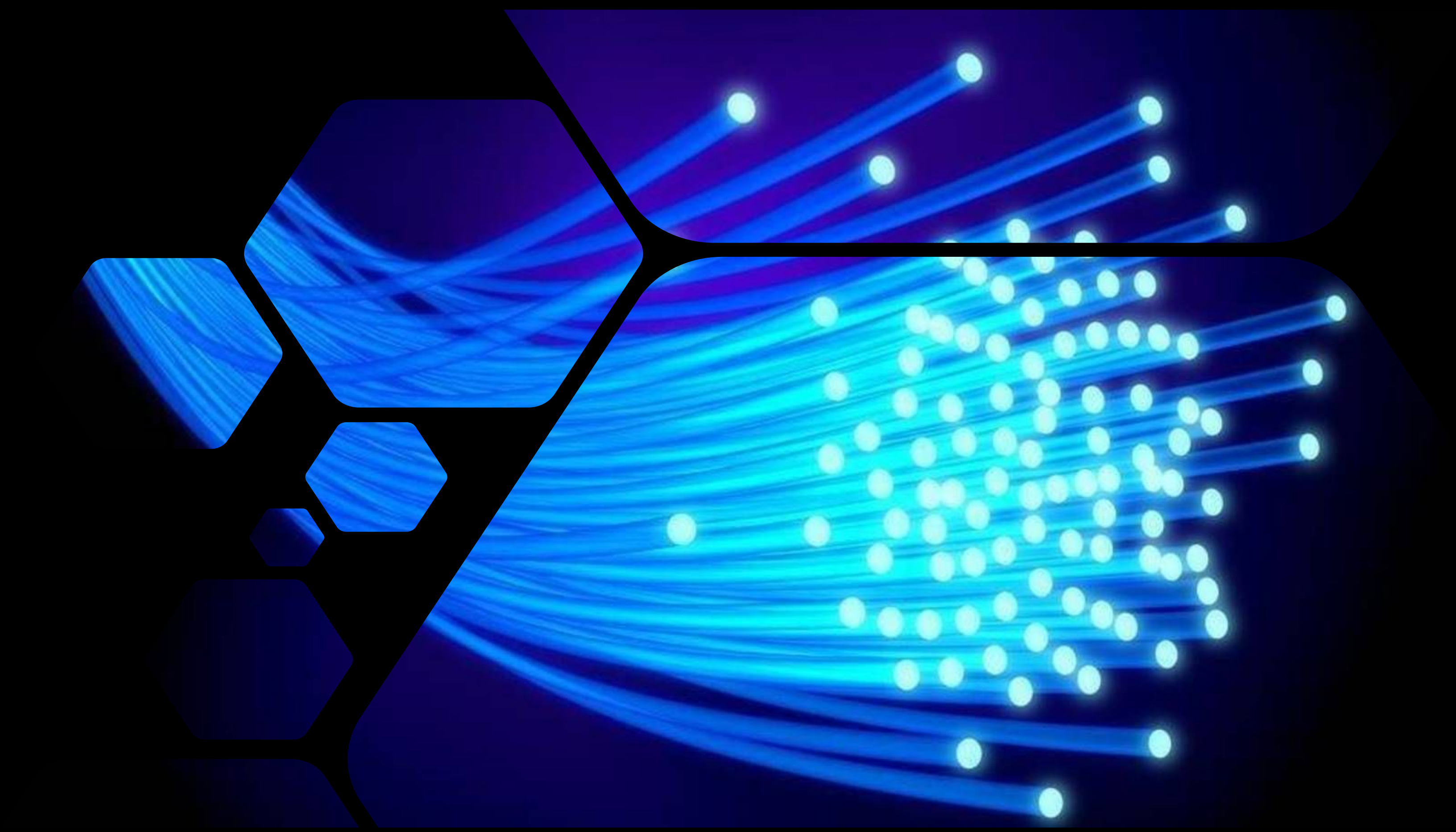
INTELLIGENT TRANSPORTATION SYSTEMS

COMMUNICATIONS MASTER PLAN

Version 1, dated July 2020



MDOT MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

MESSAGE FROM THE ADMINISTRATOR

During these challenging times, we are all navigating a rapidly evolving transportation ecosystem. We no longer travel or make decisions regarding how we travel in the same ways that we used to, and the global pandemic has further shifted the transportation landscape. The economic vitality of the State, and the ability to create better opportunities for our citizens are closely tied to transportation. The Maryland Department of Transportation State Highway Administration (MDOT SHA) understands the direct impact the movement of people and the flow of goods has on our citizen's ability to connect to life's opportunities.

As the world changes around us, technology has, and continues to be, a critical resource in managing our highway infrastructure. Continued investment in Intelligent Transportation Systems (ITS) will allow MDOT SHA to connect Marylanders to life's opportunities and deliver a safer, more reliable, and more equitable transportation ecosystem for our customers. In doing so, we make our State accessible to everyone — whether by car, bus, train, bicycle or on foot. These various travel methods must fit together into an overall system that is safe, accessible, reliable and efficient.

MDOT SHA is evolving to meet the modern needs of its customers. Implementation of the **ITS Communications Master Plan** demonstrates our commitment to creating a system-of-systems that will support our future transportation needs. This plan provides MDOT SHA staff with adaptable strategies to bolster a smarter transportation ecosystem, future-proof our system for connected-vehicle technologies, support broadband opportunities, and pursue more resource-sharing agreements.

MDOT SHA will continue to build a resilient and adaptable communications network for our customers – and this plan will help get us there.

Tim Smith, P.E.
Administrator

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Executive Summary

The Maryland Department of Transportation (MDOT) and its Transportation Business Units (TBUs) share communication network infrastructure to conduct and coordinate critical transportation and emergency activities across the State. This *ITS Communications Master Plan* jumpstarts a statewide approach to network improvement by the MDOT State Highway Administration (MDOT SHA) through enhancement of the shared network infrastructure and leveraging state and private partnerships. This Master Plan is expected to remain a 'live document' with annual edits and bi-annual updates to ensure flexibility as future directions are adjusted to meet the needs of our customers.

At a high level, the MDOT network infrastructure is used by MDOT SHA for Intelligent Transportation Systems (ITS) and developing transportation technologies along MDOT SHA roadways. ITS technologies provide the necessary tools to manage traffic and integrate with transportation innovations such as Vehicle-to-Infrastructure (V2I) communications. These technologies provide opportunity to manage existing roadways and reduce congestion more cost-effectively than roadway expansion. Additionally, existing high-speed and high-bandwidth fiber and radio infrastructure throughout the State provide an opportunity to expand Internet accessibility to disadvantaged areas through partners within the State. For example, this Master Plan details opportunity to expand rural broadband by utilizing existing partnerships and identifying opportunities to enter Resource Sharing Agreements (RSA) with long-haul fiber companies.

MDOT SHA's review of its communications network was prompted by the Office of CHART & ITS Development (CHART) and its adoption and integration of ITS technologies, foray into Transportation Systems Management and Operations (TSMO), and Connected and Automated Vehicles (CAV) program. This Master Plan details strategies to expand the accessibility, capacity, and security of the ITS network and improving network resiliency, efficiency, and equity. Through this *ITS Communications Master Plan* MDOT SHA adds a steppingstone towards achieving MDOT's core mission: "Connecting Marylanders to life's opportunities" through a connected and efficient management of our highway system.

Summarized below are the strategic topics that were the focus of MDOT SHA's analysis of the statewide ITS network:

1. **Future Traffic Management Needs –** Future traffic management will need to respond to increasing traffic demands by implementing more active control capabilities while balancing the expected cost constraints of the upcoming years. Active control capabilities will enable MDOT SHA to maximize efficiency of existing roadway resources while reducing capital costs; however, active control technologies place greater demand on network capabilities, which may require network improvements across the State.
2. **ITS Device and Network Upgrades –** Active control capabilities require integration of new ITS devices or upgrades to existing ITS devices and the ITS network. Next generation transportation technologies meant to promote a safer and more resilient ecosystem, such as CAV, require technologies with requirements that may not be supported by current MDOT SHA field network configurations. Review of ITS devices and the ITS network is necessary to:
    - Meet the communication capacity needs and characteristics of applied devices,
    - Maximize the utility of the transportation system, and
    - Support the wide range of CAV and ITS applications proposed in TSMO, connected corridor, and other MDOT SHA transportation projects.
3. **Network Redundancy –** Network redundancy is important to eliminate the risks associated with single points of failure. Adding redundancy to the network enhances the resiliency of the MDOT Enterprise Network, reducing the risk of losing critical communications to SHA field device, ITS, and Operational Technology (OT) network.
4. **Strategic Network Peering Points –** Strategic peering points are opportunities for collaboration with other public or private communications networks near MDOT SHA communication assets. Although most fiber providers in the State are currently exempt from resource share requirements, RSA with new long-haul fiber companies or State entities could strategically and cost-effectively expand the MDOT SHA ITS network and public services such as rural broadband.

5. **Rural Broadband –** Existing fiber throughout Maryland could be used to expand service to address underserved rural broadband areas and enhance the transportation experience across the state with increased ITS deployments.

The action plan and roadmap in this *ITS Communications Master Plan* addresses these strategic topics with short-, mid-, and long-term projects. Cost estimates are provided for all short-term projects, while mid- and long-term projects are described at a high-level with cost estimates if adequate information was available. Comprehensive design strategies are introduced for implementation in applicable ITS projects. In addition to the roadmap and action plan, this *ITS Communications Master Plan* recommends further research into rural broadband, operations and maintenance, as well as asset management to enhance the equity, sustainability, and efficiency of the ITS Network.

Table E-1 summarizes projects and design strategies to improve the ITS network to meet the vision of the *ITS Communications Master Plan*. **Table E-2** provides a summary of the recommendations, including policy strategies, made throughout the Master Plan. To be able to move these initiatives forward, the stakeholders should be identified that will be responsible for moving each of the Recommendations in **Table E-2**.

Table E-1 ITS Communications Master Plan Summary of Recommendations

Recommendation Type	Project Description	Estimated Project Cost
Short-Term Project	**Core Network Virtualization** – Recommends reconfiguration of the MDOT Enterprise Network to improve functionality and security for TBUs	**$838K**
	Western Backbone – Recommends the improvement of MDOT Enterprise network redundancy in Western Maryland	**$222K**
	Southern Backbone – Recommends the improvement of MDOT Enterprise network redundancy in Southern Maryland	**$190K**
	Eastern Backbone – Recommends the improvement of MDOT Enterprise network redundancy in Eastern Maryland	**$356K**

Recommendation Type	Project Description	Estimated Project Cost
	Central Backbone – Recommends the improvement of MDOT Enterprise network redundancy in Central Maryland	**N/A**
	TSMO System 1 – Recommends phased build-out of communications resources to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**Phase 1: $8.5M** **Phase 2: $2.6M**
	TSMO System 2 – Recommends phased build-out of communications resources to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**Phase 1: $18.1M** **Phase 2: $9.0M**
	I-695 HSR – Recommends aligning planned projects with this Master Plan to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**$14.4M**
Mid-Term Project	**TSMO System 10** – Recommends build-out of communications resources to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**$18.7M**
	I-495 and I-270 P3 – Recommends aligning planned projects with this Master Plan to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**N/A**
	Baltimore-Washington Parkway - Recommends aligning planned projects with this Master Plan to maximize the use of existing resources and strategically add to MDOT SHA fiber assets.	**N/A**
Design Strategies	**Establish an All-IP Network**	**N/A**
	Integrate Intelligent Network Equipment	**N/A**
	Increase Network and Route Diversity	**N/A**
	Develop Isolated Test Environment	**N/A**
	Standardize Deployment Models	**N/A**
	Establish Transportation Data Portal	**N/A**
	Design for Network Security	**N/A**
	Update Documentation	**N/A**

Table E-2 ITS Communications Master Plan Recommendations

#	Section	Recommendation	Triggering Action	Responsible Party
1	4.5.8 Documentation Updates	Update reference documents and related manuals.	Initiate effort to update reference documents and standards based on this Master Plan.	ITS Division/TBD
2	2.2.2. Access Layer	Continue to pursue IP-based and capable infrastructure, which provides better scalability, flexibility, and lower cost connectivity to devices in the field.	Continue pursuit of IP-based and capable infrastructure	ITS Division/TBD
3	4.5.1 All-IP Network	Continue to ensure all ITS field devices are natively IP-enabled to support a complete IP-based network design.	Continue pursuit of IP-based and capable infrastructure	ITS Division/TBD
4	3.1.1.2 ITS Device Needs	Improve supporting network infrastructure to enable active control capabilities that are anticipated with future traffic management.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
5	3.1.2 MDOT SHA ITS Network Needs	The ITS network must be upgraded to meet the communication capacity needs and characteristics of applied devices to support the wide range of CAV and ITS applications proposed in TSMO, connected corridor, and CATS projects.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
6	4.2.3 Network Management	As technology continues to evolve, strategically choose the types of network technologies deployed, and specify clear management capabilities for network setup, configuration, monitoring and troubleshooting activities.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
7	4.5.2 Intelligent Network Equipment	Use of intelligent, edge-computing field network devices can enhance control and visibility of the network and reduce network traffic.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
8	4.5.2 Intelligent Network Equipment	Use of intelligent, edge-computing field network devices can enhance control and visibility of the network and reduce network traffic.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD

#	Section	Recommendation	Triggering Action	Responsible Party
9	4.1.2.1 Physical Design	To better support the high network bandwidth needs of the distribution layer, fiber optic cables should be used as the network communication medium wherever possible.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
10	4.5.5 Standardized Deployment Models	Develop a standard methodology for deploying the underlying IT communications architecture.	Update ITS Design Manual based on the recommendations within this Master Plan	ITS Division/TBD
11	2.2.2. Access Layer	Migrating CCTV camera field sites from T1 lines to fiber based MetroE/TLS services can increase video quality and usability while potentially reducing monthly recurring service charges.	Continue exploration with Verizon for migration from T1 leased lines to MetroE/TLS in **Appendix X**	ITS Division/TBD
12	4.1.2.3 Carrier Leased Lines	Establish redundant service aggregation points within each leased service regional boundary.	Continue exploration with Verizon for migration from T1 leased lines to MetroE/TLS in **Appendix X**	ITS Division/TBD
13	4.5.3 Increase Network and Route Diversity	Designing network rings with cable route diversity will greatly improve field network resiliency by providing physically independent paths to support the communication network.	Initiate implementation of Backbone improvements contained within this Master Plan	ITS Division/TBD
14	3.2.1 Backbone Gaps	Establish redundant paths in areas with single points of failure to enhance the resiliency of the MDOT Enterprise Network to reduce the risk of losing critical communications.	Initiate implementation of Backbone improvements contained within this Master Plan	ITS Division/TBD
15	3.2.2 Peering Points	Identify strategic peering points with other fiber assets near MDOT SHA communication assets explore opportunities for resource sharing.	Complete audit of communications network and update resource map.	ITS Division/TBD
16	4.1.2.4 Carrier Cellular Network	Continue use of cellular data services as a cost-effective solution for non-critical network communication applications.	Continue use of cellular data services where other solutions are cost prohibitive	ITS Division/TBD
17	4.5.6 Transportation Data Portal	Create a connected vehicle data portal.	Initiate CAV data management program	CATS Division
18	4.1.1.2 Logical Design	A network virtualization overlay service support solution will need to scale across the entire infrastructure and be able to be rolled-out as a phased implementation.	Initiate network virtualization project team	ITS Division/TBD

#	Section	Recommendation	Triggering Action	Responsible Party
19	3.2.3 Rural Broadband	RSA fiber that runs through Maryland could be used to expand broadband service to address rural broadband needs in underserved areas and enhance the transportation experience across the state with ITS improvements.	Initiate outreach to the Office of Rural Broadband.	ITS Division/TBD
20	4.2.4.1 Dig Once Policy	Develop a strategic infrastructure initiative to install conduit infrastructure and associated fiber optic cabling into any ROW construction projects.	Initiate policy development team	ITS Division/TBD
21	4.4.2 I-495 & I-270 P3	While the I-495 & I-270 Project is being implemented as a P3 project, it may be possible to use the developer's fiber under an RSA or participate in a partnership-based overbuild opportunity to install additional MDOT SHA fiber.	Conduct outreach to I-495 and I-270 Project teams	ITS Division/TBD
22	4.4.3 Baltimore-Washington Parkway	The planned level of roadway construction provides an excellent opportunity to install additional fiber optic cable along the [Baltimore-Washington Parkway] corridor.	Conduct outreach to Baltimore-Washington Parkway Project team	ITS Division/TBD
23	4.5.4 Develop Isolated Test Environment	Create an isolated test environment for verification and validation.	Initiate exploratory project team	ITS Division/TBD
24	2.4.1 Physical Security	Determine the need for cabinet and fiber hut door remote monitoring or alarm.	Completion of condition assessment and audit of MDOT SHA assets	ITS Division/TBD
25	2.4.2 Cyber Network Security	Pursue cybersecurity practices in collaboration with MDOT now to establish baselines of the existing network and for future security protocols to build on.	Conduct network security assessment and audit	ITS Division/TBD
26	4.5.7 Secure Network Design	Security control features should be made available as close to the device end points as possible using defense-in-depth security strategy.	Conduct network security assessment and audit	ITS Division/TBD
27	4.5.7 Secure Network Design	For each expansion strategy, security should be evaluated from the very beginning of its implementation to the very end of its life cycle.	Conduct network security assessment and audit	ITS Division/TBD
28	2.5 Operations and Maintenance	It is critical that a clear partnership with roles and responsibilities be formed between the OT and IT organizations to ensure the services are delivered consistently.	Initiate Operations and Maintenance project team	ITS Division/TBD

#	Section	Recommendation	Triggering Action	Responsible Party
29	4.6.1 Operations & Maintenance	A performance-based approach to O&M is desirable to meet the needs identified above and maintain the quality and longevity of the ITS network now and into the future.	Initiate Operations and Maintenance project team	ITS Division/TBD
30	4.6.1 Operations & Maintenance	To support a performance-based O&M approach, a centralized system (or system of integrated systems) is recommended to manage all aspects of O&M.	Initiate Operations and Maintenance project team	ITS Division/TBD
31	4.6.1 Operations & Maintenance	Develop a comprehensive O&M Work Breakdown Structure (WBS) and perform a gaps analysis to identify existing roles and resources and determine additional roles and resources needed to accomplish O&M work and meet performance objectives.	Initiate Operations and Maintenance project team	ITS Division/TBD
32	4.6.2.2 Asset Identification and Inventory	Identify and define what devices and components are capital assets that need to be managed based on stakeholder needs.	Initiate project to define the needs and scope of MDOT SHA asset management	ITS Division/TBD
33	4.6.2.3 Condition Assessment and Data Collection	Label asset condition to establish a baseline from which to build on.	Initiate condition assessment and audit of MDOT SHA assets	ITS Division/TBD
34	4.6.2.4 Technology Systems Identification	Determine the correct suite of tools needed to establish a reliable, integrated, accessible and user-friendly asset management technology system.	Completion of project to define needs and scope of MDOT SHA asset management	ITS Division/TBD
35	4.6.2.5 System Deployment	Develop a prioritization strategy based on immediate needs, available resources, project opportunities, and possible leveraging of existing technology systems.	Completion of condition assessment and audit of MDOT SHA assets	ITS Division/TBD

Document History

Version	Author	Published
V1.0	MDOT SHA Office of CHART & ITS Development	July 2020

1 Introduction

1.1 Vision

"A statewide ITS network capable of supporting existing and future technologies, while ensuring resiliency, efficiency, and equity."

1.2 Purpose

This *ITS Communications Master Plan* establishes a robust strategy to jumpstart the many challenges associated with upgrading the Maryland Department of Transportation State Highway Administration's (MDOT SHA) legacy communications infrastructure to maximize the utility of the transportation system and support rapidly evolving Intelligent Transportation Systems (ITS) and Connected and Automated Vehicle (CAV) technologies. ITS projects including Transportation Systems Management and Operations (TSMO), connected corridors, and Connected Automated Transportation Systems (CATS) have become priorities for MDOT SHA and require strategic planning of communications infrastructure and ITS deployments. This *ITS Communications Master Plan* establishes consistency and cooperation in both funding and performing the planning, design, operations, and maintenance of communication networks required to advance MDOT SHA's ITS network. This Master Plan is expected to remain a 'live document' with annual edits and bi-annual updates to ensure flexibility as future directions are adjusted to meet the needs of our customers.

