and MDSHA could be made in Virginia near the intersection of the Capital Beltway and the Dulles Access Road spur in McLean. Communications resource share fibers in Virginia run along the Capital Beltway from the American Legion Bridge to the communications hub facility in McLean. The intersection with the Dulles Access Road spur, along which VDOT resource share fiber has been installed and is approximately a mile from the hub building. This connection would link a MDSHA communications hub in Gaithersburg with the VDOT STC.

8.4.4 NTCIP CENTER-TO-CENTER PROTOCOL

According to the latest NTCIP standard, transport/network layer specific SONET fiber network is supported by the standard over TCP/IP and ATM switch. Due to the center-to-center communications nature of the NOVA ITS Architecture, the proposed VDOT NOVA SONET ring should support CORBA and DATEX-ASN standards at the application layer. CORBA, as described in Section 6, should be used for real-time, massive data transmission with sufficient resources and DATEX-ASN otherwise.

9 INFRASTRUCTURE DEPLOYMENT

This section will consider the deployment of the NOVA ITS communications architecture and overall network evolution. Recommendations will be presented for establishing critical aspects of the architecture within the timeframe of the Communications Plan. The recommendations made will support the overall goals and objectives established for NOVA ITS.

In order to facilitate the deployment of infrastructure in support of NOVA ITS communications, certain criteria must be set. Firstly, the existing VDOT NOVA synchronous optical network (SONET) fiber should be completed in order to create a true SONET ring architecture. This will provide some redundancy on the existing network and also facilitate VDOT's participation as part of the regional information exchange. Secondly, the infrastructure deployment should take into consideration short-term deployments (5 years or less) versus long-term deployments (more than five years), as well as a stakeholder's current infrastructure. The incident and emergency management stakeholders need to be brought online as soon as possible. Lastly, the stakeholders should be analyzed in order to discern "heavy users", i.e., those requiring large amounts of bandwidth (typically video feeds) as opposed to those stakeholders who may only periodically need to receive information.

9.1 SONET UPGRADES

At present, VDOT NOVA has communications infrastructure in place along most of the local interstates (I-95, I-495, I-395, and I-66) with a majority of this infrastructure utilizing fiber optic cabling as the communications medium. The system utilizes SONET as the standard for broadband communications. However, the current SONET architecture is deployed in a linear fashion (point-to-point) and only provides a singular path to network nodes. VDOT NOVA currently has a resource-sharing project that would provide the Department with fiber strands along Route 234 in Prince William County. The completion of this link will provide VDOT NOVA with a complete SONET ring topology as shown in Figure 37.

The benefits of such a topology include protection against a single fiber cut or node failure and switching of the information path depending on whether the path switched ring topology or line switched ring topology is implemented. Path switched or unidirectional ring topologies utilize two fiber rings for redundancy. This topology routes traffic in one direction (typically clockwise) unless trouble occurs. If trouble does occur, traffic is routed via the second ring (counterclockwise). Line switched or bi-directional ring topologies can employ a two fiber or four fiber ring. With a two-fiber ring, traffic is routed in both directions to make efficient use of the system and its resources. In a four-fiber ring configuration, each working fiber has a corresponding protect fiber. That is, if there is a problem on one fiber, traffic is rerouted in the opposite direction via the protect fiber.

Additionally, VDOT currently has multi-mode fiber deployed on I-495/I-95 between the Springfield Interchange and the Woodrow Wilson Bridge. There is no communications infrastructure on I-495 from American Legion Bridge to the Springfield Interchange. The deployment of single mode fiber optic cable along this complete route (American Legion Bridge to the Woodrow Wilson Bridge) would provide VDOT with communications links to future and existing ITS field components and provide an alternate ring topology if there are any problems on the Rt. 234 fiber segment. It would also enhance the communication path along I-495/I-95 because single mode fiber has a higher bandwidth and smaller attenuation losses when compared to multi-mode fiber.