In addition to supporting Maryland transportation needs, communication assets that are utilized by the ITS network and other transportation applications such as fiber optic and radio networks are leveraged by other public and private agencies to bolster interoperability and reliability across the state. Resource Sharing Agreements (RSA), cooperative agreements, and Memoranda of Understanding (MOU) have been established with these agencies to enable each entity to utilize the communications infrastructure. Because of the resultant patchwork of agreements and shared assets, MDOT SHA reevaluated its strategy and developed an adaptable framework to guide ITS deployments needed to enhance operations and accommodate existing and future technologies.

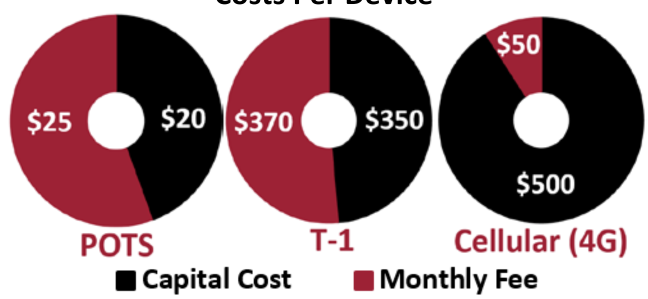
This *ITS Communications Master Plan* provides the adaptable strategy that supports MDOT SHA's current and future needs to deploy high quality, resilient, and cost-effective ITS assets in an agile manner. Additionally, it details recommendations and next steps to direct the planning of existing and future ITS, TSMO, and Connected and Automated Transportation System (CATS) projects.

1.3 Background

ITS systems and transportation technologies have historically been integrated across the State by prioritizing expediency and rapid deployment strategies. This practice in addition to the rapidly evolving advances in ITS and communications technologies in the transportation industry, resulted in a disjointed ITS network that relies on network service providers without a strategy for expansion or unification of the ITS network. Access layer connections utilize 4G cellular and T1 leased line solutions based on the data requirements of each device.

Table 1-1 ITS Communication Network Costs

Costs Per Device[i]



Monthly Communications Costs[ii]			
Device Type	**POTS[iii]**	**T1**	**Cellular (4G)**
CCTV	-	$45,517	-
Traffic Signal	$30,800	-	$1,000
RTMS	-	-	$7,341
DMS	-	-	$5,292
RWIS	-	-	$2,183
SHAZAM	-	-	$1,466
HAR	$739	-	$420
ATR	-	-	$2,100
Total	**$31,539**	**$45,517**	**$19,802**

While these technologies can reduce the time to deploy devices, they do not establish an infrastructure that can be built upon to expand connectivity or functionality in the region. Additionally, while initial capital expenditures for these technologies are a fraction of fiber optic cabling [See estimates for fiber installation in various conditions in

[i] Fiber is not provided for comparison because CHART does not utilize fiber for access layer communications. Additional information about the capital and maintenance cost of fiber installation can be found in Appendix IX

[ii] Approximate communication cost information developed by MDOT SHA CHART Communications Infrastructure Study based on the approximate number of devices.

[iii] The monthly communications cost of POTS varies based on the polling interval of devices connected with this communication medium. As the polling frequency increases, the cost of using POTS increases. The polling interval for POTS lines considered when developing this estimate is not stated within the 2019 Study.

Appendix IX], available bandwidth becomes a limiting factor for application of CAV technology and recurring operation and maintenance fees for these leased services can offset the initial capital savings over time. Plain Old Telephone Service (POTS) provides 52kbps and T1 offers 1.5Mbps, while 4G cellular can provide 20Mbps and fiber can provide bandwidth on the order of Gbps. The patchwork network topology that results from these technologies and the limited bandwidth provided relative to fiber infrastructure (e.g. Gigabit Ethernet) makes this approach inadvisable for expanding a statewide ITS network. The 2019 Infrastructure Study conducted by AECOM and RK&K compared the costs of acquisition, operation, and maintenance associated with each of these technologies, as summarized in **Table 1-1**, which demonstrate long term operations cost of these communication strategies. Based on the Report, recurring fees for all POTS, Cellular, and T1 are more than $96,000 per month.

Estimated capital costs of first-mile[iv] fiber installation can range from $89,500 to $365,000 depending on construction requirements and roadway and field conditions, while fiber maintenance can be approximately $100 per mile per year for contracted services[v]. As device density increases along MDOT SHA roadways, return on the capital investment could be seen through integration of multiple devices onto fiber cable rather than individual point-to-point T1 leased services. Additionally, the future communications infrastructure will require a strategic approach to deploy technologies that can provide higher levels of performance and bandwidth speeds to accommodate the implementation of complex CAV and TSMO systems.

Existing statewide ITS systems are currently connected to over 800 miles of MDOT's Enterprise Network fiber optic cable and microwave radio components. RSA and MOU with statewide cooperatives, service providers, and the Maryland Department of Information Technology (DoIT) have been established to support the Enterprise Network. Because the MDOT Enterprise Network is the critical backhaul for MDOT SHA's ITS network, this plan addresses opportunities to improve network redundancy and resilience of the backbone.

This Master Plan provides guidance for MDOT SHA regarding how the ITS networks can be built in a sustainable and cost-effective manner. Future projects detailed in this report consider

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[iv] Installation of additional fiber in a project would yield a less expensive capital cost per mile of fiber.
[v] Fiber maintenance cost estimate based on peer agency maintenance contracts.

opportunities to leverage State and county resources through resource sharing, Public-Private Partnerships (P3), and broadband cooperatives to expand the ITS network. MDOT's Enterprise Network utilizes statewide public and private fiber assets through RSA and MOU as the network backbone supporting ITS communication needs.

1.4 Goals

The primary goals of this Plan are to:

1. Propose a strategy to ensure consistent statewide deployment of ITS infrastructure.
2. Provide guidance for the deployment of an integrated ITS network that is capable of sustaining future technologies and systems.

1.5 Scope

This document highlights ITS needs and provides a vision and roadmap for future ITS deployments necessary to address MDOT SHA's ITS goals and support the expansion of emerging technologies such as CAV. Although the primary focus of this *ITS Communications Master Plan* is MDOT SHA ITS needs, other state and county level needs are also considered for a better understanding of how the network might perform for potential stakeholders.

First, an analysis of the existing conditions and environment is provided to:

- Define project stakeholder roles.
- Provide an overview of CHART's ITS architecture.
- Describe existing Resource Sharing Agreements (RSA).
- Detail existing regulations and standards for security, operations, and maintenance of the ITS network.
- Identify existing fiber and other ITS assets that may be leveraged by MDOT SHA.

Next, ITS network, rural broadband, and equity needs are highlighted to provide the basis for the recommendations and action plan.

An overview of the MDOT SHA network architecture is then provided, followed by the project roadmap and action plan which includes:

- Prioritized deployments.
- Deployment timeline.
- Forecast of capital, operations, and maintenance costs for near-term, mid-term, and long-term ITS projects.

Lastly, general recommendations, best practices and additional resources are provided.

This document does not provide detailed designs or specifications. However, the concept, recommendations, and best practices provided in this document should be used as a guiding reference when developing specific requirements, specifications, detailed designs, and other plans for ITS, TSMO and CATS projects.

This *ITS Communications Master Plan* will be reviewed annually to update the status of short-term projects and will require biennial updates to incorporate new applications, technologies, and transportation needs. It is expected that updates to this Master Plan will be coordinated with updates to the MDOT SHA ITS Design Manual and the Office of Traffic and Safety (OOTS) Signal Design Guidelines.

1.6 Stakeholders

Primary stakeholders of this *ITS Communications Master Plan*: CHART, OOTS, and Office of Information Technology (OIT). All actions and recommendations within this Plan are directed towards MDOT SHA.

Secondary stakeholders of this *ITS Communications Master Plan*: MDOT Secretary’s Office (TSO), MDOT Transportation Business Units (TBUs), Maryland Department of Information Technology (DoIT), partners such as the Maryland Transportation Authority (MDTA), Maryland counties, and municipalities. This document does not specify actions to be taken by secondary stakeholders; however, the actions taken by MDOT SHA may require interaction and coordination with these secondary stakeholders.

1.7 Studies & Resources

The following studies and resources were utilized in the development of the ITS Communications Master Plan:

- MDOT SHA CHART Communications Infrastructure Study, August 26, 2019.
- CHART Long Range Strategic Deployment Plan (LRSDP), 2013.
- Maryland Statewide ITS Architecture, November 2016.
- MDOT SHA TSMO Strategic Plan, October 2018.
- MDOT Consolidated Transportation Program FY2019 to FY2024.
- MDOT SHA ITS Design Manual, June 2016.
- MDOT SHA Traffic Control Devices Design Manual, July 2017.
- Maryland Department of Information Technology (DoIT) Information Security Policy, Version 3.1, February 2013.
- Resource Maps (various).

In support of this *ITS Communications Master Plan*, an online resource map was also developed to detail existing and proposed ITS network infrastructure. This map was developed in coordination with the CHART ITS Division, which maintains an interactive Geographic Information System (GIS) layer of ITS infrastructure and devices that may be leveraged to address MDOT SHA's ITS network needs. Professional engineering plans or an audit of communications infrastructure should be reviewed and verified to confirm all information included in the resource map. Please contact the MDOT Division Chief of the ITS Division (jfrenkil@mdot.maryland.gov) with any questions or comments or if you are the owner of the infrastructure detailed within the resource map and wish to provide relevant or updated information.

1.8 Acknowledgements

Special thanks to the *ITS Communications Master Plan* Support Team for subject matter expertise and preparation led by Jacobs Engineering Group Inc. in association with Drive Engineering Corp, Skyline Technology Solutions, and Whitman Requardt and Associates, LLP.

Acknowledgements also to the internal MDOT team who supported the development of this plan, spanning across MDOT SHA CHART, OOC, OIT, and MDOT TSO.

2 Analysis of Existing Conditions

This section provides a description of the MDOT SHA ITS network's existing conditions to highlight the needs of the network and establish a baseline for the actions detailed in **Section 4**. The following topics of MDOT SHA's review are detailed:

- **2.1** ITS Device Inventory
- **2.2** ITS Communication
- **2.3** Network Architecture
- **2.3** Resource Sharing Agreements
- **2.4** Physical and Cyber Security
- **2.5** Operations and Maintenance

2.1 ITS Device Inventory

MDOT SHA utilizes the ITS network to communicate between central data centers, operation centers, and ITS field devices such as Closed-Circuit Television (CCTV), Remote Traffic Microwave Sensors (RTMS), Dynamic Message Signs (DMS), Road Weather Information Systems (RWIS), SHAZAM signs, and Highway Advisory Radios (HAR). **Table 2-1** details MDOT SHA's existing ITS device inventory.

Please Note: Although Traffic Signals and ATRs are listed in **Table 1-1** to demonstrate MDOT SHA device communication costs, Traffic Signals and ATRs are not always included throughout sections of this document since they are maintained by different offices (MDOT SHA OOTS and MDOT SHA Office of Planning and Preliminary Engineering (OPPE), respectively). Should management changes occur for these technologies they will be added to this plan during annual or bi-annual revisions.

According to the 2019 MDOT SHA CHART Communications Infrastructure Study, there are 392 low-speed field devices including DMS, RTMS, HAR, and SHAZAM signs that operate using cellular communication. T1 connections are used to communicate with 210 CCTV sites. **Table 2-2** summarizes which communication technologies are utilized for these ITS devices.

The information included in **Table 2-1** and **Table 2-2** were gathered from CHART and the MDOT SHA CHART Communications Infrastructure Study and confirmed by the ITS Division in Winter 2020.

Table 2-1 MDOT SHA Field Device Summary

County	CCTV	DMS	HAR	RTMS	RWIS	SHAZAM	Traffic Signals
Allegany	9	5	2	0	5	3	13
Anne Arundel	30	14	3	8	4	0	210
Baltimore City	2	0	0	0	0	0	308
Baltimore	41	22	4	51	3	3	0
Calvert	0	0	0	0	1	0	15
Caroline	2	0	1	0	1	3	4
Carroll	0	0	0	0	3	1	65
Cecil	0	3	0	0	3	0	16
Charles	0	1	0	0	1	0	40
Dorchester	1	0	1	0	2	0	5
Frederick	10	5	2	13	3	3	55
Garrett	5	2	0	0	2	0	5
Harford	0	0	0	0	5	0	88
Howard	13	8	2	20	3	3	86
Kent	0	0	0	0	0	0	7
Montgomery	13	6	2	72	4	0	12
Prince George's	44	18	4	77	6	2	392
Queen Anne's	8	3	0	0	1	2	8
Somerset	0	0	0	0	0	0	2
St Mary's	5	0	0	0	0	0	32
Talbot	4	0	1	0	0	3	16
Washington	10	0	2	0	5	4	77
Wicomico	5	2	1	0	1	2	48
Worcester	8	5	1	0	1	2	78
TOTALS	**210**	**94**	**26**	**241**	**54**	**31**	**1582**[1]

[1] The total number of Traffic Signals shown in **Table 2-1** may represent communications to isolated signals and/or signal systems.

Table 2-2 MDOT SHA Field Communications Summary

Communications Type	CCTV	DMS	Facilities	HAR	RTMS	RWIS	SHAZAM	Traffic Signals
POTS								X
Cellular		X		X	X	X	X	X
T1	X							
Fiber Optic			X					

2.2 ITS Communication

This section provides a general overview of the existing MDOT SHA ITS communication network architecture supporting CHART ITS devices and OOTS traffic signal control operations. Both functional groups are supported through independent communication solutions as shown in the Existing Network Conceptual Architecture in **Figure 2-1**. These networks were designed and custom-built to support a specific application or service; therefore, they have evolved independently of one another, greatly limiting the ability to support a network wide system of communication. The current architecture consists of a field access layer and a backbone core layer. The field access layer is used to interconnect field devices to the backbone core using various leased services.

2.2.1 Backbone Core Layer

The core layer of the MDOT SHA communication network consists of data services supporting all ITS application data processing. Primary and backup servers are located at Glen Burnie datacenter and MDOT SHA Headquarters (HQ) in Baltimore. Network services and public carrier network termination points are established at MDOT HQ in Hanover and at the Glen Burnie datacenter, the MDOT SHA Statewide Operations Center (SOC) in Hanover, and several Traffic Operations Centers (TOC) throughout the state. These components are all interconnected across a fiber backbone network comprised of fiber owned by MDOT SHA, shared through RSA, or accessed through MOU. The backbone layer interconnects the field access layer with the CHART Advanced Traffic Management System (ATMS) and traffic signal system application data processing components.

At the backbone core, MDOT provides Internet Protocol (IP) network services for all traditional Information Technology (IT) applications and services through a single common routed MDOT Enterprise Network. The MDOT Enterprise Network effectively provides a communications backbone for all TBUs. The MDOT Enterprise Network includes direct support of MDOT SHA facility Local Area Networks (LAN) as well as Wide Area Network (WAN) communications supporting the ITS and traffic signals as well all other traditional business IT services.

MDOT Enterprise Network traffic is controlled at the edge Network Interface Device (NID) and data is not segmented within the network. In other words, all TBU communication traffic is transmitted on the same logical network regardless of application. Currently VLANs are used at the datalink layer (2) to provide logical separation however the default gateways for these VLANs are supported by the same device so they share a common network at the network layer (3). Therefore, while there is logical separation at the datalink there is not separation at the network layer of the existing infrastructure. For more information regarding network security and how network traffic is controlled, please refer to **Section 2.4.2**.

MDOT has leveraged private and commercial fiber through various RSA and MDOT-owned fiber assets along MDOT SHA right-of-way to establish a high-speed network infrastructure capable of 1Gbps and 10Gbps data transmission speeds. Due to the limited number of fibers within key RSA backbone resources as well as the physical limitations of optical networking technologies, MDOT has designed this backbone service infrastructure as a single enterprise network infrastructure, permitting each TBU to take advantage of the high speed communication services. A conceptual diagram of the existing MDOT Enterprise Network is presented in **Figure 2-1.** In the current network configuration, each facility on the network has an established Point of Presence (POP) for the MDOT Enterprise Network.

The MDOT Enterprise Network permits communication between MDOT facilities in a partial mesh topology, where facilities are connected to the common backbone based primarily on geographic proximity to other MDOT facilities. It is not uncommon for a single linear extension of the network to incorporate several facilities. To that end, each facility may provide 'transit' services for other facilities regardless of their associated TBU or function. The reliance of many MDOT SHA facilities on single extensions of fiber cables places many facilities and connected devices at risk of network failure due to the risk of damage to the cables. The physical backbone architecture supporting the existing MDOT Enterprise Network is summarized in more detail in Appendix II. The existing enterprise infrastructure enables a high-speed network for the benefit of each of the MDOT TBUs. However, to ensure the MDOT Enterprise Network remains secure, the governance of the infrastructure and its end systems is centralized. Implementations of the required security services are distributed; however, governance and decision making for security is centrally managed. External network service integrations such as the Internet, business-to-business network connections, and Virtual Private Network (VPN) services are also centrally managed.

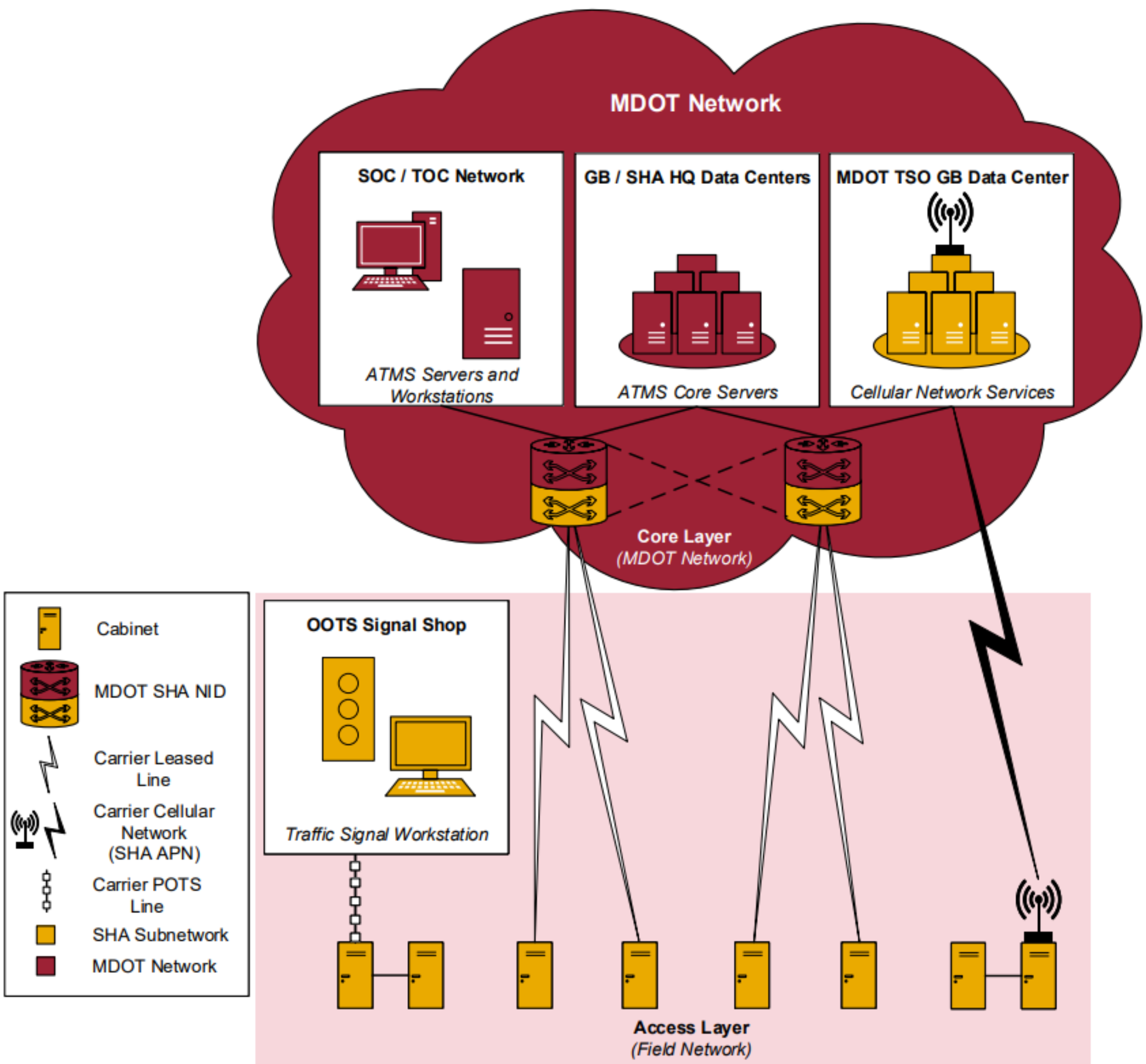


Figure 2-1 Existing Conceptual Communications Architecture

2.2.2 Access Layer

While MDOT provides backbone communication services to connect the MDOT SHA facilities into the common MDOT Enterprise Network, MDOT SHA is responsible for the access layer field network infrastructure and related services. The field network connects the field devices listed in **Section 2.1** to application servers on the core network.

Due to the complexities of ITS and roadside equipment field network configurations in terms of function, features, and operational support requirements, MDOT SHA is responsible for operating and maintaining access layer communications. These ITS field networks are typically regionalized based on leased line costs or geographic proximity. The connection to the backbone core is primarily over a leased service, since there is limited fiber optic cable with field hub facilities and point-to-point private wireless solutions to interconnect MDOT SHA field cabinets.

2.2.2.1 T1 Leased Line

MDOT SHA primarily utilizes T1 leased lines to interconnect CCTV cameras to the closest aggregation facility servicing its respective geographic region. CCTV encoding devices are typically configured for dual video streams: currently 400kbps and 192kbps. Most CCTV locations are single camera; however, there are a number of locations where two cameras are connected to the same leased line. A T1 service can provide 1.54Mbps of throughput; therefore, a single service can support up to three (3) cameras although some reduction to the dual video stream bandwidths is necessary in such instances.

Verizon supplied T1 services are point-to-point Time Division Multiplexed (TDM) leased circuits that are charged in a distance-based method, otherwise known as a geographic costing metric. These leased lines are typically terminated at the nearest established MDOT SHA aggregation facility with a network security enclave POP that is within the same Verizon Local Access and Transport Area (LATA) to avoid inter-LATA service charges.

The T-carrier hierarchy defines 28 DS-1 (T1, 1.54Mbps) signals to be mapped into a single DS-3 (T3, 45Mbps) circuit. Aggregation facilities that terminate more than approximately seventeen (17) T1 connections typically do so using a single channelized T3 which is more cost-effective. Verizon has been working to transition most copper-based field circuits to fiber optic delivery mechanisms including T1 services. In such cases, Verizon provisions T1 based service extension over a fiber optic cable delivery method. Verizon can also offer Metro Ethernet (MetroE) Transparent LAN Service (TLS) over fiber optic delivery. These services can provide higher bandwidth at a lower cost and do not have the same associated distance-based variability in leased costs.

> **Recommendation**: Migrating CCTV camera field sites from T1 lines to fiber based MetroE/TLS services can increase video quality and usability while potentially reducing monthly recurring service charges.

In some cases, the continued use of a higher bandwidth TLS service may be justified if it can be used to support multiple devices more cost-effectively than a private solution. For more information regarding TLS, please refer to **Appendix X**.

2.2.2.2 POTS Line

Verizon supplied dial-up POTS lines have been the traditional means by which the traffic signal system has been managed. MDOT SHA Traffic Operations Division (TOD) operates and maintains the majority of state traffic signals with a few exceptions. State traffic signals in Montgomery County and a few signals in Anne Arundel, Baltimore, Frederick, and Howard counties are operated and maintained by the counties and are reimbursed by the State. Traffic signal communications have traditionally used a combination of dial-up POTS lines, Twisted Wire Pair (TWP) cable, and in some cases MDOT SHA multi-mode fiber optic cable.

Within signal systems, legacy on-street field master controllers connect to local controllers using the TWP or fiber optic cable while also communicating with a central management station using dial-up POTS lines. Traffic signal operation is largely based on analog communications but is being transitioned to IP-based communications as described in **Section 2.2.2.3**. To accomplish this transition, dial-up POTS line service is being replaced with cellular data modems, TWP is supporting Ethernet-over-copper, and any fiber optic cable is using Ethernet fiber media converters. Previous stand-alone signal controllers were also being connected to the central traffic signal control system using dedicated cellular data modems. The centralized traffic signal control system is being hosted in the primary and backup data centers. Using the newer IP-based scheme all field traffic signal controllers will have constant communication with a centralized traffic control system.

Recommendation: Continue to pursue IP-based and capable infrastructure, which provides better scalability, flexibility, and lower cost connectivity to devices in the field.

This older POTS analog service is not compatible with modern day IP-based field devices and is slowly being phased out by service providers. MDOT SHA is also currently transitioning away from this service in favor of cellular data modems. It is expected that within the next 2 years all POTS lines will have been deactivated.

2.2.2.3 Cellular Data

Cellular data modems have been used as the primary means to interconnect lower speed field devices, such as DMS, RTMS, RWIS, HAR, and SHAZAM, as well as mobile or transportable devices to the backbone core. Recently, cellular data modems are also being used to support traffic signal controllers as these devices are migrated from POTS lines. Automated Traffic Recorders (ATR) and Virtual Weigh Stations (VWS), while not currently CHART devices, are also supported by the cellular data network. Cellular services are also leveraged to support mobile and trailer transportable CCTV cameras. Fixed CCTV cameras are also sometimes supported by cellular data modems where T1 service is difficult to provision, although cellular carriers discourage continuous use by high bandwidth devices such as CCTV.

Currently, AT&T is the primary carrier for ITS devices while Sprint is the primary carrier for traffic signal controllers. MDOT is currently in discussions with Verizon regarding similar services. Both providers support a 4G service and have implemented an Access Point Network (APN) solution providing backend virtualized services across the public cellular network to redundant geographically dispersed carrier network centers. The APN solution keeps MDOT SHA traffic isolated from other cellular network users. Separate and redundant IP Security (IPSEC) based VPN tunnel connections from each carrier provided APN network service is provided across the public

Internet to both the MDOT SHA primary and secondary network centers. MDOT supports this service on behalf of MDOT SHA providing a secure handoff between the NID of both networks.

The cellular monthly cost structure includes an approximately $50 cost per subscriber modem line per month based on bandwidth and throughput requirements in addition to a fixed APN cost. As end devices are added only the incremental subscriber modem cost is realized while the APN cost remains the same assuming total bandwidth is not exceeded. This makes cellular data service a very cost-effective solution. Cellular services do not have a geographic cost component associated with them and are therefore aggregated within the carrier network structure and presented to MDOT SHA at two redundant network data center locations. As detailed above, however, the integration occurs over the public Internet using IPSEC-based VPN services.

2.3 Resource Sharing Agreements

The majority of RSA occur on MDOT-owned Right of Way (ROW); however, the expansion of MDOT SHA's capabilities would involve access to ITS infrastructure and communications assets that may be owned and maintained by other public and private entities through RSA contracts developed by MDOT's Secretary's Office (TSO). Most current private companies with fiber deployed in MDOT SHA ROW are exempt from resource sharing requirements; however, new long-haul fiber companies may provide opportunity as they may not be exempt.

From the public perspective, interagency sharing agreements are established by developing MOUs between MDOT SHA and public entities to share ROW, fiber, conduit, and other assets. **Figure 2-2** provides an ITS resource sharing map that details fiber ownership and area allocation. Further information about the fiber utilized through RSA and MOU can be found in the Resource Map (**Section 1.7**). Each agreement is unique and has specific language regarding the ability to share the fiber with others. All RSA, except RSA with Level 3 Communications (Level 3), prohibits State agencies' ability to share, trade, or allow usage of the fiber with commercial entities that provide similar services to the company that provide the RSA fiber. Because the MDOT SHA backbone is 95% RSA fiber, the ability to dedicate fiber for the use of rural broadband is greatly limited. Details regarding how public and private entities can enter into RSA with MDOT SHA are presented in **Appendix XI**.

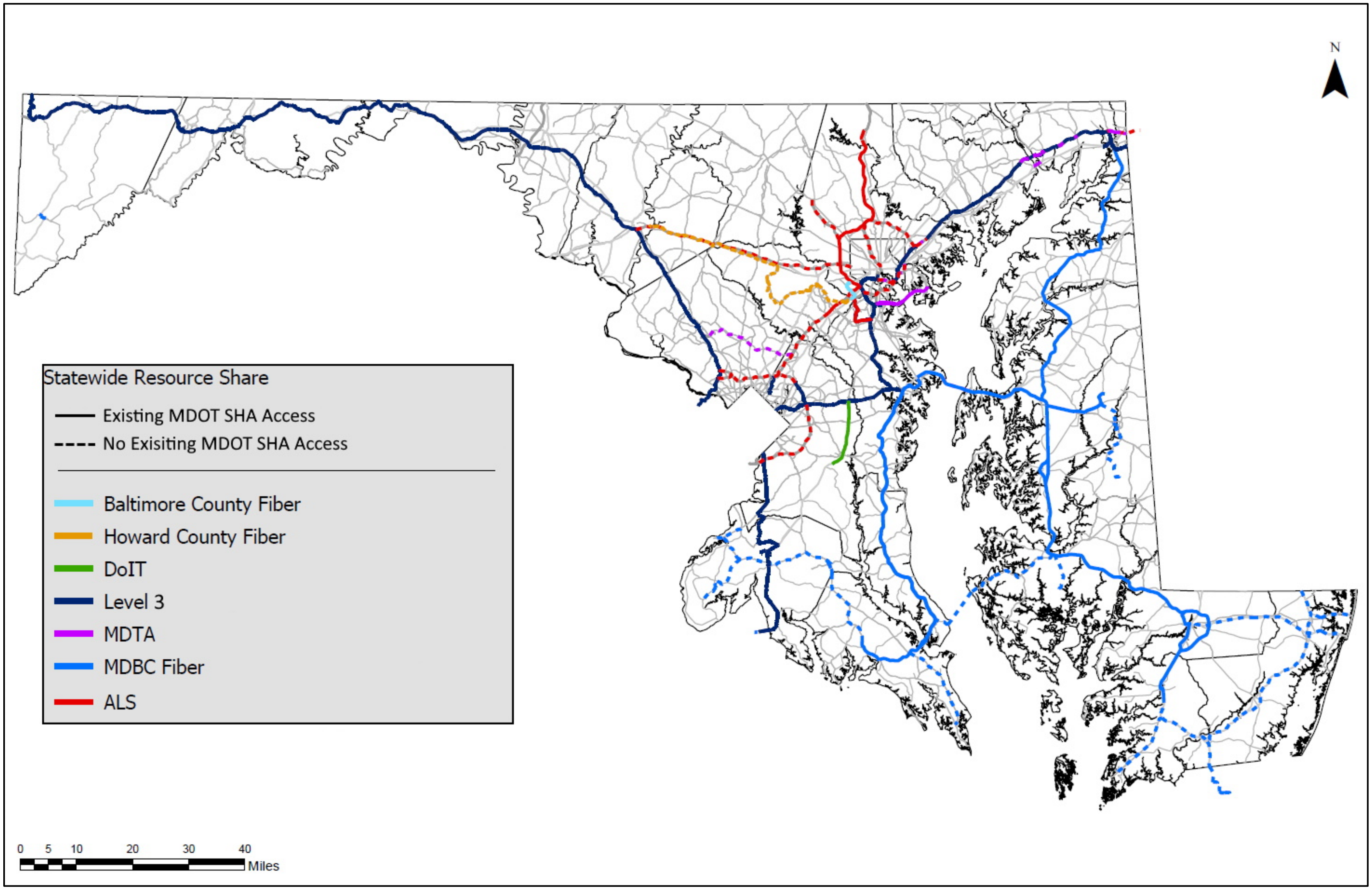


Figure 2-2 Statewide Resource Share Agreement Overview

2.4 Physical and Cyber Security

MDOT SHA ITS communications security includes both physical and cyber network security. Historically, communications security has not been a high priority in the transportation industry primarily due to a low threat level resulting from the use of proprietary protocols over legacy analog communications and limited field device functionality. As technology progresses, the threat of security events increases as field devices become more connected and capable, and as more common protocols and communication technologies are used. The advances in communications that enables much of the ITS capabilities also introduce potential vulnerabilities highlighted within the following sections.

2.4.1 Physical Security

Providing controlled access to network infrastructure is the first line of defense in a typical multi-layered approach to security. MDOT SHA currently locks all field ITS and traffic signal cabinets using an industry standard off-the-shelf key. All fiber hut facilities, towers, and buildings hosting telecommunications equipment are also locked. Cabinet and fiber hut doors are not currently remotely monitored or alarmed.

Recommendation: Determine the need for cabinet and fiber hut doors remote monitoring or alarm.

2.4.2 Cyber Network Security

Under the current design, the field networks are considered a separate security zone or level when compared to the MDOT Enterprise Network. The NID of the MDOT SHA field network and the MDOT Enterprise Network boundary provide logical separation and network security to control this traffic. Firewall type features of the NID provide Layer-3 traffic filtering (IP address and port number) as well as session control capabilities by only allowing communications to originate from the central end, which supports the current poll-response communications environment. Additionally, MDOT SHA utilizes Layer-2 (i.e. port blocking) security features with field cabinet switches to prevent unauthorized access of rogue devices through hard-set media access control addressing per production enabled port and interface.

MDOT follows widely accepted industry best practices for network administration, operations, and maintenance. Where applicable, these standards then flow down to the MDOT SHA field access network. MDOT SHA makes requests of MDOT IT whenever there are changes to field devices that results in a network change, i.e. adding or removing a CCTV camera. MDOT handles assigning IP address blocks and setting all IP and port number policies on security layer interfaces to the MDOT network. MDOT also scans all end point white list devices unless explicitly identified as not to be scanned.

Recommendation: Pursue cybersecurity practices in collaboration with MDOT now to establish baselines of the existing network and for future security protocols to build on.

2.5 Operations and Maintenance

MDOT SHA relies on MDOT, contracted resources, and other service providers for non-ITS related support. Operations Technology (OT) elements of the network include Supervisory Control and Data Acquisition (SCADA) equipment including traffic management and related control devices. OT equipment may be characterized as follows:

- Purpose-built specialized computing machines to support narrowly defined field functions.
- Designed to operate in harsh field environments in unconditioned cabinets.
- Limited processing hardware capabilities typically tuned to the needs of the supported application and not expandable.
- Typically utilize specialized embedded operating systems (i.e. Linux) or no operating system.
- Supports Ethernet and IP communications although at lower speeds. OT equipment may not support all IP protocols and may not be capable of heavy network traffic due to limited processing capabilities.

- Limited cybersecurity and device-level information security hardening capabilities. Many OT systems run older software platforms that are not easily secured.
- Operational availability is the most important metric. It is typically more effective to isolate, harden, and limit access to the subnetwork or security enclave, and applying endpoint hardening as a secondary security measure if possible.

IT elements support management and workflow of digital information in support of the OT devices. IT elements include all the back-office servers, workstations, databases and other core services related to the traffic management system, and may be characterized as follows:

- Use of general-purpose computing machines using common processing architecture and operating systems (i.e. Microsoft Windows).
- Equipment is typically designed for conditioned environments.
- High performance and expandable processing hardware capabilities able to support multiple applications in a high workload environment.
- Fault-tolerant and redundant systems providing high reliability.
- Supports high levels of cybersecurity capabilities including information security hardening and device operational availability. Best practices such as frequent operating system and application level patching along with system scans to detect and correct vulnerabilities are common.

MDOT SHA utilizes a Hybrid Ownership model for OT and IT partnership while maintaining complete ownership for the field ITS communications areas of the network. The hybrid approach permits separation of roles based on the clear demarcation point between IT and OT responsibilities. OT and IT must establish a joint role in the ultimate success of the organization goals.

Recommendation: It is critical that a clear partnership with roles and responsibilities be formed between the OT and IT organizations to ensure the services are delivered consistently.

2.5.1 MDOT SHA Roles and Responsibilities

MDOT SHA retains OT assets and core personnel to support ITS service delivery and define ITS operational requirements. Generally, MDOT SHA has limited proactive monitoring capabilities and relies on MDOT for this service. When an issue is identified, MDOT SHA responds to field issues with corrective measures. The MDOT SHA Radio Shop does utilize device-specific element management system tools to remotely troubleshoot telecommunications problems.

Staff are typically trained as electronics technicians to setup, configure, troubleshoot, and repair field electronic communications equipment. As field equipment becomes more technically advanced, MDOT SHA staff will need to maintain proficiency in various information and communications networking technologies. MDOT SHA has limited fiber repair capabilities including fiber test and repair equipment. Fiber repair is typically used to repair small fiber cables of short runs to individual ITS and signal cabinets. Larger fiber troubleshooting and repair work is typically outsourced. T1 lines are the responsibility of the Radio Shop who perform initial troubleshooting and involve Verizon as needed.

POTS lines used for traffic signal control are the responsibility of the TOD. TOD maintenance crews typically isolate the problem and then coordinate with the carrier Verizon as needed. TOD is also responsible for maintaining all hardwire signal interconnect between signals, comprised of copper TWP or fiber.

A concern with the existing system is the inability to remotely monitor network health and status is limited to monitoring access to the attached end point devices.

2.5.2 MDOT Roles and Responsibilities

MDOT is responsible for the MDOT Enterprise Network and controls the interface to the TBU subnetworks, such as MDOT SHA. The MDOT Enterprise Network includes all IT network devices that are located at the backbone core layer and support back office servers, workstations, databases, and other services related to the traffic management system.

MDOT operates a configuration control board with MDOT SHA as a member to help manage, plan, and coordinate network changes. The OT and IT networks are tightly integrated with the MDOT Enterprise Network; therefore, there is a high degree of cooperation and oversight through a mature change control process, which requires that the organizations work together to ensure cohesive designs and functionality.

MDOT staff are IT-trained professionals with greater capabilities to manage the more complex aspects of the overall network. MDOT provides network management services to monitor the MDOT SHA network using contracted services from a Network Operations Center (NOC) in Silver Spring, MD. The NOC is also used to monitor the uptime of each field device on a regular basis. The NOC notifies MDOT SHA when devices go off-line for a predefined period.

MDOT is also responsible for provisioning, administering, and managing the cellular data network on behalf of MDOT SHA. Cellular network configuration and data modem settings are established by MDOT. Field installation and troubleshooting is performed by TOD for traffic signal controllers or the Radio Shop for ITS devices.

3 ITS Communication Needs

This section details the needs identified by MDOT SHA stakeholders during workshop meetings and indicated through review of the existing conditions of the ITS network. MDOT SHA ITS network needs are presented in the following categories:

3.1 MDOT SHA ITS Network Needs

3.2 Secondary Stakeholder Network Needs

3.1 MDOT SHA ITS Network Needs

This section provides an evaluation of existing ITS network needs as they pertain to MDOT SHA arterial and freeway operations. A high-level summary of those needs is available below:

- Unify field device networks into a single integrated field network.
- Establish functional subnetworks to segment ITS applications.
- Support new communications patterns to enable the integration of CAV technologies.
- Standardize network design throughout the state.
- Expand geographic reach of the ITS network.
- Design the network to easily expand to support additional applications.
- Diversify network expansion opportunities.
- Enhance network security.

3.1.1 General ITS and Field Device Needs

3.1.1.1 Field Cabinet Needs

Each field cabinet represents a field network node point with certain network performance requirements. The exact needs vary depending upon the requirements of the devices that are being supported. For initial network planning purposes, the following design points allow for an approximate 80% growth over expected demands (**Table 3-1**).

Table 3-1 Field Cabinet Network Design Requirements

Field Cabinet Type	Network Design Requirement
Standalone Traffic Signal Cabinet	1 Mbps
Coordinated Traffic Signal Cabinet	3 Mbps
Smart Traffic Signal	5 Mbps
ITS Cabinet	5 Mbps

3.1.1.2 ITS Device Needs

The following ITS and field devices in **Table 3-2** and **Table 3-3** will be supported by the proposed network.

Table 3-2 Existing ITS System Needs and Requirements

ITS Device or Application	System Needs and Requirements
Bluetooth Reader	• Bandwidth requirement: 50 kbps • Operate with poll-response protocol
CCTV	• Utilize H.264 encoding standard and H.265 in the future • Bandwidth requirement: Dual unicast video 600 kbps (192 kbps[1] and 400 kbps) • Delay requirement of less than 200ms and jitter less than 50ms • Cellular mobile cameras require single unicast video 400kbps
DMS	• Bandwidth requirement: 50 kbps • Operate with poll-response protocol • Polled at 4-minute intervals
HAR	• Bandwidth requirement: 50 kbps • Operate with poll-response protocol
RTMS	• Bandwidth requirement: 50 kbps • Operate with poll-response protocol • Polled at 5-minute interval
RWIS	• Bandwidth requirement: 50 kbps
SHAZAM	• Bandwidth requirement: 50 kbps • Operate with poll-response protocol
Traffic Signal Control	• Bandwidth requirement: 100 kbps • Operate with poll-response protocol • Polled on once-per-second interval

[1] 256 kbps and 400 kbps are the anticipated bandwidth requirements for dual unicast video.

Other general technology advances including edge processing, artificial intelligence, and video analytics will impact the nature and type of communication patterns to be expected and the need for network traffic isolation by type.