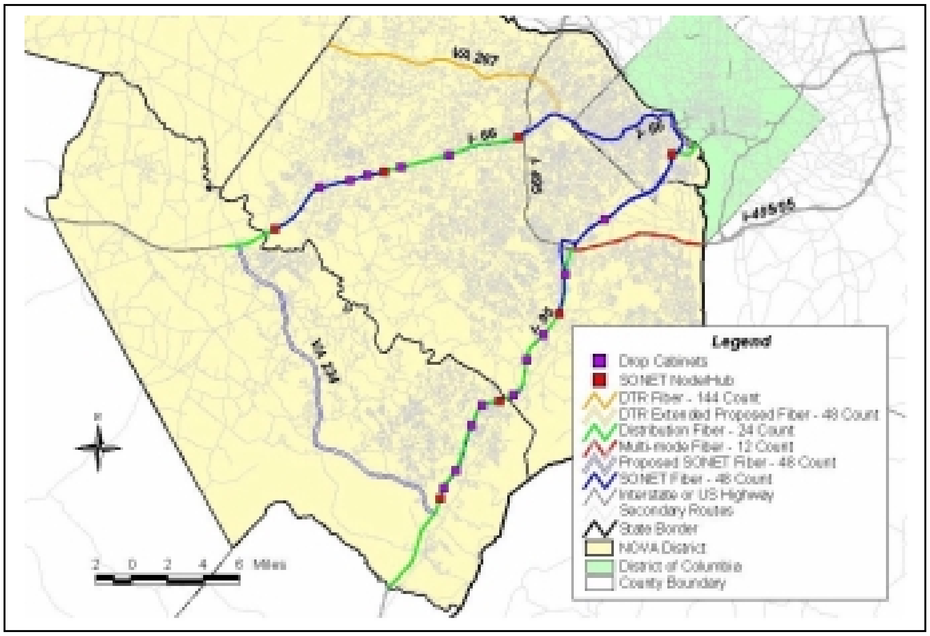

Figure 37 – VDOT NOVA SONET Ring Topology

There is also a dark 48-strand fiber optic cable along the Dulles Access Road, between I-66 and Spring Hill Road. This cable can provide interconnection to both VDOT fibers running along I-66 and Dulles Toll Road fibers along the Dulles Corridor (after Spring Hill Road). The existing Dulles Toll Road fibers are in the process of being reconfigured to provide fiber allocation to the toll plazas and to provide spare fiber capacity that wasn't available before.

VDOT is also looking to improve service levels related to the NOVA Smart Traffic Signal System (STSS) which currently serves approximately 900 intersections. The current system employs a Digital Data Service (DDS) multi-drop network provided by Verizon to communicate with field devices. A frame relay network will replace the existing network as a result of its high performance switching technology and its ability to integrate future LAN and video exchanges.

9.2 DEPLOYMENT STATUS

In response to the events of September 11, 2001, the VDOT NOVA STC has also determined that certain stakeholders have a need for access to regional information, video imagery in particular, to facilitate any emergency deployment on their part. As such, the short-term deployment plan should include setting up the infrastructure, as needed, between all of the incident and emergency management stakeholders and the NOVA STC to facilitate information flows (video, data, and voice) between entities. Long-term deployments will then focus on the infrastructure necessary to bring the traffic operations, planning, transit, and other internal VDOT stakeholders online.

9.3 REGIONAL INFORMATION EXCHANGE

As mentioned earlier, completing the SONET upgrades would provide some redundancy on the existing network and also enhance VDOT's participation as part of the regional information exchange. The regional information exchange would facilitate the sharing of data and information between VDOT other regional transportation agencies including the Washington Metropolitan Area Transit Authority (WMATA), the District of Columbia Department of Transportation (DCDOT), and the Maryland State Highway Administration (MDSHA). Data exchanged could include real-time roadway information (video images from CCTV cameras, traffic signal status, etc) and historical data (traffic volumes).

In a study[7] conducted in 2000 by Computer Sciences Corporation, in conjunction with PB Farradyne, certain steps were provided to ensure a true regional network. Potential enhancements include:

- Connecting WMATA and MDSHA fibers near the Beltway at WMATA's Greenbelt or New Carrolton Stations.
- Connecting WMATA and VDOT fibers at a predetermined strategic location.
- Connecting VDOT fibers along the Dulles Corridor and/or I-495 with the MDSHA Net.Work.Maryland fibers, when both installations are completed.
- Connecting VDOT and/or WMATA fibers with Fairfax County's I-Net system once it's completed.
- Connecting Prince William DPW facilities to VDOT fibers once the Rt.234 connection is completed.
- Connecting the City of Fairfax DPW Signal Shop to the VDOT fibers along I-66.
- Connecting the Potomac Rappahannock Transit Commission (PRTC) facilities in Woodbridge to VDOT fiber along I-95, once the I-95 expansion is completed.
- Connecting Arlington County DPW to VDOT fibers via the two strands of fiber optic cable that the County gets from Cox Communications. This connection should occur after the coaxial cable on I-66 (inside the Beltway) and I-395 is upgraded to fiber.
- Connecting the City of Alexandria's I-Net system to VDOT fibers. This would also occur after the coaxial cable on I-66 and I-395 is upgraded to fiber.
- Connecting Metropolitan Washington Airports Authority (MWAA) fibers at Dulles Airport with Loundoun County DPW facilities.
- Connecting WMATA and Montgomery County fibers along Rockville Pike or Georgia Avenue.
- Connecting MDSHA Net.Work.Maryland fibers along I-270 with the Montgomery County fibers. The connection point would occur at the County Maintenance Facility on Seven Locks Road.
- Connecting MDSHA Net.Work.Maryland fibers with the Frederick County's fibers leased from GS Communications, Inc. This connection would occur at the new County Public Safety Building which will house the State Police, County Fire and Rescue Operations, and the Sheriff's Department.
- Connecting MDSHA Net.Work.Maryland fibers with Prince George's County fibers. Prince George's County has a resource sharing agreement with Comcast Cable, Inc. to provide fibers.

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[7] "Multi-Jurisdictional Transportation Telecommunications Study for MD SHA and MWCOG", Computer Sciences Corporation and PB Farradyne, June 2000

- Connecting DCDPW fibers to WMATA fibers via a nearby Metro Station. DCDPW anticipates the deployment of a fiber optic network in the near future.
- Connecting WMATA fibers to the Metropolitan Washington Council of Governments (MWCOG)

9.4 VIDEO SHARING

VDOT NOVA STC has also put aside funding to facilitate immediate video distribution support for the Virginia Sate Police (Division 7) and the Fairfax County Police / Fire and Rescue facility which includes a dispatch center and a Disaster Operations Center (DOC). This support will occur through a third party video distribution partner (VDP). It is in the NOVA architecture that NOVA Smart Traffic Signal System's video feeds would be made available through STC for regional sharing.

It is expected that other regional agencies (stakeholders) will also receive video distribution images (in the mid- to long-term). These include, but are not limited to the following stakeholders:

- Arlington County Fire and Police – Emergency Communications Center (ECC)
- Arlington County Signal System
- Alexandria City Police – Public Safety Center
- Alexandria City Fire and Rescue
- Alexandria City Signal System
- Prince William County Police / Fire and Rescue – Public Safety Communications Center (PSCC)
- City of Fairfax
- VDOT Springfield Information Exchange Center
- Montgomery County Department of Public Works and Transportation
- Maryland State Highway Administration
- Maryland State Police
- Washington Metropolitan Area Transit Authority (WMATA)
- Metropolitan Washington Airports Authority (MWAA)
- U.S. Secret Service
- FBI
- National Park Police
- DC Department of Transportation
- DC Metropolitan Police

9.5 FUNDING OPPORTUNITY

Funding is a critical part of the infrastructure deployment. It is assumed that a majority of the funds needed to complete the communications plan infrastructure deployment will come from VDOT itself or through public-private partnership. Based on this assumption, any funding available should initially be used to complete the SONET ring along Route 234. The completion of this ring will provide redundancy on the fiber network that will come in handy should a fiber be mistakenly cut anywhere along the ring.