Recommendation: Improve supporting network infrastructure to enable active control capabilities that are anticipated with future traffic management.

General network characteristics to support the new ITS devices and applications in **Table 3-3** include:

- Network resiliency, including the need for fault-tolerant network design and use of redundant network paths to allow network to automatically reconfigure and continue operations.
- Fault-tolerant and fail-safe field hardware allowing field operations to revert to a known and predefined state under network failure conditions.
- High network performance, including latency, bandwidth, and security performance matching the needs of the end application.
- Machine-to-machine level information transactions as more traffic management processes will be automated.
- Integrated operation where the traditional distinction between traffic control and ITS will be less evident as applications are co-mingled in the same field cabinet. The need to support various applications across a common network infrastructure will be needed.
- Dynamic edge application of security controls based on centralized policy definition. As mission critical and increasingly diverse applications are added to the MDOT SHA field networks the ability to apply security controls at the edge of the network (access point) based on the dynamic understanding of the device(s) being attached will become increasingly important. A centralized control system with the ability to seamlessly deploy policy in a distributed enforcement manner will be critical to ensure that the operations team can deliver on this expected reality.

Table 3-3 Future ITS System Needs and Requirements

ITS Device or Application	System Needs and Requirements
Active Traffic Management (ATM)	ATM requires combinations of existing ITS technologies utilized by MDOT SHA: • Hard Shoulder Running (HSR) using Lane Use Signals (LUS) to communicate open/closed shoulder operation to the driver. Full CCTV coverage to support shoulder operation • Queue Warning System (QWS) with DMS to display real-time warning messages to alert motorists of slowdowns • Dynamic Speed Advisory (DSA) to display safe speeds based on travel conditions • Dynamic Lane Assignment (DLA) is similar to LUS with HSR but is typically applied to all running lanes • Video Image Detection System (VIDS), although currently used for arterials may become more prevalent along freeways in support of ATM strategies.
CAV	Integration of CAV applications can have wide-ranging impacts on the ITS network due to the generation and transmission of large volumes of data. The following are estimates of CAV requirements based on existing technology: • Support existing Signal Phase and Timing (SPaT) deployments o Initial bandwidth requirement: 1 Mbps • Support Pedestrian Safety, Curve Warning, and Bridge Warning deployments o Initial bandwidth requirement per technology type: 1 Mbps • Longer term CAV needs are expected to span anywhere from 6 – 27 Mbps due to data package transfers but are not yet defined.
Ramp Metering	• Peer-to-peer coordination between Ramp Meter locations and traffic signal controllers • Bandwidth requirement: 500 kbps

ITS Device or Application	System Needs and Requirements

Traffic Signal Control	Requirements vary based on type of corridor:
	• Smart Corridor (highest level of connectivity)
	  o Support Adaptive Traffic Signal Control and CAV applications
	  o Bandwidth requirement: 1 Mbps
	• Coordinated Corridor
	  o Supports applied video detection and remote monitoring
	  o High resolution controller data collection
	  o Bandwidth requirement: 500 kbps
	• Standalone Corridor
	  o Supports periodic monitoring and remote troubleshooting
	  o Bandwidth requirement: 200 kbps

3.1.2 MDOT SHA ITS Network Needs

The ITS network must apply the following improvements in **Table 3-4** to enhance network resiliency, redundancy, extendibility, and flexibility.

Table 3-4 MDOT SHA ITS Network Needs

Network Need	Description
Single Integrated Field Network	The network must be "application-aware" to ensure that resource usage between competing applications can be effectively managed and secured.
Functional Subnetworks	Separate logical subnetworks (enclaves) based on function, operation, performance, and security needs must be developed to support micro-segmentation of the independent ITS functions as required. Additional subnetworks to support CAV and other future applications may be required.

Network Need	Description
New Communications Patterns	The traditional poll-response communication patterns used in the center-to-field communications networks will also need to support other traffic topologies such as peer-to-peer to support advanced applications associated with adaptive traffic control, active traffic management, and CAV applications. With the addition of other intelligent devices, there may be more peer-to-peer and event-driven communications initiated by the field equipment and signal cabinet devices.
Standardized Design	Design networks for ease of understanding for network operations and maintenance purposes. As a result of organic growth and short-term planning, existing documentation of current network is not always easy to understand. The number of different parties involved can also complicate the recovery or restoration of communications services.
Broad Geographic Reach	As ITS implementation expands, operational efficiency needs will impose requirements to integrate these geographically dispersed regions into a cohesive service network.
Application Support Extendibility	Support the flexibility to “snap on” new systems that may need to be isolated from each other in separate network enclaves. The network should be designed in such a way as to readily provide the ability to support virtual isolation for applications as they are introduced into the environments.

Network Need	Description
Network Expansion Flexibility	The network should easily support additional ITS devices as they are installed without requiring extensive network modifications. Additionally, there should be a logical upgrade path to allow the network to scale to support additional services and bandwidth needs, while improving reliability to eliminate single point and security failures.
Enhanced Security	The supporting field devices of the CHART ATMS and traffic signal system will require further logical separation into separate security enclaves according to the application requirements of each associated subsystem and function. To accomplish this, enclaves will need to be established and maintained as systems are deployed and expansion efforts are implemented. This will require automated device recognition and subnetwork assignment capabilities to ensure complexities for field operations staff are not exponentially increased. In addition to application-specific security needs, basic physical and cybersecurity best practices should be implemented. These include: • Field cabinet physical access control and monitoring • Port monitoring and blocking • The ability to deploy network equipment security patches in an efficient manner to help ensure networks are maintained at an optimal and secure level

Network Need	Description
Network Power Controllers	Enhance and standardize the ability to control power to individual devices and their associated electronic components remotely via Network Power Controllers (NPC). NPC provides operators with an efficient and cost-effective solution to turn on, turn off, or reset power to devices and can be configured to send alerts when power is lost or otherwise degraded. This is particularly useful for devices and components that may not have remote control capabilities, and where maintenance issues can generally be solved by a simple reset. Where possible, leveraging Power Over Ethernet (POE) services to facilitate such centralized power services should also be evaluated as a mechanism for deployment.

Recommendation: The ITS network must be upgraded to meet the communication capacity needs and characteristics of applied devices to support the wide range of CAV and ITS applications proposed in TSMO, connected corridor, and CATS projects.

3.2 Secondary Stakeholder Network Needs

This section identifies known ITS and statewide utility needs of Secondary Stakeholders as they pertain to the MDOT Enterprise Network. A summary of the Secondary Stakeholder network needs is provided below:

- Establish redundant paths in areas with single points of failure to enhance resiliency.
- Identify strategic peering points with other ITS asset owner operator facilities in close proximity to current communication assets.
- There are three cables from the Level 3 RSA that run through Maryland that could be used as the backbone to distribute broadband service to address rural broadband needs.

3.2.1 Backbone Gaps

Review of MDOT SHA access to the MDOT Enterprise Network indicated risk for single point failures across the network. In particular, single points of failure have been identified in the western, eastern shore, and southern regions of the state.

Recommendation: Establish redundant paths in areas with single points of failure to enhance the resiliency of the MDOT Enterprise Network to reduce the risk of losing critical communications.

3.2.2 Peering Points

Opportunities may exist for resource sharing in other counties, municipalities, or with private entities.

Recommendation: Identify strategic peering points with other ITS asset owner operator facilities in close proximity to current communication assets to begin exploring opportunities for resource sharing.

3.2.3 Rural Broadband

The Rural Broadband Task Force was created to identify areas in Maryland that currently have limited or no availability to broadband services. The Rural Maryland Council tasked the Eastern Shore Regional GIS Coop with mapping broadband service provider coverage. Statewide mapping was conducted to identify census blocks that are classified as un-served or underserved from a broadband perspective. A census block is considered un-served or underserved if only one broadband service provider offers wireline broadband or if the providers do not offer greater than 25Mbps upload speed and 3Mbps download speed. **Figure 3-1** presents the broadband availability across the state. Further investigation would need to be conducted for specific service provider partnership opportunities, however the map indicates areas of broadband need and expansion opportunity. As additional distribution layer ITS buildouts are performed within underserved areas, it is recommended that the latest rural broadband mapping data be referenced to identify overbuild opportunities. While existing service providers and private companies in the State are statutorily exempt from partnering or entering RSA, opportunity exists with fiber resources currently under RSA.

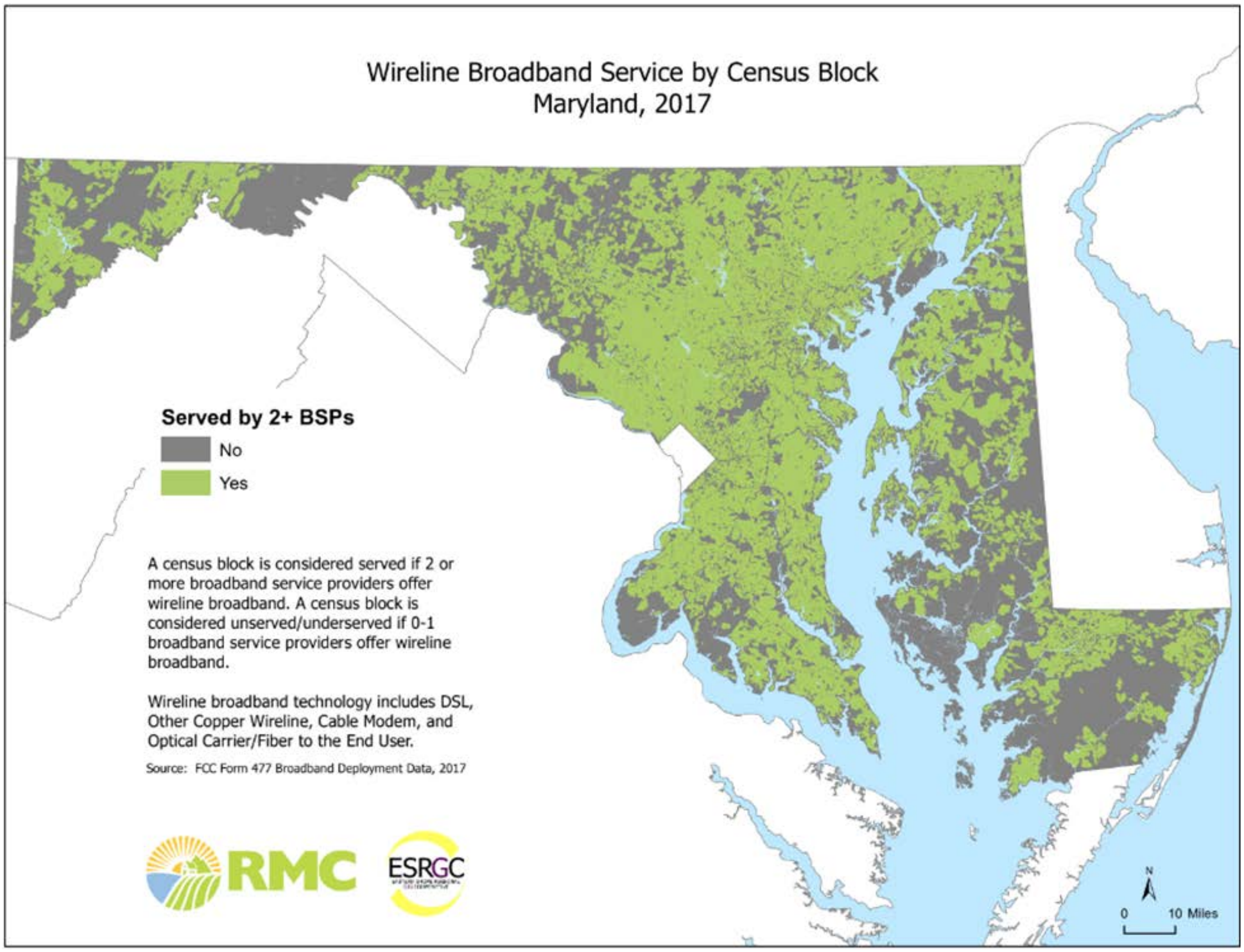


Figure 3-1 Maryland Broadband Coverage

While MDOT SHA has several RSA that are regionally and geographically located across the state, only Level 3 presents opportunity to expand rural broadband. Level 3 backbone is the only fiber RSA that provides MDOT SHA the flexibility to share fiber with commercial companies that would otherwise compete for services with Level 3. The RSA fiber sharing is limited to 12 strands of the 48 within the cable that was allocated for the use of the State.

Each of the backbone cables originate at the Level 3 Gateway building located in McClean, VA. Cable 1 (Richmond) runs through Washington D.C. and southern Maryland along MD-210 and US-301 and ends at the Maryland-Virginia line at the Governor Harry W. Nice Memorial, Senator

Thomas “Mac” Middleton Bridge. Cable 2 runs through Montgomery County along I-495, North on I-270, and West on I-70 and I-68 ending at the Maryland-Pennsylvania state line. Cable 3 runs east through Washington D.C. along US-50 to Annapolis, north on MD-97 to I-695 through Baltimore, and North along I-95 to Delaware.

Recommendation: RSA fiber that runs through Maryland could be used to expand broadband service to address rural broadband needs in underserved areas and enhance the transportation experience across the state with ITS improvements.

4 Roadmap and Action Plan

Through analysis of the existing conditions and needs of the ITS network, the Project Support Team collaborated with primary stakeholders to detail a roadmap and action plan for advancement of the ITS communication network. The roadmap and action plan detailed in this section provides a high-level description of the proposed network, outlines the methodology for expanding and improving MDOT SHA's communications infrastructure, and details specific short-term and mid-term improvement projects in addition to comprehensive design strategies. **Figure 4-1** provides a geographical summary of this ITS Communications Master Plan's recommendations for ITS network expansion.

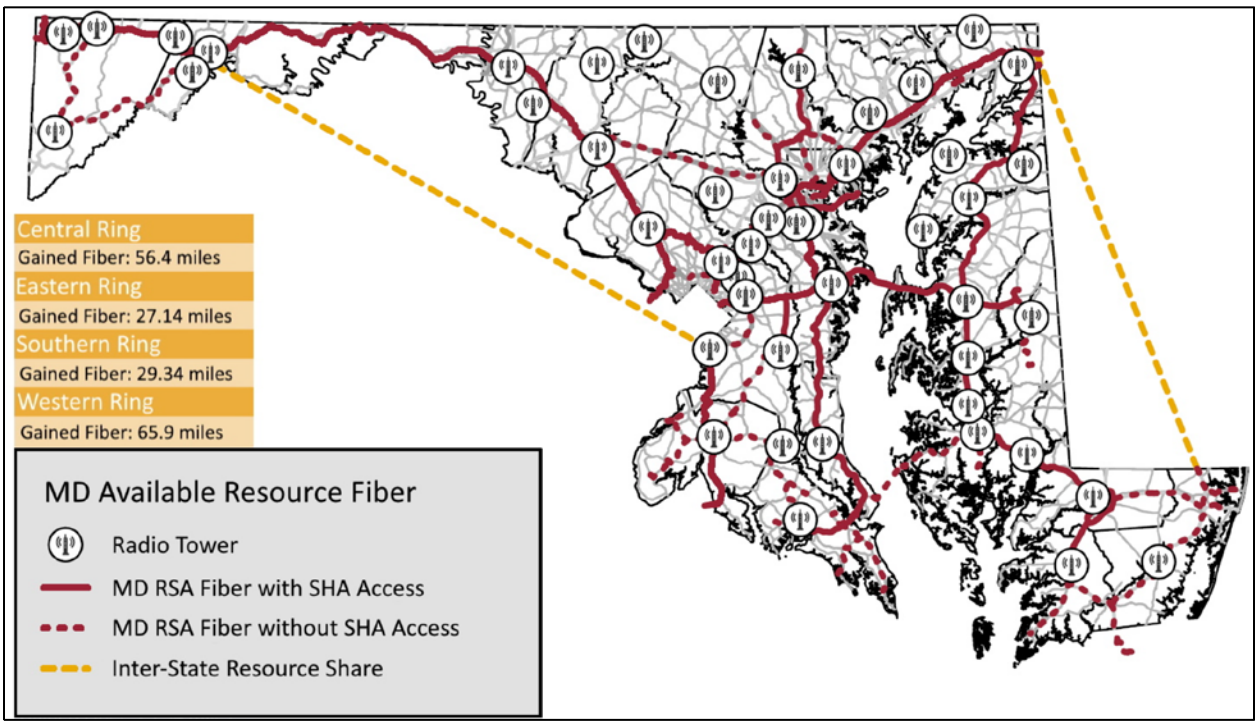


Figure 4-1: Maryland Available Resource Fiber

4.1 Proposed MDOT Enterprise Network Architecture

The analysis of existing conditions combined with the anticipated communication needs, highlighted gaps, and opportunities begin to outline a roadmap for improvement the MDOT SHA ITS communication architecture. This section provides a high-level description of a recommended

ITS Communications Architecture. The proposed architecture follows a traditional layered network design with core, distribution, and access layer elements as shown in **Figure 4-2**.

4.1.1 Backbone Layer

The backbone layer would support high bandwidth transport connections between all MDOT SHA network POPs, enabling easy integration of regionally distributed MDOT SHA traffic management resources. The ease of integration is accomplished through the implementation of a virtualized network overlay where logical network tunnel connections are created between each MDOT SHA node. Within the backbone layer, the MDOT NID provides the traffic filtering, security, data inspection, encapsulation, and routing services required to interconnect the various MDOT SHA end points. This virtualized network overlay enhances the backbone network design by improving scalability while making the network easier to administer, operate, and maintain. Additionally, the virtualized network overlay provides separation of MDOT SHA ITS data from all other MDOT traffic and supports the concept of security enclaves to enforce logical separation of network traffic by the needs of each application. This architectural change would result in the ability to connect disparate OT infrastructure elements into a common WAN with consolidated integration points and allow traffic monitoring and enforcement across subnetwork boundaries.

Security enclaves would improve the security of communications, improve performance, provide automated failover, and enforce the segmentation of network data. The goal of this proposed approach is to ensure the network can provide micro-segmentation at scale to enable mitigation of threats to and from both OT and IT field network assets.

4.1.1.1 Physical Design

Access to the backbone layer would be achieved by connecting to a NID boundary point between the MDOT SHA network and the MDOT Enterprise Network. If the backbone is accessed within an MDOT SHA facility, then this may simply require installation of additional equipment in an existing rack. If the backbone is accessed in the field, then a new communications hut facility would be required.

The physical design of the proposed backbone is supported by MDOT-owned fiber optic cable or via RSA. However, access to RSA fiber in the field will be dependent upon the RSA, which typically limits the number and location of access points. A typical service tie-in configuration is shown in Appendix V.

4.1.1.2 Logical Design

Numerous protocols may be required to support a virtualized network overlay. Best practice network encapsulation protocols that assist in the implementation of a virtualized network overlay include Multi-Protocol Label Switching (MPLS – RFC3031) and Virtual Extensible LAN (VX-LAN – RFC7348).

MPLS was originally designed to provide tunneling of data technologies across a common IP backbone. Virtual Extensible LAN (VX-LAN) is a newer IP tunneling protocol that can be used to extend a network overlay across a larger network infrastructure. Additional vendor-specific protocols and solutions may be considered prior to final design.

> **Recommendation**: A network virtualization overlay service support solution will need to scale across the entire infrastructure and be able to be rolled-out as a phased implementation.

Virtualized paths and security enclaves to be defined are based on the following:

- Field ITS traffic between distribution layer boundary point and data center application-specific servers.
- Public carrier (leased line and cellular) traffic between distribution layer boundary point and data center application-specific servers.
- CHART ATMS workstation connections between the SOC and TOCs and data center application-specific servers.
- Systems Administration enclave connecting field network equipment management ports with Network Management System (NMS) tools at the core.
- Possible CAV application connections between external third-parties and internal CAV services; and
- Published transportation data services between internal data center core services and external users provided through a Demilitarized Zone (DMZ).

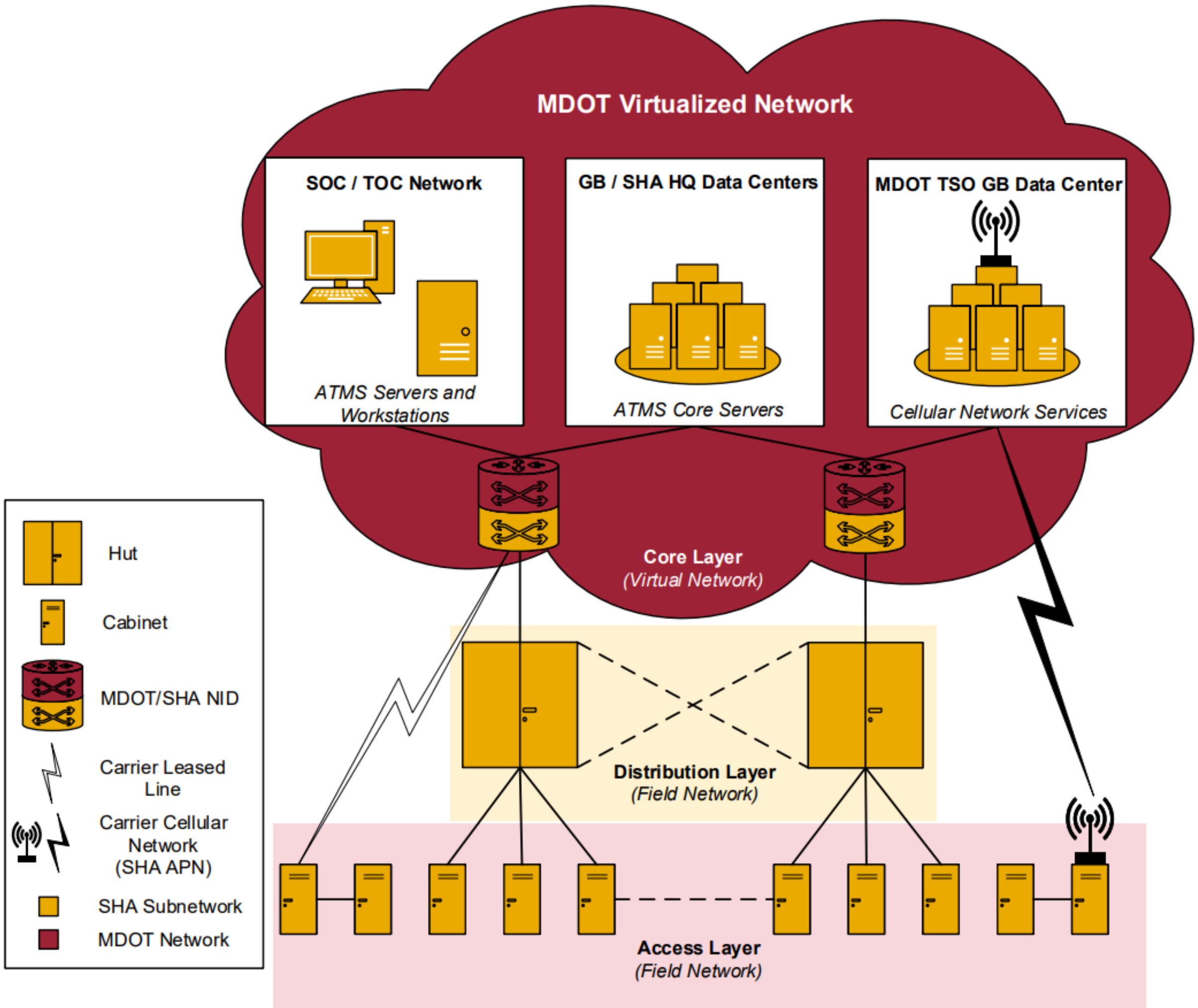


Figure 4-2 Proposed Conceptual Communications Architecture

4.1.2 Distribution Layer

The distribution layer provides aggregation services to interconnect and route multiple access layer network connections onto higher bandwidth links to the central core. The distribution layer can take on different forms and provides varying levels of service based on application need, available physical technology, and the provider.

Existing and new field communication hubs are natural aggregation points or locations where the access layer field network components transition to the distribution layer. Access layer field network components may include field equipment cabinets, communication hut buildings, or radio tower huts. A summary of recommendations is provided below:

- Existing radio towers may be used to aggregate field communications and transition to fiber.
- Fiber optic cables should be used as the network communication medium wherever possible.
- Leased TLS services have the potential of providing greater bandwidth than current T1 lines at a lower cost and could present a viable alternative to MDOT SHA infrastructure-based solutions.
- Continued use of cellular data modems is recommended as a cost-effective solution for many network communication applications.

4.1.2.1 Physical Design

The physical design of the distribution layer may require the support of multiple media and technology solutions. As part of a construction project, MDOT SHA-installed fiber may connect to an existing facility, such as a maintenance facility or radio tower site, where fiber backhaul capability already exists. Field access to existing MDOT or RSA dark fiber may be possible where a simple fiber tie-in may be used to backhaul communications to the nearest MDOT Enterprise POP. In the case of RSA fiber, access will be dependent upon contractual limitations and the number and location of access points. A typical RSA fiber tie-in configuration is shown in Appendix V.

Recommendation: To better support the high network bandwidth needs of the distribution layer, fiber optic cables should be used as the network communication medium wherever possible.

4.1.2.2 Logical Design

The distribution layer terminates and aggregates Layer-2 uplinks from the access layer field cabinets. Additionally, the distribution layer provides Layer-3 routed services across multiple uplinks to the backbone layer and routing services between field VLANs to support peer-to-peer application communications between field cabinets. The distribution layer may also provide additional traffic filtering and shaping across these routed interfaces.

4.1.2.3 Carrier Leased Lines

Carrier leased lines may include any type of fiber-based public carrier network transport services. As Verizon transitions from copper to fiber-based service delivery newer leased line services such as Ethernet TLS are being deployed.

TLS services are still geographically bounded based on defined LATA boundaries; however, they do not have distance-based costing structures associated with the traditional T1 services. TLS services also have the potential of providing greater bandwidth than current T1 lines at a lower cost and could represent a viable alternative to MDOT SHA infrastructure-based solutions. It is possible to establish two (2) redundant service aggregation points within each LATA boundary to support all field network services that leverage these leased services. Additional details about leased opportunities are provided in **Appendix X**.

Leased lines would terminate at a MDOT Enterprise NID boundary point to connect with backend servers via virtualized backbone services.

Recommendation: Establish redundant service aggregation points within each leased service regional boundary.

4.1.2.4 Carrier Cellular Network

More robust multi-carrier field network designs are also possible to eliminate any cellular network carrier reliability concerns. With the transition to 4G-LTE and eventually 5G there will also be additional tiered service offerings that may be tailored toward network needs by supporting both high and low bandwidth services.

The cellular network carrier services would terminate at a MDOT Enterprise Network interface to connect with backend servers using the virtualized backbone service. Aggregation services can be migrated to a direct network integration via a leased service line instead of the current IPSEC over the public Internet approach that is currently leveraged. This would provide more consistent performance for these increasingly critical communication services.

Recommendation: Continued use of cellular data services as a cost-effective solution for non-critical network communication applications.

4.1.3 Access Layer

The access layer provides "last mile" connectivity of ITS field devices, equipment, and cabinets to each other and into the distribution and backbone layer. The access layer not only includes the interconnection of devices within a field cabinet, but also the field network which interconnects the cabinets to a distribution node point. A summary of recommendations is provided below:

- Conduit and fiber should be installed in small sections as construction projects allow.
- Various VLAN-based security enclaves should be established for each network application.

4.1.3.1 Physical Design

There are numerous field network media and technology options to support an all-IP network. The access layer represents the largest segment of the overall ITS communications layer, and as a result, can be expected to support the greatest diversity in physical design, media and technology use. To better support the increasing network bandwidth needs of the access layer, fiber optic cables should be considered as the network communication medium wherever possible. Conduit and fiber should be installed in small sections as construction projects allow. These isolated sections can then be interconnected via various other media. These isolated fiber islands may then expand and be interconnected as future construction opportunities arise.

The access layer field network designs should support single fail-over capability where each field cabinet has at least two independent communication paths to the distribution layer. Eliminating single point failures also means fewer emergency maintenance repairs as operations continue uninterrupted. Redundant paths can take many forms and may also include a mix of different physical media as shown in **Appendix IV**.

4.1.3.2 Logical Design

The access layer terminates all device communications within the cabinet and then interconnects cabinets to the distribution aggregation point. Device-specific traffic is separated into Virtual

LANs (VLAN). These VLANs enforce traffic separation for both security and performance reasons and allow all field applications to utilize a common network infrastructure. Traffic prioritization may be implemented at this layer where limited bandwidth physical media is being used or in cases where uplink capacity can be overwhelmed by downstream access capacity. Intercommunication between these VLAN security enclaves, if needed, is typically enforced at the distribution layers in traditional deployment methodologies; however, newer technologies are being introduced that permit higher end services to be available on the edge equipment. Different security enclaves may include:

- Traffic signal control systems and related devices such as smart vehicle and pedestrian detection equipment.
- CCTV – these components are typically assigned a separate VLAN enclave due to bandwidth and latency performance requirements.
- ITS – lower speed traditional traffic and environmental monitoring and traveler information equipment.
- ATM – due to the active control nature of this equipment a separate enclave to enforce different security protocols may be desired.
- CAV – Security and Credentialing Management System (SCMS) authentication and authorization support of communication between vehicle and infrastructure, related roadside equipment management, and CAV application support.
- Infrastructure Management – support field network equipment configuration, monitoring, troubleshooting and patching. Automated field provisioning could also be supported across this VLAN. This may also include all other cabinet-level systems support such as Uninterruptable Power Supply (UPS) management and reporting.

4.2 Master Plan Considerations

The following subsections describe the considerations applied to the improvement projects of this Master Plan.

4.2.1 Priorities

The below are key priorities, further detailed in following subsections, for consideration when building out the MDOT SHA ITS communications network and define the types of projects recommended in this roadmap and action plan:

- Economic Development
- Connectivity
- Consolidation
- Resiliency
- Legacy Technology Replacement

4.2.1.1 Economic Development

Rural economic development opportunities may drive priorities depending upon project and funding sources, location, and leveraging existing resources.

4.2.1.2 Connectivity

Connectivity projects involve new construction with the intention of providing network access to new device deployments or an opportunity to consolidate infrastructure to existing devices. These projects are typically driven by transportation capital improvement projects. They may include incrementally expanding new capabilities to support near-term functional needs, while planning for future upgrades towards a more permanent solution. For example, a connectivity project may include using private wireless or cellular to support initial ITS device deployment while developing of a plan to install fiber cable during future anticipated roadway construction projects.

4.2.1.3 Consolidation

Consolidation projects provide an opportunity to combine existing services onto a new service for cost-saving or service improvement (i.e. greater bandwidth and reliability) reasons. Examples include replacing T1 lines with private wireless or fiber connections.

4.2.1.4 Resiliency

Resiliency projects involve network enhancements to provide for greater redundancy and or resiliency. These projects remove single-point failures from the network. The value added from such an enhancement typically increases from the field access layer toward the backbone.

4.2.1.5 Legacy Technology Replacement

Legacy technology replacement projects involve removal and upgrade of existing devices or technology typically due to end-of-life issues or due to functional and performance improvement needs. Examples of these projects include replacing POTS lines with cellular data modems; replacing TWP and Ethernet Extender field access layer technology with more intelligent and capable TWP and DSL devices; upgrading smart corridors with fiber and Ethernet; and replacing T1 lines with newer Verizon fiber-based services such as TLS.

4.2.2 Selecting Communication Media

This section provides a detailed comparison of communication media for MDOT SHA's consideration when planning network improvements and expansion. Communication media selection should be applied uniformly to all communications projects to standardize expansion of MDOT SHA and MDOT's communications infrastructure and considers:

- Fiber Optic Cable
- Twisted Wire Pair Cable
- Private Wireless Data Radio
- Cellular Data Radio
- Carrier Leased Line

4.2.2.1 Fiber Optic Cable

Single-mode fiber optic cable is the preferred communications medium over which data communications networks are built. Fiber optic cable should be considered under the following conditions:

- As part of other Highway construction work where the cost of installing required supporting conduit infrastructure may be less.
- Where the density of supported field devices makes installation of cable a reasonably cost-effective solution.
- Where reliability, bandwidth, and distance needs exceed other technologies. Fiber optic cable can transport large amounts of data securely over long distances with high reliability.
- Along strategic corridors where resource sharing opportunities may exist.

Fiber optic transceivers are responsible for converting the electrical network signals to light for transport across the cable. The cost and performance capabilities of these components continue to improve. Electronics can continue to be upgraded to support ever-increasing capabilities across the same fiber optic cable. Wave Division Multiplexing (WDM) is another complimentary technology which allows more light waves to be placed on the same fiber effectively multiplying capacity by the number of supported light waves. WDM may be desired where multiple independent networks need to be supported across a limited number of fiber strands, such as with RSA fiber or where distances between terminating end points exceed 80km, otherwise use of standard transceivers is recommended. For access and distribution layer transport transceivers, bandwidth speeds between 100 Mbps to 1 Gbps is typical. For backbone network transport 1 to 10 Gbps is typical. 40 Gbps to 100 Gbps fiber is possible but currently cost prohibitive and unlikely to be necessary for MDOT SHA and MDOT applications in the near future. Underground installation using conduit or vault infrastructure is recommended but can be expensive especially in urban environments. Aerial self-supporting cable is another alternative, but pole attachment agreements can be time consuming and expensive to obtain. MDOT SHA should construct fiber optic infrastructure whenever feasible even if this results in an “island” of fiber optic cable. These islands may be interconnected on either end via other technologies in the near-term, with the fiber optic coverage expanding with future project opportunities.

4.2.2.2 Twisted Wire Pair Cable

Twisted wire pair cable may be the preferred solution for traffic signal interconnect along minor arterials as part of a maintenance replacement program of existing TWP and for locations that are not identified for near- or mid-term upgrade to smart corridors. TWP and DSL technology is typically capable of about 20 Mbps and transmission distances of up to several miles depending upon the type of copper cable. These higher bandwidths are possible through “bonding” where multiple pairs of copper TWP cable are electrically bonded together by the DSL electronics to provide greater throughput capability. Since MDOT SHA typically uses 12-pair cable this is a possible solution. TWP along with the use of DSL provides an easy means to extend IP communications to signal cabinets that do not need the broadband capabilities of fiber. Other considerations when replacing TWP with fiber include the type and condition of existing conduit infrastructure and maintenance capabilities. The conduit size, fill, and radius may limit the size and type of fiber that may be used. At a minimum, fiber splice vaults may need to be installed at each cabinet to support the cabinet drop cable. Fiber maintenance also requires specialized equipment and training, while TWP cable maintenance is typically well understood by maintenance technicians. Similar to fiber optic cable, underground installation of TWP is preferred where possible.

4.2.2.3 Private Wireless Data Radio

Public safety band 4.9Ghz radio technology may be a suitable technology where cable is not practical or feasible, or where construction timelines of other solutions is not acceptable. This is a licensed band that supports point-to-multipoint (i.e. master radio to many remote radios) or point-to-point topologies and can be used to interconnect many isolated field cabinets or possibly “islands” of cable interconnected field cabinets. Radio link surveying and FCC licensing through an MDOT licensing manager or frequency coordinator would be needed. These radios are capable of 260 Mbps and have up to 40 miles range. The many existing MDOT SHA radio towers as well as possible county resource share towers could be leveraged to serve as master radio locations. These technologies often have limitations in terms of latency and packet per second transmission capacities. As such, care should be taken in considering this technology for deployment to ensure the proposed applications can be properly supported in aggregate.

4.2.2.4 Cellular Data Radio

Continued use of 4G cellular data radio is a viable solution where other technologies are not feasible and where expediency of connectivity is paramount. Cellular data radio may also be used as a near-term solution until a more permanent solution is engineered and constructed. The criticality of the communications must be considered when deploying these devices as cellular may experience regional outages and brown-out events. Using data radios with dual-redundant carrier support or using multiple radios providing uplink distribution layer connectivity for a local access layer field network can provide additional service redundancy but may not systemically address brown-out conditions invoked by regional increases in end client loads as often as these events can affect multiple carriers concurrently.

Greater network service differentiation is now possible with machine-to-machine Cat-M type data modems. MDOT SHA currently uses Cat-4 type modems with unlimited data network plans. Cat-M modem data plans are designed for very low bandwidth infrequent communication at a lower cost. For applications and use cases where very simple field device monitoring and control is required this could be a very cost-effective solution.

Future 5G standard radios are expected to provide even greater capabilities. Broadband capabilities of 5G are expected to support upwards of 2Gbps although at a reduced distance of about 0.7miles depending on "line of site" obstruction. Abstraction technologies such as Software Defined Networking in a WAN (SD-WAN) can be leveraged to lower the deployment complexities and introduce conditional traffic steering to increase the overall environments and requirement conditions where cellular-based services can be deployed.

4.2.2.5 Carrier Leased Line

Public carrier leased-line solutions may still be a viable option where other solutions are not practical, feasible, or as cost-effective. These solutions are not as quick to deploy as cellular data modems but are typically quicker than built infrastructure and may also be used to provide redundancy to otherwise non-redundant network segments. If used, then it should be considered as an uplink distribution layer connection terminating other possible local access layer field network connections. Due to typically heavier associated recurring monthly service costs their use should be carefully evaluated compared to other options.

Leased lines may include any type of newer fiber-based public carrier network transport services such as TLS. These are all packet-based services which are easily integrated into the new Ethernet-IP based network architecture. The logical services can be point-to-point or point-to-multipoint in nature. Logical services can also be multiplexed onto single physical UNI services, which permit a single local circuit to be logically connected to redundant aggregation circuits permitting a level of redundancy that is not currently available with the current T1-based services. Layer 3-based leased service such as Verizon Private IP should also be considered for field network services as these services are not LATA-bounded and have the potential for reducing the need for multiple aggregation POPs within the MDOT SHA backbone network. These services are also more readily integrated with cellular APN services provided though the same service providers and may provide an attractive solution depending on pricing structures. Depending on service provider, Layer-3 services can also support multicasting services natively, ensuring replication occurs within the carrier network potentially reducing the bandwidth requirements within the MDOT SHA regional access networks and offer direct site communications which may be of benefit as more machine-to-machine and distributed processing applications are integrated into the environment.

4.2.3 Network Management

The approach to managing the network should be carefully considered and reflected in the detailed design and equipment specification and selection. The ability to proactively monitor, identify and isolate issues, and provide a timely response in the invocation of corrective measures becomes more critical as the network grows. The use of centralized configuration management software tools can help to reduce complexities of the actual device level configurations and are used to aid in equipment provisioning and operations support activities.

Recommendation: As technology continues to evolve, strategically choose the types of network technologies deployed, and specify clear management capabilities for network setup, configuration, monitoring and troubleshooting activities.

A general-purpose Network Management System (NMS) software tool views the entire network and monitors general equipment health, network traffic flows, network faults, and overall conditions. This is currently performed at the MDOT level for the entire MDOT Enterprise Network and TBU subnetworks.

Vendor-specific Element Management System (EMS) software tools are designed to remotely monitor and manage specific elements of the communications network. EMS tools have the following capabilities:

- Network Discovery – automatically discovers and maps network elements to show interconnection and relationship.
- Configuration Management – the EMS is designed to access vendor-unique features of the equipment and to maintain individual equipment configurations. This may also include "zero-touch" provisioning capabilities where, with minimal equipment identification, the configuration may be automatically downloaded once a new device is detected.
- Fault Identification and Reporting – typically at a more detailed level than the NMS.
- Performance Monitoring – develop a performance baseline of normal operations so that optimization may be a continual process; and that alarm conditions, and thresholds may be established so that anomalies may be detected earlier, all leading to more proactive network management.

The EMS may communicate summary information up to the NMS. Standardizing network equipment vendors will limit the number of required EMS tools. The EMS is a one-time purchase that should be included with the initial project and then integrated into the overall MDOT SHA fault operational workflow systems to ensure detected event responses are streamlined for remediation. Often toolsets can overlap in function and it is important that SHA work with MDOT to map out the formalized toolset to ensure that required functionality is clearly mapped between toolsets in an overall operations plan to avoid the work associated with service duplication and the resulting disparate system of records for specific pieces of information that can occur.

4.2.4 Construction Considerations

The below policies, detailed in the following subsections, should be enacted to ensure future projects enable expansion of the ITS network:

- Dig Once Policy
- Refine and Apply Better RSA
- Intergovernmental Partnering

4.2.4.1 Dig Once Policy

A Dig Once Policy is used by many states to support installation practices for utility facilities and private lines on roadway projects to minimize excavation and reduce installation costs. There are also a few states that have required the installation of conduit as part of any road construction project. Delaware, Arizona, Utah, Virginia, and Minnesota all have resource sharing policies that promote development and deployment of common telecommunications infrastructure to expedite network expansion. Broadband infrastructure deployment has been accelerated by the USDOT's Executive Order for Broadband Deployment.

Recommendation: develop an infrastructure strategic initiative to install conduit infrastructure and associated fiber optic cabling into any ROW construction projects. Recommend this policy to other responsible entities.

This will ensure that opportunities to couple the fiber infrastructure to already initiated construction projects are leveraged to the greatest extent.