Thereafter, any funding should go to complete the infrastructure needed for the short-term deployment stakeholders (incident and emergency management) followed by the long-term deployment stakeholders. It should be noted that while the funding needed to bring stakeholders online will probably come from the Department, stakeholders who are deemed long-term deployments and have their own funding, may be able to be included as part of the short-term deployment.

10 COMMUNICATIONS PLAN MAINTENANCE STRATEGY

This section will present an overall strategy for VDOT to maintain the Communications Plan. The strategy presented will include the use of the Geographic Information System (GIS). A proposed Communications Plan update schedule will also be provided.

The principal objective of this Communications Plan development is to directly support the NOVA-Centric ITS Architecture, which has been developed based on the National ITS Architecture and customized mainly by VDOT NOVA with input from regional stakeholder. The purpose of Communications Plan is to provide guidance and recommendations to VDOT NOVA District and the regional stakeholders on investing in and deploying communications infrastructure and/or establishing services. It serves as a reference document on communications technologies and networking as they relate to ITS. A major component of the Communications Plan is to address infrastructure and services that are currently available or planned within Northern Virginia. Due to the dynamic nature of ITS assets and facility data gathering in this project, a GIS is a useful tool to geo-code and link their locations spatially for communications and architectural analysis. Thus, a VDOT NOVA ITS Asset and Communications Infrastructure GIS Baseline, which defines data dictionary and asset attributes, has been developed for this purpose. An example of the data dictionary and attribute that are part of the GIS is shown in the Figure 38.

NOVA ITS Architecture Asset – Baseline Data Dictionary (release 5.0)
Bold & Highlighted - Base Attributes

Item	Attribute Name	Short Name	Data Type	Length / Format	Units	Dictionary Notes
0	Item					Arbitrary item no. for this category of asset
1	**GIS Tag**	**GISTAG**	**Alpha**	**Decimal**		**Unique identifier for GIS inventory purposes**
2	**Asset Name**	**ASSET_L**	**Alpha**			**Ordinary asset name in standard nomenclature**
3	Asset Short Name	ASSET_S	Alpha			Special short name as assigned
4	**Asset ID**	**ID**	**Alpha**			**VDOT designation or identifier, or blank**
5	**District**	**DIST**	**Alpha**			**Standard District Name**
6	Residency	RESID	Alpha			Standard Residency Name
7	County	COUNTY	Alpha			County Name or Code
8	Route	ROUTE	Alpha			Conventional use; e.g. I-81, Rt.20
9	Route Direction	RT_DIR	Alpha	5 char.		East, West, North or South
10	Side of Centerline	SIDE_CL	Alpha		Right, Left	
11	**Latitude Decimal Degrees**	**LATITUDE**	**Decimal**	**xx.12345678**	**Degrees**	**Eight decimal places needed**
12	Latitude DMS	LAT_DMS	Integer	dd.mm.ss	DMS	dd=Degrees, mm=Minutes, ss=Seconds
13	**Longitude Decimal Degrees**	**LONGITUDE**	**Decimal**	**xx.12345678**	**Degrees**	**Eight decimal places needed**
14	Longitude DMS	LONG_DMS	Integer	dd.mm.ss	DMS	dd=Degree, mm=Minutes, ss=Seconds
15	Status	STATUS	Alpha			Existing or Proposed
16	Date Installed	DATE_INST	Date			
17	Planned Installation Year	PLAN_YR	Integer	4 char.	Year	Year in four digits, If asset is planned
18	Planned Project (Program)	PROJ	Alpha			Project Name or Number, if available
19	Milepost	MILEPOST	Decimal	xxx.x	Tenths of Mile	Mile Post designation, if known
20	Location Description	LOCATION	Alpha			Ordinary location as street address or intersection of...
21	Data Rate Requirement	DATA_RATE	Decimal	xx.xxx	Mb/sec	Voice circuit is 64 Kb/s or 0.064 Mb/s
22	Protocol	PROTCL	Alpha			Voice for Call Box
23	Device Interface	I/F	Alpha			2-Wire, 4-Wire, RS-232, Ethernet, or other
24	Criticality Requirement	CRIT	Alpha			Requires redundancy or backup route
25	Latency Requirement	LATEN	Decimal		Sec.	Must be real time
26	End User(s)	USER	Alpha		Short Name	Choose 'Short Name' from schedule of VDOT Facilities List
27	**Owner**	**OWNER**	**Alpha**			**If not VDOT, indicate VSP, BAM etc.**
28	Data Source	SOURCE	Alpha			Cited source of this information