- Strategically construct conduit and fiber to increase redundant connections of various District and Regional aggregation points.

- Target roadway corridors with a high number of field assets already present and always include conduit and fiber infrastructure with all new field asset deployments.
- Aid in the quick adoption of future technologies through lowering communications cost requirements as a high cost of entry.

4.2.4.2 Refine Resource Sharing Agreements

Prior to installing new technology or ITS infrastructure, MDOT and MDOT SHA should explore opportunities through RSA to achieve its objectives across the State. By leasing existing fiber infrastructure from a third party, MDOT SHA can keep up with technology and quickly expand network reach without the burden of new construction. These agreements should be refined based on the lessons learned from previous RSAs.

For roadway sections where RSA fiber assets are already present, additional fiber construction may still be required. ITS field networks typically require many more strategic splice points along the road and are best served using a separate fiber and conduit system. Typical RSA fiber is designed with limited splice points along the path and is therefore typically only used for long-haul communications. Where possible the SHA should also consider the physical nature of the proposed RSA construction and if feasible insist that state access splice-cases be engineered into the solution where all provided state fiber assets are presented and a zero-cost agreement to access these dedicated points is agree upon. Typically access to the more general backbone RSA provider cases can be more limited and are associated with a high cost of entry for each required event adding significant cost and delays incurred for projects requiring fiber asset changes and splicing.

As shown in **Figure 4-3**, out of Maryland's 24 counties, seven (7) counties in central Maryland have invested in building high capacity fiber, which indicates opportunity to MDOT SHA for access to fiber assets categorized as "backbone" infrastructure. Each of the counties has direct ownership of the fiber assets and independently have the ability to lease, trade, or share excess capacity. Many counties receive access to fiber through their Cable TV Franchise Agreements; however, the Franchise fiber is limited in strands and availability and is strictly limited in the Franchise Agreements for "county use" only.

Additionally, most of the franchise agreements that allow the counties use of fiber do not have specific Service Level Agreements (SLAs) written with regards to repair and response time. For these reasons, franchise fiber should not be considered usable from an ITS perspective.

The other three (3) clusters of counties have not installed what would be considered "backbone" fiber. While these counties have installed their own fiber, it is largely "campus" style fiber and not usable for ITS purposes. However, there are counties that received fiber due to Cable TV Franchise agreements.

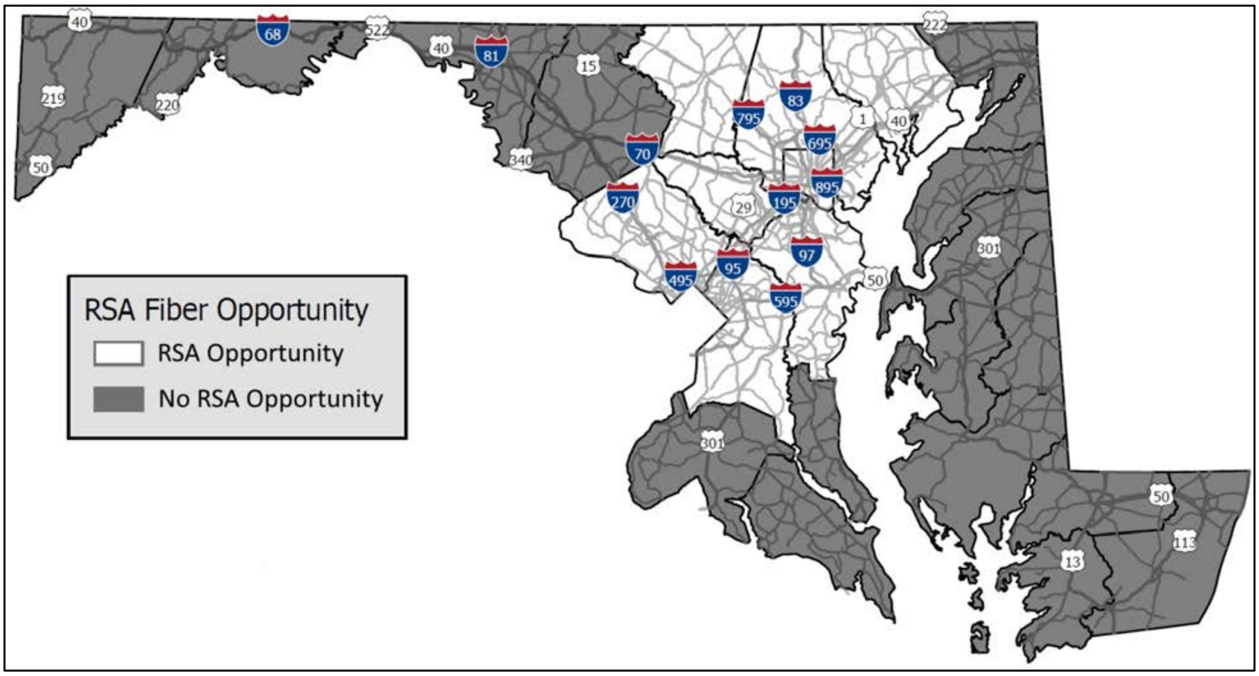


Figure 4-3 County Fiber RSA Potential

4.2.4.3 Intergovernmental Partnering

MDOT may also utilize intergovernmental partnerships with Pennsylvania, Virginia, Washington D.C., Delaware, and West Virginia to improve network reach and redundancy. Virginia in particular, has fiber-rich infrastructure. Opportunities to establish RSA could enable MDOT and MDOT SHA to provide additional service to the western and southern regions of the State.

4.2.5 Funding

4.2.5.1 Federal Funds & ITS Architecture Conformance

The United States Department of Transportation (USDOT) Executive Order for Broadband Deployment is an order to encourage the acceleration of broadband infrastructure deployment.

It also states that Federal-Aid Highway Program (FAHP) funding may be used for broadband deployment activities in the highway ROW if the technology is used to meet a transportation-related purpose, such as connecting traffic control devices to an operations facility. Title 23, United States Code defines that the costs associated with construction and engineering of Federal-aid eligible highway projects can include "…improvements that directly facilitate and control traffic flow…channelization of traffic, traffic control systems…" (23 U.S.C. § 101 (a)(4)(g)).

Overbuilding, to provide excess capacity in conduit or fiber is also permissible provided it meets an identified transportation need. Overbuild capacity that is set aside for other purposes may not be reimbursed; however, there may still be efficiencies gained if using a Dig Once policy.

To qualify for federal funding per the Federal Highway Administration (FHWA) Final Rule (23 CFR 940), the project must comply with the Maryland Statewide ITS architecture. The statewide ITS architecture covers all the needs and services of the various transportation owner-operators and other stakeholders throughout the state. The architecture is comprised of service packages that are used to capture the various basic building blocks, relationships, data flows and interconnects needed to support the statewide transportation vision. The Master Plan provides the underlying enabling data exchange capability of the various subsystems to support the ITS architecture.

4.2.5.2 Public Private Partnerships

In addition to FAHP funding, Public-Private Partnerships (P3) are a potential option to fund future network build outs. Although additional studies, market research, and procurement processes would be required to pursue this option, private communications companies may find P3 appealing considering the potential for viable and untapped markets in underserved areas and the potential to construct other commercial telecommunications infrastructure within MDOT SHA ROW to expand their own networks. Benefits of P3 to MDOT SHA would include the transfer of risk to a private entity to fund and build out additional network infrastructure; the potential to collect revenue shares in exchange for ROW to offset Operations and Maintenance (O&M) costs and fund future projects; and the potential for a long-term partnership that could expedite network expansion.

4.2.5.3 Dig Once Policy

Another funding option is to leverage overbuilding and Dig Once policies to construct extra conduit and fiber beyond the immediate and projected future needs of MD SHA for the purposes of pursuing commercialization agreements. With this extra infrastructure in place, MDOT SHA could pursue contract(s) with private entities to commercialize the infrastructure and potentially build commercial telecommunications infrastructure within MDOT SHA's ROW. This option could benefit MDOT SHA in the form of commercial revenue splits to offset O&M costs and fund future projects, as well as the potential to utilize the commercialization entity to fund and build out mutually strategic areas of the network while still retaining the contractual freedom to expand the network via other means. Although quite similar to a true P3, this option may appeal to commercialization entities with a lower risk appetite because the initial construction costs would be borne by MDOT SHA. Additionally, this option would allow greater in-house control of network design aspects and project prioritization. This approach also has the added benefit of attracting potential service providers to underserved regions of the state geography through the offer of a lower cost of entry and initial investment.

4.3 Near-Term Phased Implementation Roadmap

This section provides a listing of near-term (1 to 5 years) project descriptions and includes a mix of network specific enhancements as well as ITS project deployments. Any dependencies or relative priorities between these projects, if any, are identified in the descriptions. Component cost estimates required to address the recommendations and requirements throughout this section are provided in **Appendix IX**.

4.3.1 Network Core Upgrade and Virtualization

Upgrade of the network core and virtualization of the MDOT Enterprise Network System are co-dependent and should be closely coordinated. These activities should be completed in the near term to support the various project-based communication upgrades. Virtualization of the MDOT Enterprise network is a generic term that references the augmentation of the current network hardware to support a ubiquitous capability of supporting multiple simultaneous virtual network overlays over the same common WAN connections and infrastructure. While this can be accomplished in many ways the intent is to develop a core network solution that provides the flexibility of defining new virtual network services quickly and easily that can be delivered to any point within the network infrastructure. The primary goal of this virtualization capability is to provide the ability for the network to support end to end communication between end points associated within the same security zone or enclave to communicate without the expressed need to be routed through a full security boundary. For example, today any communication between a field device in one geographic region to another geographic region must traverse 2 full security boundaries since the only available transport network is the MDOT Enterprise main enclave. While this is sufficient for the current command and control-based application set, this will prove administratively burdensome as more edge to edge coordinated communications based applications are delivered.

4.3.1.1 Core Network Virtualization

Virtualization of the MDOT Enterprise Network System should begin in the near term to support security enclaves and the various field to data center core connections. Next steps for the backbone Network Virtualization design and deployment include the following:

1. Explore and refine the proposed concept with MDOT to determine if multitenancy support can be added to the existing MDOT network service such that distinct routed VPN services can be supported across the infrastructure with add and drop ability at all network POPs, roles and responsibilities, and potential cost sharing.
2. Identify all requirements including expected numbers and types of potential security enclaves, growth, and performance. Care should be taken to devise a common control strategy to avoid network virtualization sprawl so that a common criteria set can be used to determine when a new application warrants a new custom virtual environment or it can be added to an existing defined one.
3. Investigate potential technical solutions to create the virtualized network overlay after the concept and requirements have been further defined. This will require market research and consultation with prospective vendors.
4. Perform an audit of the network infrastructure to be impacted and to determine which MDOT SHA assets and applications are currently comingled with other potential enclaves.

5. Develop a plan including priorities by region location and data type to organize assets into the appropriate enclaves to create logical isolation.
6. Develop a phased implementation plan by which the virtualized overlay network may be deployed. This sequencing may need to consider other backbone upgrades and integration of field networks.

The total estimated cost for the backbone Network Virtualization is **$838K** and includes all planning, design, construction, and commissioning costs. Cost details are provided in **Appendix XIX**. This may be deployed in phases depending upon further investigation and design efforts in coordination with MDOT.

4.3.2 MDOT Enterprise Network Backbone Improvements

The MDOT Enterprise Network can be broken down into 4 geographic regions (Eastern, Central, Southern, Western). Currently, the only region that has physical redundancies built into the network is the Central Region. Outlined in the following projects are backbone improvements that should be performed in the eastern, southern, and western regions to provide physical redundancies in the form of "rings" in each region. The overall Proposed Backbone Architecture is shown in **Appendix III**. The backbone improvements are summarized in **Figure 4-4**.

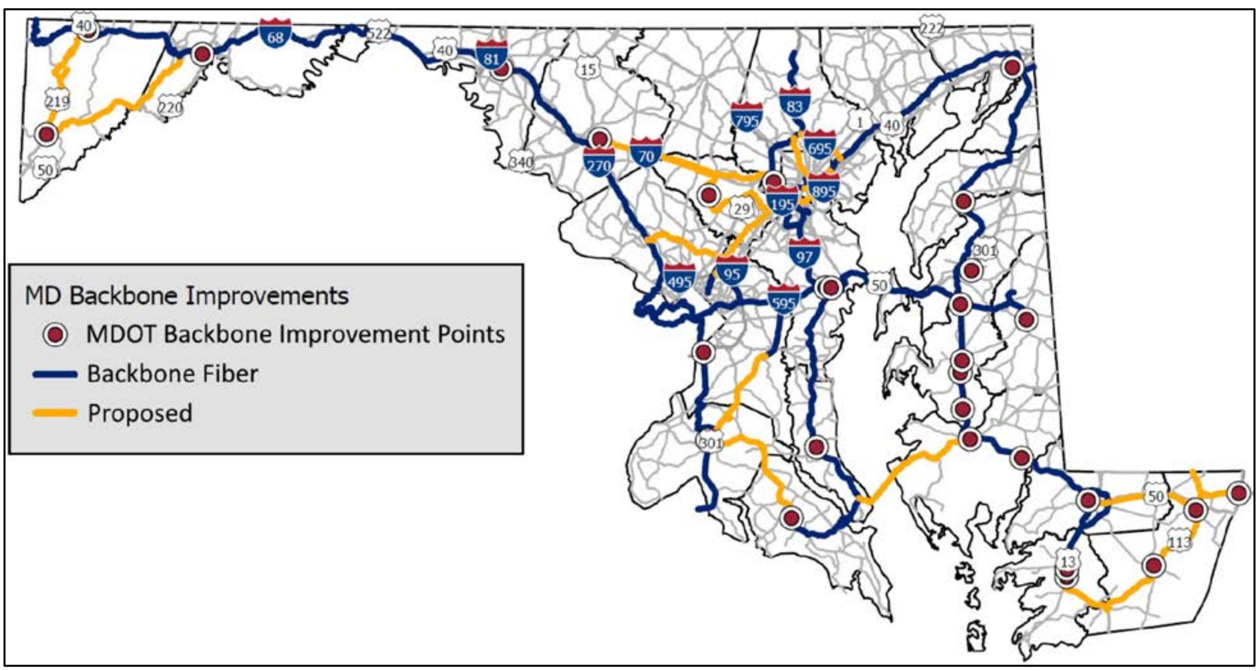


Figure 4-4 Summary of MDOT Backbone Improvements

In each region, existing fiber can be utilized to create the rings to provide these physical improvements to the MDOT Enterprise Network. The result is a minimal financial investment to provide significant improvements in backbone resiliency and increased reliability to transmit ITS data. Additionally, this will extend the reach of MDOT's network footprint to increase regional connectivity of field devices, bandwidth, and physical redundancies and reduce or eliminate leased costs. **Figure 4-5** provides a summary of the MDOT Enterprise Network Backbone improvements that are recommended in these projects.

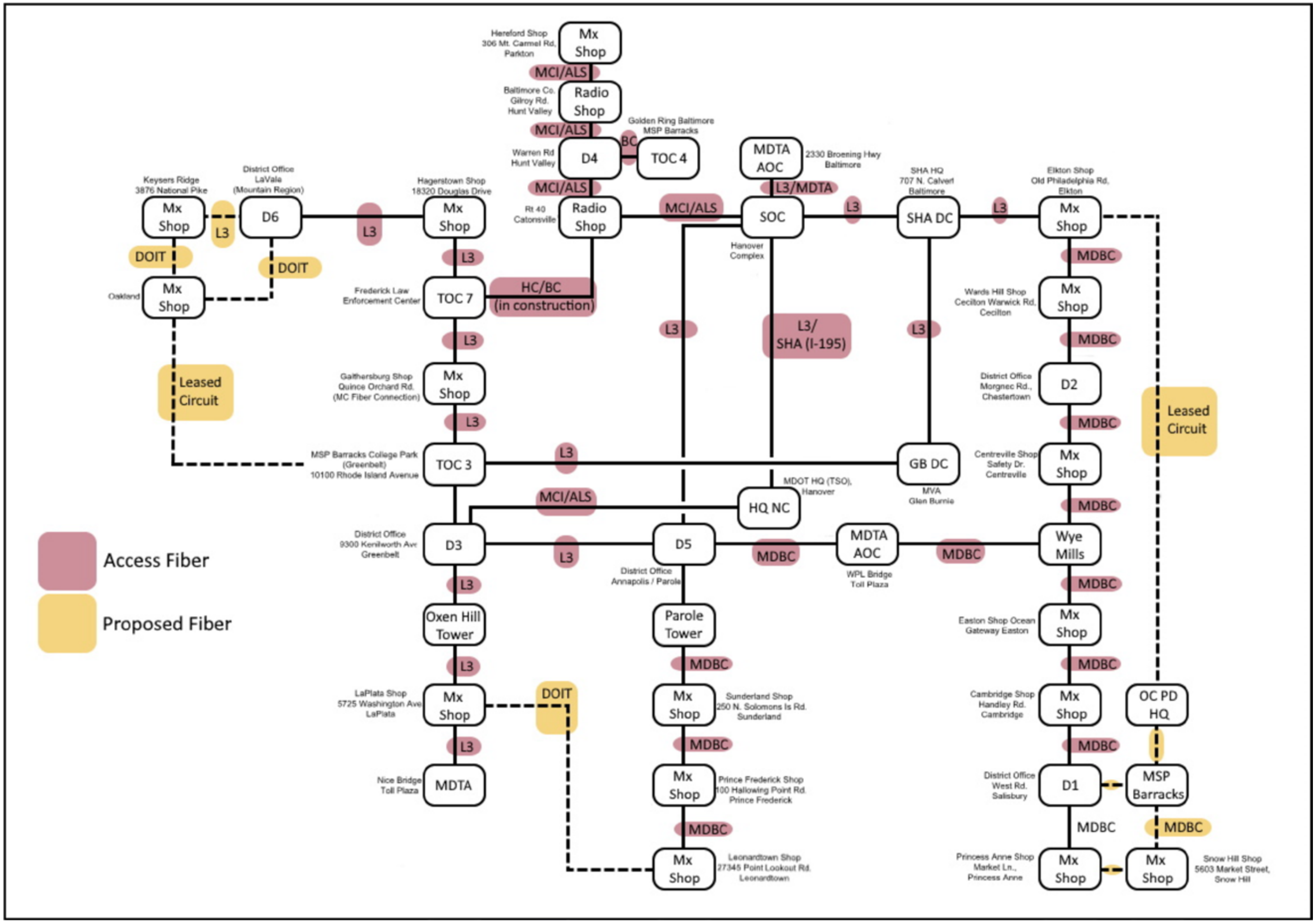


Figure 4-5: MDOT SHA Backbone Summary

4.3.2.1 Western Backbone

The MDOT Enterprise Network currently has presence in the Western Region through the Level 3 RSA fiber. This physical pathway starts at the Frederick Law Enforcement Center (FRED LEC) continuing west along I-70 through Hagerstown, Hancock, LaVale, and ending at Keysers Ridge. The entire Western Region is susceptible to interrupted services in the event of fiber damage anywhere along the I-70/I-68 corridor as it is single-threaded from FRED LEC to points west. **Figure 4-6** provides a high-level graphical representation of the Western Backbone.

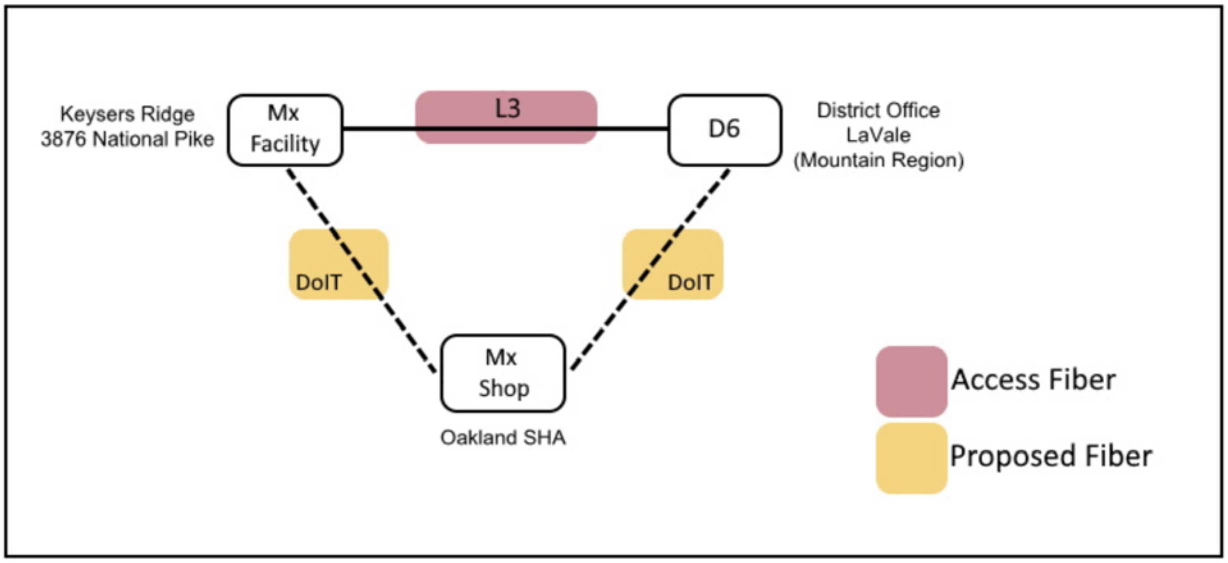


Figure 4-6: Western Backbone Diagram

The proposed improvement creates a physical ring in the western portion of this region and significantly improves the footprint to reach field devices and expand enterprise network presence beyond the current limits of I-70 and I-68 median. The ring originates at the LaVale SHA District Shop extends west on I-68 turning south on Rt 36 to Western Port. From Western Port the run heads south west on MD-135 to Oakland SHA. The ring then heads north along MD-219 from Oakland through McHenry, Accident, back up to I-68 and ends at Keysers Ridge SHA. DoIT backbone fiber exists along the entire route as do the lateral fiber cables into each facility. Engineering, splicing, and testing would be required to make this improvement. No underground fiber construction would be required.