Figure 38 – Data Dictionary and Asset/Facility Attribute of GIS Baseline

For information sharing and maintenance purposes, the GIS Baseline has been placed on the VDOT Intranet via a customized ArcIMS interface, specifically for the NOVA ITS Architecture project, and the GIS Integrator. This provides access to any VDOT personnel with privileges who wants to view or make redline suggestions or additions, as well. This Intranet-based approach increases the accessibility of the tool from local desktop installations and extends to the entire VDOT network. Figure 39 shows a screen capture from the VDOT Intranet.

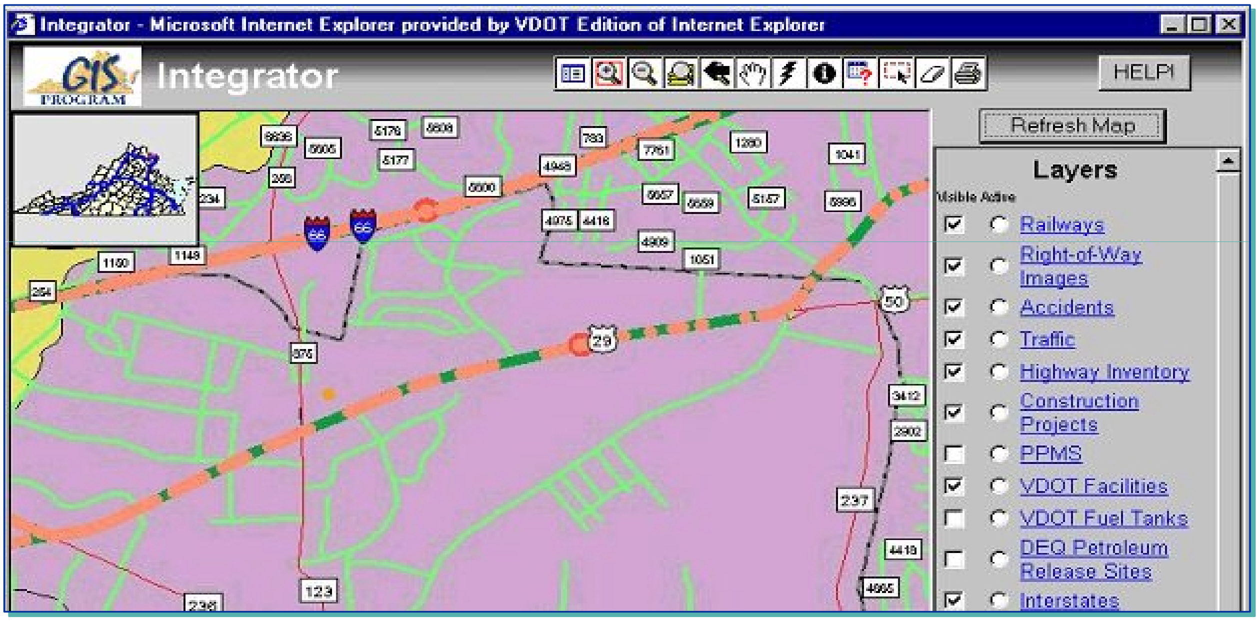

Figure 39 – A NOVA GIS Asset Baseline Screen Capture From VDOT Intranet

Due to the dynamic nature of the asset/facility attributes, it is very important to maintain a continuous data collection/update effort for to maintain the integrity of the data. A “snapshot” view of the data would be limited and lose value over time. The NOVA ITS Asset/Facility GIS Baseline is a data-driven tool, therefore proper and timely maintenance/update of the Baseline database will be essential to the usefulness of the data.

10.1 MAINTENANCE STRATEGIES

As indicated in the separate VDOT NOVA ITS/GIS Asset Baseline Report, there are two approaches for maintaining and updating the NOVA ITS Asset and Communications GIS. The first approach requires that each stakeholder initiate the data updating process and NOVA GIS implements it. The second approach uses NOVA GIS is the single entity responsible for maintaining and updating ITS assets and facilities information for all stakeholders.

10.1.1 MAINTENANCE STRATEGY #1

This maintenance strategy is based on a distributed process. Under this maintenance strategy, the stakeholder has the responsibility for keeping the asset/facility GIS data up-to-date. Thus, the stakeholder should initiate calls for data maintenance and updates. By doing so, the stakeholder can either update its corresponding Excel spreadsheet(s) or redline the database or map posted on VDOT’s Intranet. NOVA GIS then performs the actual GIS database modifications. The NOVA GIS Administrator may have to coordinate with each individual stakeholder in advance to define data updating steps and processes. The success of this strategy will depend upon the relationship developed between the NOVA GIS Administrators and the stakeholders, and the efficiency of the updating procedure.

10.1.2 MAINTENANCE STRATEGY #2

Unlike Maintenance Strategy #1, this strategy is a centralized process. Under this maintenance strategy, each stakeholder does not have the responsibility for asset/facility updates. Instead, each stakeholder must send asset/facility update data to NOVA GIS in a variety of formats, such as email, phone or fax. The NOVA GIS Administrator is responsible for ITS asset or facility GIS database update based on information received.

10.1.3 RECOMMENDATIONS

Maintenance strategies #1 and #2 have distinct advantages and disadvantages. Strategy #1 distributes maintenance loads to stakeholders, who are more knowledgeable on the status of their own ITS assets/facilities. However, the stakeholders may have none or a limited knowledge of GIS, and require training. In contrast, Strategy #2 allows stakeholders to use conventional means for GIS data updating. The NOVA GIS Administrator is the single point-of-contact responsible for all GIS asset/facility data maintenance and updates. This strategy will require coordination between the NOVA GIS Administrator and the stakeholder. Table 16 displays pros and cons of each strategy:

Table 16 – Pros and Cons of Maintenance Strategies

	Maintenance Strategy #1	Maintenance Strategy #2
Advantages	• Stakeholder knowledgeable on own assets/facilities • Stakeholder responsible for updates • Can use existing Intranet GIS update feature	• Single point of contact • Release burden on responsible owner/agency
Disadvantages	• May require GIS Training	• NOVA GIS Administrator less knowledgeable on stakeholder assets/facilities • NOVA GIS responsible for updates • Requires coordination between NOVA GIS and stakeholder

- **Near-term Recommendations**
  The accuracy of the asset data is always the primary concern with regards to evaluating maintenance strategies. It is apparent that the strategy #1 requires more stakeholder involvement as they more knowledgeable on the assets/facilities under their jurisdictional boundary. Although this strategy may require basic GIS training, the training should be focused on specific GIS areas and resources consumed are expected to be limited. In addition, the strategy can utilize the existing VDOT Intranet GIS feature for data updating.

- **Long-term Recommendations**

Considering either one of the maintenance strategy mentioned may be sufficient for near-term solution, but two drawbacks exist. First, none of the strategies described are automatic and in turn may be labor intensive. Secondly, none of the strategies link with Configuration Management (CM), a necessary procedure for document control.

Activities related to GIS database maintenance and updating should clearly be monitored and documented. Configuration Management is a perfect tool for that purpose. No database modification should be completed without going through the CM process. Figure 40 depicts the recommended long-term maintenance strategy that is automotive and CM-controlled