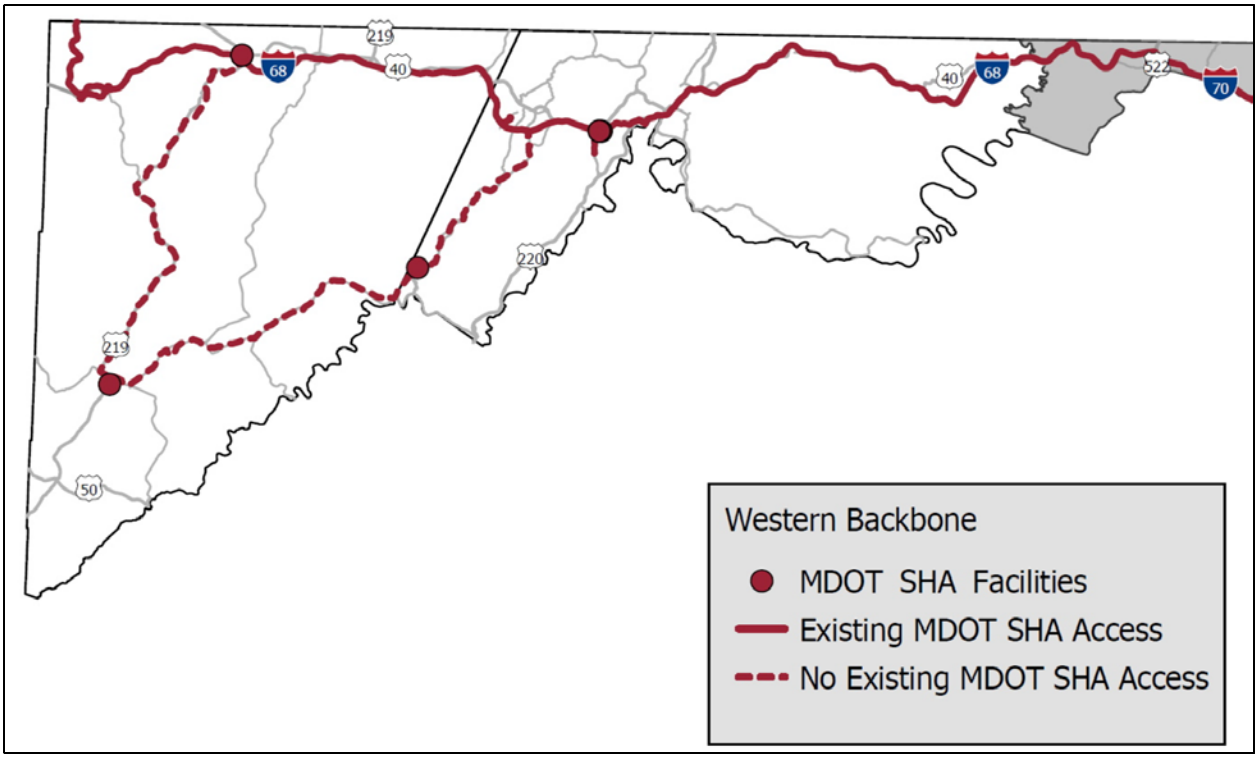


Figure 4-7: Western Backbone Map

An additional lease line service is proposed between the Oakland facility and TOC 3 to eliminate the remaining single-tread section between LaVale and FRED LEC. Western Backbone existing fiber and potential fiber opportunities can be seen in **Figure 4-7**.

Next steps for the Western District Backbone build include:

1. Explore and refine the proposed concept with MDOT including RSA access, possible cost sharing.
2. Explore possible tie-in with the new Governor Harry W. Nice Memorial and Senator Thomas “Mac” Middleton Bridge and possible RSA with Virginia to provide redundancy to the remaining single thread section between LaPlata and the bridge.
3. Identify and investigate strategic peering points (i.e. radio towers and hut facilities) where MDOT SHA/MDOT fiber infrastructure would be located and could offer local providers a “meet up” location for long haul (i.e. rural broadband) opportunities.
4. Identify and investigate MDOT SHA radio tower facilities that may serve as master radio locations to wirelessly connect field devices to the backbone.
5. Identify possible CCTV T1 leased circuit termination cost savings.

6. Perform field inspection and audit of the required fiber cable and network infrastructure.
7. Explore leased circuit options and termination points with available service providers and develop initial costs.
8. Verify integration to core and develop a phased implementation plan.

The total estimated cost for the backbone build is **$222K** and includes all planning, design, construction and commissioning costs. The proposed architecture is shown in context of the overall backbone in **Appendix III** and in detail in **Appendix VII**. Cost details are provided in **Appendix IX**.

4.3.2.2 Southern Backbone

The MDOT Enterprise Network currently has presence in the Southern Region through the Level 3 RSA fiber that extends out of DC along MD-210 and continues south on US-301 to the Governor Harry W. Nice Memorial/Senator Thomas "Mac" Middleton Bridge and Virginia state line. MDOT Enterprise Network presence in this area is limited along MD-210 and US-301. The physical pathway that provides network services to the southern region is single threaded and does not currently have physical redundancies south of MDOT SHA District 3 Greenbelt. The lack of redundancy leaves the backbone susceptible to a fiber damage/cut and loss of connectivity to the region. **Figure 4-8** provides a high-level graphical representation of the Southern Backbone.

The proposed improvement will create a physical ring of the entire Southern Region resulting in improved resiliency and eliminating the single point of failure, while expanding the footprint to reach field devices through MDOT Enterprise Network connectivity. The Southern Region ring will originate in Annapolis at the MDOT SHA D5 office head west to MDOT SHA Greenbelt D3 office then turn south to MDOT SHA LaPlata Shop. The ring will continue east from LaPlata to Shop Leonardtown, then turn north to Prince Frederick continuing to Annapolis MDOT SHA D5 office. DoIT backbone fiber exists along the entire route as do lateral fibers into each facility. Southern Backbone existing fiber and potential fiber opportunities can be seen in **Figure 4-9**. Engineering, splicing, and testing would be required to make this improvement. No underground fiber construction would be required.

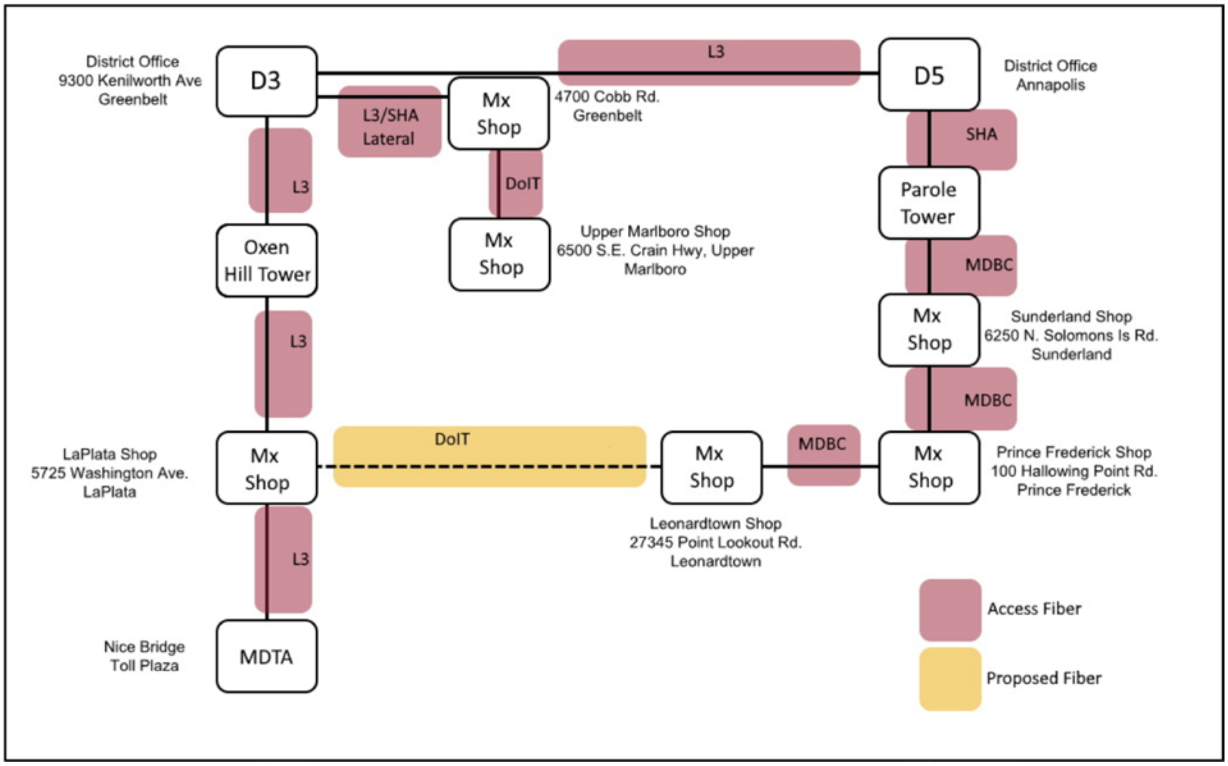


Figure 4-8: Southern Backbone Diagram

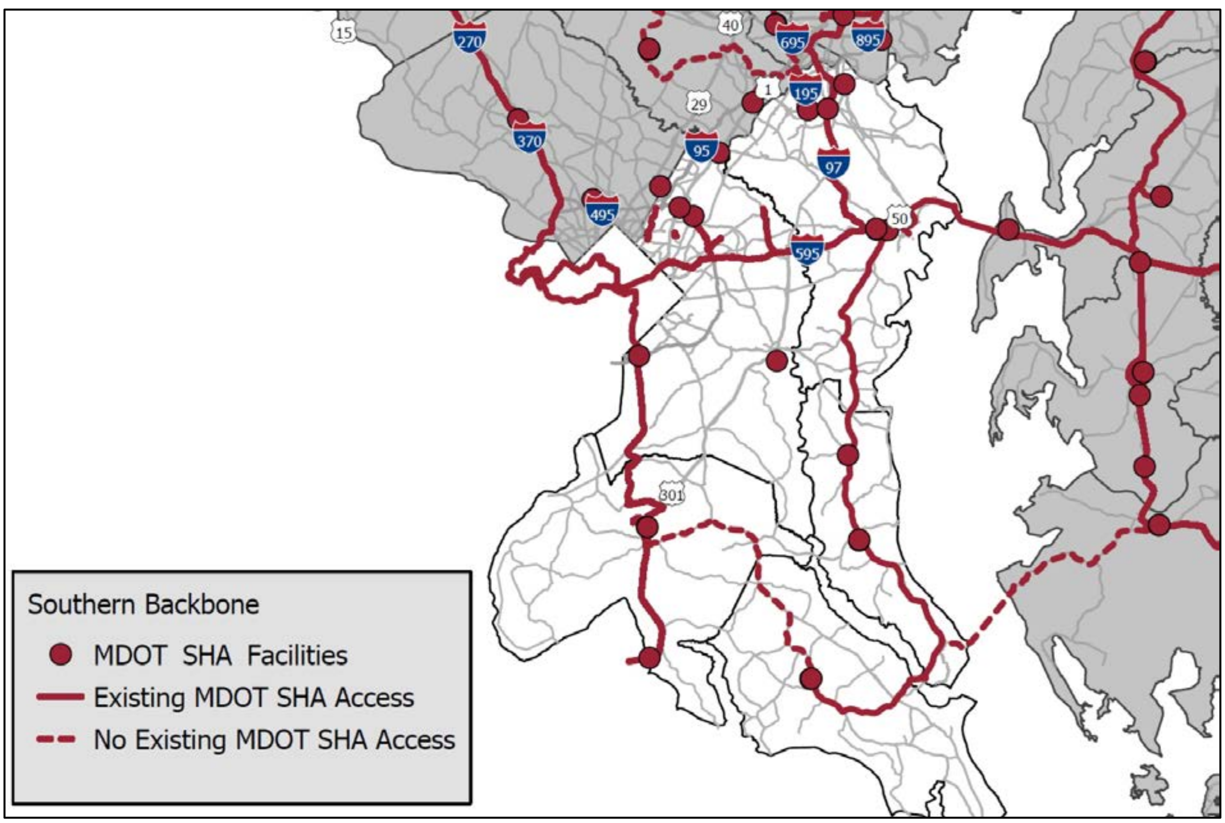


Figure 4-9: Southern Backbone Map

Next steps for the Southern District Backbone build include:

1. Explore and refine the proposed concept with MDOT including RSA access, other improvements, and possible cost sharing. An existing DoIT Chesapeake Bay crossing connecting southern and eastern regions originating from the Parole Tower location could provide additional redundancy.
2. Identify and investigate strategic peering points (i.e. radio towers and hut facilities) where MDOT SHA/MDOT fiber infrastructure would be located and could offer local providers a "meet up" location for long haul (i.e. rural broadband) opportunities.
3. Identify possible CCTV T1 leased circuit termination cost savings.
4. Identify and investigate MDOT SHA radio tower facilities that may serve as master radio locations to wirelessly connect field devices to the backbone.
5. Perform field inspection and audit of the required fiber cable splicing and network infrastructure.
6. Verify integration to core and develop a phased implementation plan.

The total estimated cost for the backbone build is **$190K** and includes all planning, design, construction and commissioning costs. The proposed architecture is shown in context of the overall backbone in **Appendix III** and in detail in in **Appendix VII**. Cost details are provided in **Appendix IX**.

4.3.2.3 Eastern Backbone

The MDOT Enterprise Network currently has presence in the Eastern Region through the Maryland Broadband Cooperative (MDBC) RSA fiber that extends out of Annapolis and across the Chesapeake Bay Bridge continuing east on US-50 to the Salisbury District 1 office. A portion of the Eastern Region currently has network redundancy, but only for the locations along the MD-213 corridor in Queen Anne, Kent, and Cecil Counties. All locations east of Wye Mill and Denton are susceptible to network disruption in the event of a fiber cut or damage along US-50. **Figure 4-10** provides a high-level graphical representation of the Eastern Backbone.

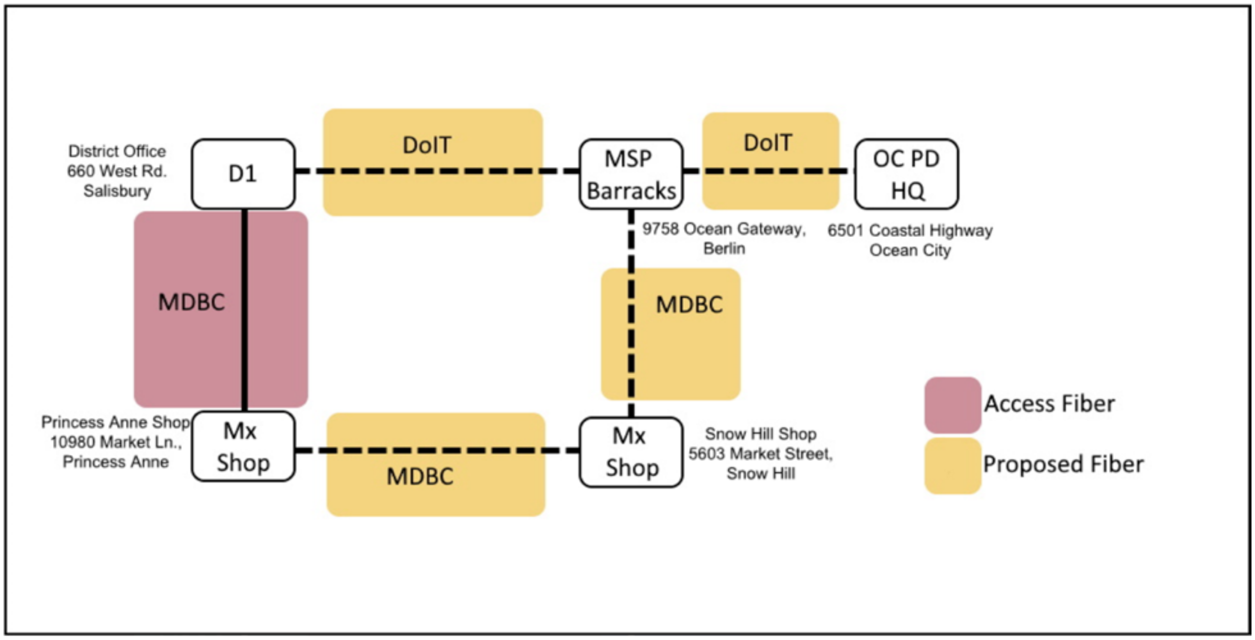


Figure 4-10: Eastern Backbone Diagram

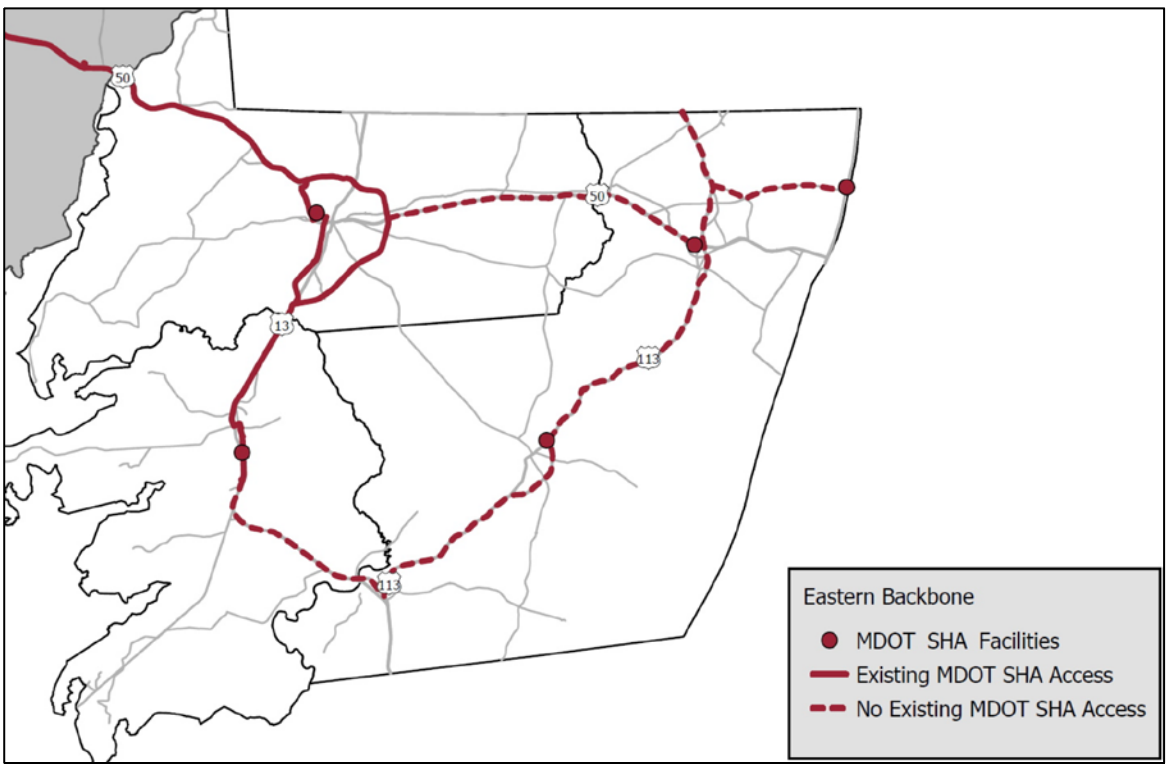


Figure 4-11: Eastern Backbone Diagram

The proposed improvement will create a physical ring in the eastern portion of this region resulting in improved resiliency and eliminating the single point of failure, while expanding the footprint to reach field devices through MDOT Enterprise Network connectivity. Additionally, this physical expansion will provide connectivity to the most recent RSA fiber made available in Ocean City by Crown Castle. The Eastern Region ring will originate in Salisbury at the MDOT SHA D1 office extend South through Princess Anne, head east to Snow Hill, north to Berlin and close by turning west back to Salisbury. DoIT and MDBC backbone fiber exists along the entire route to complete this connection and no additional backbone construction is required.