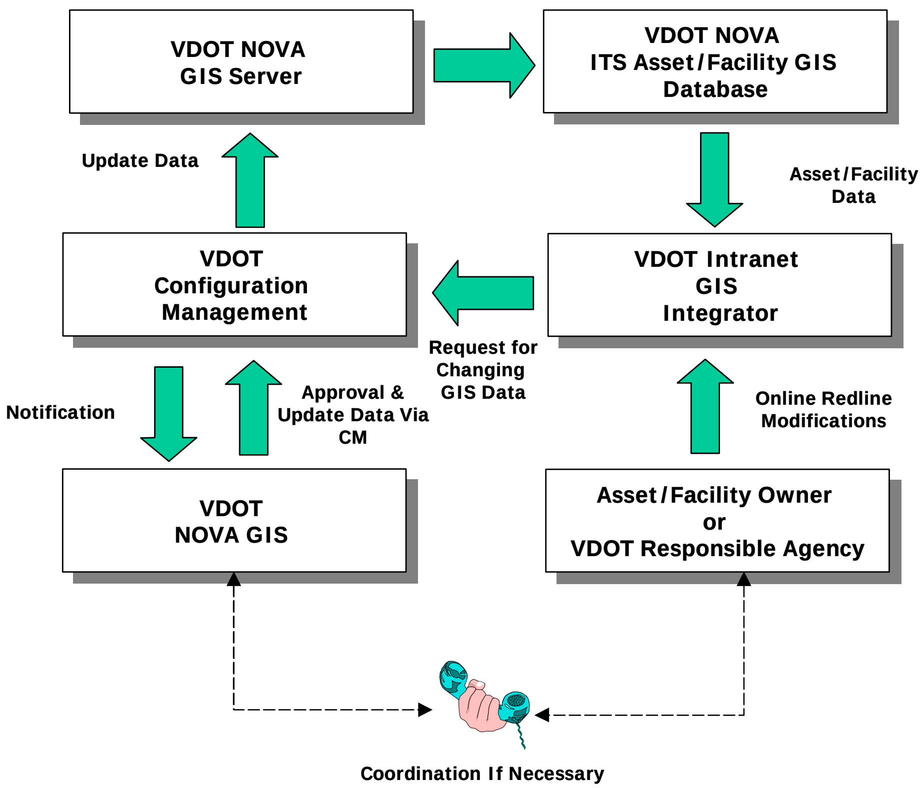

Figure 40 – Long-Term CM-Controlled Maintenance Strategy

Under this maintenance strategy, stakeholders can redline the desired data changes online via VDOT's existing GIS Integrator. Upon receiving the changing request, the GIS Integrator will issue a GIS data change request to the Configuration Management tool. A notification will be sent to GIS Administrator requiring approval of the GIS database change. Once the approval is in place, the CM tool will implement the specified data update via the GIS server and log all the related events including time-stamp, requested personnel, etc.

10.2 PLAN UPDATE SCHEDULE

Asset data update frequencies vary depending on the numbers of the ongoing projects that affect asset/facility status in each of the respective jurisdictions. In general, a per month data update should be conducted in the jurisdiction that construction or maintenance projects are ongoing to keep asset data up to date. Otherwise, a quarterly update on asset data should be sufficient to keep the value of the data.

APPENDIX A – LIST OF ACRONYMS

LIST OF ACRONYMS

ATM	Asynchronous Transfer Mode
ASN.1	Abstract Syntax Notation One
CORBA	Common Object Request Broker Architecture
DATEX-ASN	Data Exchange Protocol in ASN.1
DII	Dynamic Invocation Interface
DSI	Dynamic Skeleton Interface
EDIFACT	Electronic Data Interchange for Administration, Commerce and Transport
FDDI	Fiber Distributed Data Interface
FSK	Frequency Shift Keying
FTP	File Transfer Protocol
GIOP	General Inter-ORB Protocol
IDL	Interface Definition Language
IIOP	Internet ORB Protocol
IP	Internet Protocol
MIB	Management Information Base
MS/ETMCC	Message Sets for External Traffic Management Center Communications
NTCIP	National Transportation Communication for ITS Protocol
ORB	Object Request Broker
PDU	Protocol Data Unit
PMPP	Point-to-Multiple-Point Protocol
PPP	Point-to-Point Protocol
SLIP	Serial Line Internet Protocol
SNMP	Simple Network Management Protocol
SONET	Synchronous Optical Network
STMP	Simple Transportation Management Protocol
TCP	Transmission Control Protocol
TFTP	Trivial File Transfer Protocol
TMDD	Traffic Management Data Dictionary
UDP	User Datagram Protocol