Lateral fiber cable is present at each location except for the Snow Hill MDOT SHA facility where a new fiber lateral cable will need to be constructed in addition to other engineering, splicing and testing. An additional lease line service is proposed between the Ocean City Police Department Headquarters (PD HQ) and the Elkton maintenance facility to eliminate the remaining single-thread section between Wye-Mills and the Salisbury district office. Eastern Backbone existing fiber and potential fiber opportunities can be seen in **Figure 4-11**.

Next steps for the Eastern District Backbone build include:

1. Explore and refine the proposed concept with MDOT including RSA access and possible cost sharing. An existing DoIT Chesapeake Bay crossing connecting southern and eastern regions originating from the Parole Tower location could provide additional redundancy. Investigate alternatives to the leased line including possible DoIT service from D1 to D2, and DelDOT fiber “meet up” opportunities.
2. Identify and investigate strategic peering points (i.e. radio towers and hut facilities) where MDOT SHA/MDOT fiber infrastructure would be located and could offer local providers a “meet up” location for long haul (i.e. rural broadband) opportunities.
3. Identify and investigate MDOT SHA radio tower facilities that may serve as master radio locations to wirelessly connect field devices to the backbone.
4. Identify possible CCTV T1 leased circuit termination cost savings.
5. Perform field inspection and audit of the required fiber cable and network infrastructure.
6. Explore leased circuit options and termination points with Verizon and develop initial costs.
7. Verify integration to core and develop a phased implementation plan.

The total estimated cost for the backbone build is **$445K** and includes all planning, design, construction, and commissioning costs. The proposed architecture is shown in context of the overall backbone in **Appendix III** and in detail in **Appendix VII**. Cost details are provided in **Appendix IX**.

4.3.2.4 Central Backbone

In the Central Region of the MDOT Enterprise Network physical typology there are redundancies built into the connectivity between Greenbelt, Hanover, Annapolis, and Baltimore. Until recently there was only one physical pathway to connect the Central Region to the Western Region. The pathway from the FRED LEC to the MDOT SHA Radio Shop is currently under construction to close the gap within this region up to the Frederick area. The proposed Western Backbone improvements will complete this redundancy.

In recent years, there have been significant fiber assets built out by individual counties in the Central Region. Baltimore, Howard, and Montgomery Counties have all made significant investment in private fiber and each may have excess fiber capacity that can be used by outside entities, both private and public.

Incorporating county fiber could provide significant improvements to the MDOT Enterprise Network through additional redundant connections between the Western Region and Central Region as well as provide a "northern ring" in the Central Region. As improvements are made to the overall network and network trafficking capabilities of the MDOT Enterprise Network similar benefits will also be realized by the MDOT SHA ITS communications subnetwork.

Next steps for the Central District Backbone build include:

1. Explore and refine the proposed concept with MDOT including county RSA access.
2. Identify and investigate strategic peering points (i.e. radio towers and hut facilities) where MDOT SHA fiber infrastructure could be located with counties as "meet up" locations.
3. Identify and investigate both county and MDOT SHA radio tower facilities that may serve as master radio locations to wirelessly connect field devices to the backbone.
4. Perform field inspection and audit of the required fiber cable and network infrastructure.
5. Identify integration priorities.

4.3.2.5 Cellular Integration Improvements

It is recommended that MDOT SHA consider exploring alternatives to the current AT&T and Sprint IPSEC-based Internet tunnel supporting cellular data APN connections to provide more dependable service. This may include obtaining at least two (2) private IP (PiP – MPLS L3VPN) service connections from each carrier (including Verizon based on current projects that may leverage services from Verizon) that are able to support differentiated 4G-LTE and future 5G services. A leased direct line integration will allow MDOT SHA to avoid delay, jitter, and packet loss associated with the general internet best efforts services currently leveraged for transport services.

4.3.3 TSMO Project Recommendations

4.3.3.1 TSMO System 1

The MDOT SHA TSMO program has identified a series of deployments. The TSMO System 1 corridor includes a section of I-70 and parallel arterials including US-29 bounded by MD-32 on the west and I-695 on the east as shown in **Figure 4-12**. The project requires connection of the following devices to the MDOT/MDOT SHA network:

- Vehicle Detection
- DMS
- CCTV
- Traffic Signals
- ATM (HSR LUS, DSA, and QWS)

The communications schemes within TSMO System 1 occur in two separate phases. Depending upon how the project is developed it may be more cost and time efficient to upgrade field communications in multiple phases. Detailed schematics of each phase are provided in **Appendix VIII**.

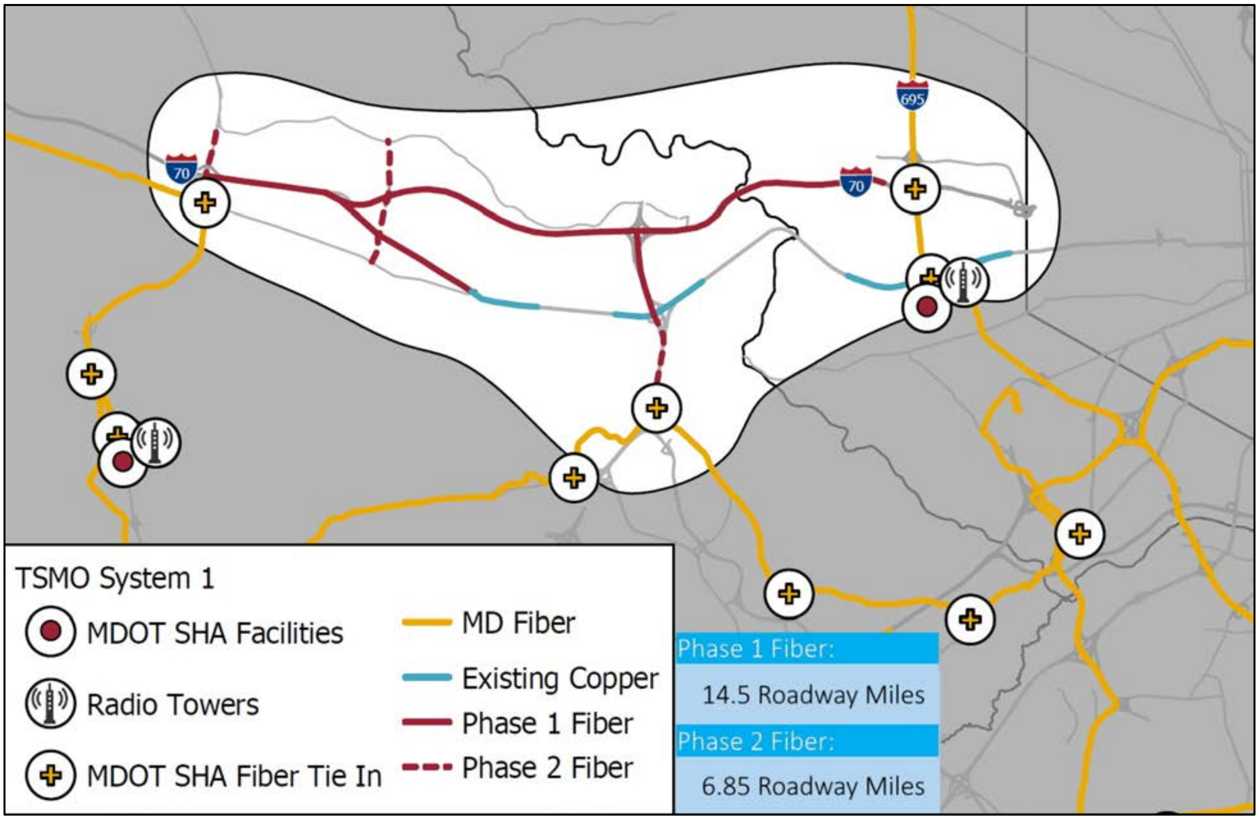


Figure 4-12: TSMO System 1 Map

Phase 1 provides baseline communications capability to support ITS and traffic signal control while supporting and building towards the ultimate network configuration. Project Phase 1 recommendations include the following:

- New fiber along MD-32 along with a new communications hut to tie the western portion of the corridor to the ALS RSA backbone at MD-32 and MD-144 for interconnect with the nearest MDOT Enterprise Network POP. The nearest MDOT Enterprise Network POP may be the Jessup or Dayton Maintenance Shops.
- New fiber along I-70, US-40, and US-29 as shown in **Figure 4-12** primarily interconnecting CCTV, DMS, vehicle detection, and initial ATM (DSA and QWS) along I-70 while also connecting CCTV on the other corridors. Full route redundancy is provided along I-70 with collapsed ring redundancy provided along US-29 between I-70 and US-40. Existing T1 circuits along the fiber sections can be removed. The eastern backbone connection is via private point-to-point wireless from the end of the I-70 fiber to the Radio Shop.

- Traffic signals along US-40 interconnect via existing copper signal interconnect and DSL to fiber access points. Instead of DSL these may also be interconnected via new fiber cable. US-40 signals near the Radio Shop would connect directly to the existing MDOT POP at the Radio Shop.
- Traffic signals along MD-99 and MD-103 are already connected via cellular data modem and would continue during Phase 1.

Phase 2 completes the communications buildout interconnecting all field devices and providing greater network redundancy where possible. Full ATM including possible HSR may result in more device density during this phase along I-70 and US-29 and would require the added redundancy. Project Phase 2 recommendations include the following:

- Complete fiber construction along I-70 to the eastern backbone tie-in point at I-695 along with a new communications hut. Completion of this segment should be coordinated with the future Triple-Bridges Project.
- Complete fiber construction along US-29 to the MD-100 split interconnecting all ITS devices along this corridor and connecting the MD-103 spur.
- Traffic signals along MD-103 and the CCTV T1 drop at the US-29 and MD-100 split would interconnect to the US-29 fiber.
- New fiber along MD-32 north of I-70 will interconnect these signals to the RSA backbone at MD-32 and MD-144.
- New fiber along Marriottsville Rd. will interconnect all devices with connections at I-70 and US-40.

The cost estimate for the TSMO System 1 communications is **$11.1M** ($8.5M in Phase 1 and 2.6M in Phase 2) and includes all planning, design, construction, and commissioning costs. Cost details are provided in **Appendix IX**.

Next steps for the TSMO System 1 communications design and deployment include the following:

1. Refine the communications design in coordination with overall project development to maximize cost efficiencies of the Dig Once policy and supplementing with leased line services as a temporary measure where needed. Note that the current cost estimate is independent of any other project construction considerations.

2. Investigate potential ALS RSA service use and tie-in points at MD-32 and MD-144. This section of RSA fiber is currently being completed. MDOT SHA does not currently have access to the ALS fiber in this region and would require a request from MDOT SHA to MDOT IT for this service.
3. Initial network planning to verify MDOT POP tie-in location at the Radio Shop and RSA fiber link and identify NID requirements.
4. Investigate, test and qualify the TWP copper cable interconnect along US-40 to support private DSL communications.
5. Investigate possible upgrade of T1 service to TLS for camera at the US-29 and MD-100 split.
6. Perform wireless communications survey from Radio Shop tower to I-70, inspect tower to support master radio equipment, and perform site surveys at radio tower and I-70 to determine final equipment location.
7. Identify all existing ITS and traffic signal cabinets along this corridor that would be moved onto fiber and perform initial planning for integration to the new MDOT POP location.
8. Investigate potential Intercounty Broadband Network fiber alignment, access and availability along MD-99 that may allow these traffic signals to be removed from cellular service. MDOT SHA should request MDOT IT to explore a potential RSA agreement.

4.3.3.2 TSMO System 2

TSMO System 2 includes a section of I-95, MD 295 and MD 32 as shown in **Figure 4-13**. The project requires connection of the following devices to the MDOT & MDOT SHA network:

- Vehicle Detection
- DMS
- CCTV
- Traffic Signals
- ATM (HSR LUS, DSA, and QWS)

TSMO System 2 presents the opportunity to consider replacement of legacy technology, while improving the communications infrastructure in the region.

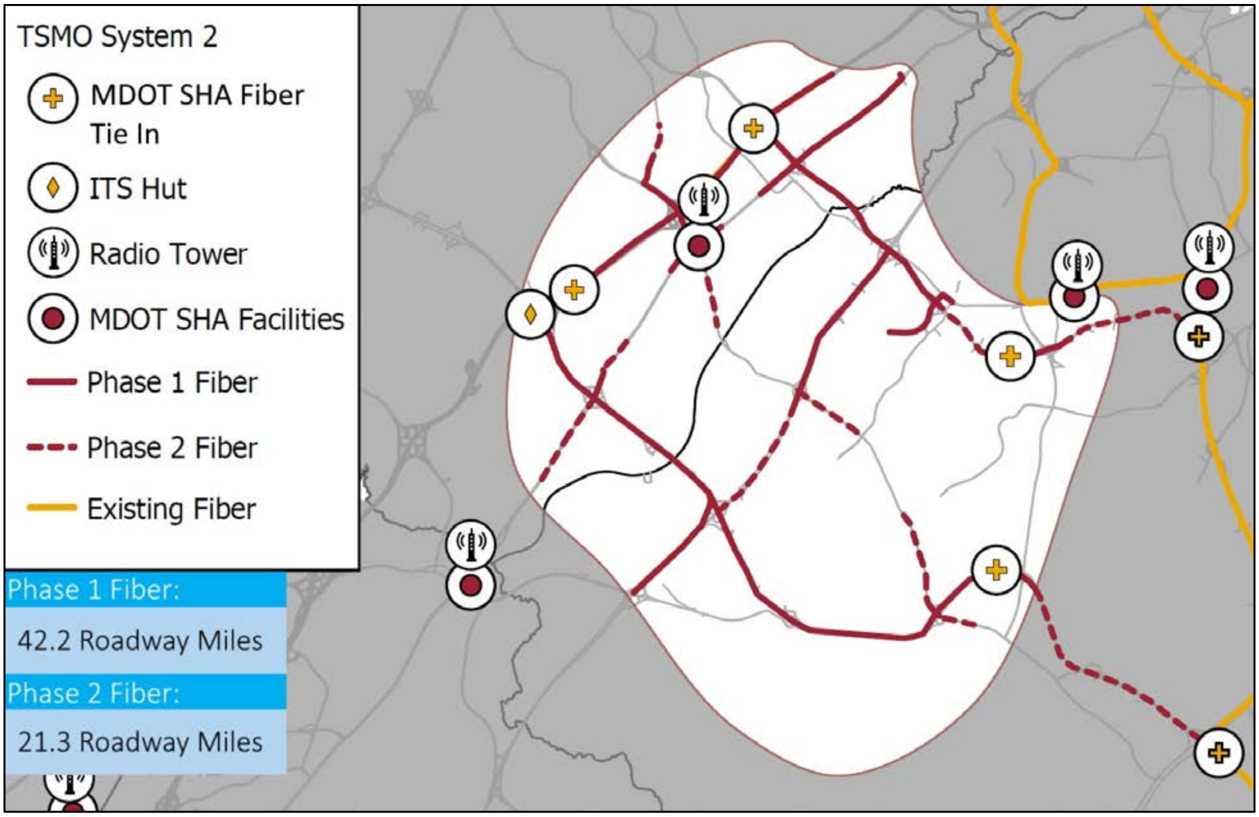


Figure 4-13: TSMO System 2 Map

The communications schemes within TSMO System 2 occur in two separate phases. Depending upon how the project is developed it may be more cost and time efficient to upgrade field communications in multiple phases. Detailed schematics of each phase are provided in Appendix VIII.

Phase 1 provides baseline communications capability to support ITS and traffic signal control while supporting and building towards the final capability. Details include the following:

- New fiber along I-95 between MD-32 and MD-100 with potential tie-in points to the L3 RSA backbone and Communications Huts at either or both locations. These tie-in points provide the backbone communication connection. There is also a small segment of fiber along MD-175 connected to the I-95 fiber.
- New fiber along MD-32 from I-95 to MD-170 interconnecting ITS cabinets along this corridor. Collapsed ring redundancy is possible within this cable back to one of the I-95 tie-in points.

- New fiber along MD-100 from I-95 to MD-713, and along portions of Arundel Mills Blvd. and New Ridge Road as shown in **Figure 4-13**.
- New fiber along portions of I-295 as shown interconnecting to fiber along MD-32 and MD-100 to provide a path back to tie-in points on I-95.
- New fiber along portions of US-1 as shown to interconnect traffic signals to fiber along MD-32, MD-100, and MD-175. There may also be another tie-in opportunity to RSA fiber at the northern end of the US-1 corridor.
- Any existing T-1 circuits along any of the fiber routes may be removed.

Phase 2 completes the communications buildout interconnecting all field devices and providing greater network redundancy. Details include the following:

- Extend fiber along MD-32 to I-97 with potential tie-in point to the L3 RSA backbone along with Communications Hut to provide independent redundancy to the I-95 tie-in.
- Extend fiber along MD-100 to I-97 with potential tie-in point to the L3 RSA backbone along with Communications Hut to provide independent redundancy to the I-95 tie-in.
- Complete the middle section of fiber construction along MD-295 to interconnect ITS cabinets and provide additional route redundancy through the middle of this system.
- Additional fiber along US-1 and MD-175 to interconnect additional traffic signals along these corridors.

The cost estimate for the TSMO System 2 Communications is **$27.1M** ($18.1M in Phase 1 and $9.0M in Phase 2) and includes all planning, design, construction and commissioning costs. Cost details are provided in **Appendix IX**.

Next steps for the TSMO System 2 Communications design and deployment include the following:

1. Refine the communications design in coordination with overall project development to maximize cost efficiencies of the Dig Once policy and supplementing with leased line services as a temporary measure where needed. Note that the current cost estimate is independent of any other project construction considerations.
2. Investigate potential ALS RSA service use and tie-in point at I-95 and MD-32, I-95 and MD-100, I-97 and MD-32, I-97 and MD-100. MDOT may also have some of its own fiber along I-95. MDOT SHA request of MDOT IT for this service.

3. Initial network planning to verify MDOT POP tie-in locations and identify NID requirements.
4. Investigate existing copper interconnect alignment along US-1 (aerial or conduit) and inspect conduit to support new fiber cable.
5. Investigate and inspect existing copper interconnect alignment and conduit along MD-713 to support new fiber cable.
6. Investigate potential fiber resources along Maryland Transit Administration (MTA) MARC Line corridor which may intersect fiber cable at MD-32 and MD-100 and could serve as a potential tie-in point alternative.

4.3.3.3 I-695 HSR

The I-695 HSR innovative congestion relief project is currently in the planning and preliminary engineering stage and includes shoulder improvements, construction, and additional ITS device deployments along both inner and outer loops of 19-miles of I-695 between I-70 and MD-43. A fiber backbone cable is proposed for the entire length of the project area and extending on the eastern end to I-95 and on the western end to US-40. These two extensions will provide key tie-in points not only for this project but are also required by the TSMO System 10 I-83 project backhaul.

In addition, the TSMO System 1 project may also benefit by an eastern end tie-in at I-695. This fiber installation represents a strategic link along the I-695 corridor.

Details of the communications scheme include the following:

- New fiber along the entire length of I-695 between I-95 and US-40 with tie-in points to MDTA fiber at I-95, MDOT SHA fiber at I-70, and the MDOT SHA Radio Shop at I-695 and US-40.
- The existing Radio Shop master radio installed as part of TSMO System 1 may be used to interconnect I-695 field cabinets within line-of-sight of the tower.
- Any existing T1 circuits along this portion of I-695 may be removed.

The cost estimate for the I-695 Communications is **$14.4M** and includes all planning, design, construction and commissioning costs. Cost details are provided in Appendix XIX.

Next steps for the I-695 Communications design and deployment include the following:

1. Refine the communications design in coordination with overall project development to maximize cost efficiencies of the Dig Once policy and supplementing with leased line services as a temporary measure where needed. Note that the current cost estimate is independent of any other project construction considerations.
2. Investigate potential MDTA RSA service use and tie-in point at I-95 including verifying the nearest MDOT POP tie-in location and NID requirements. MDOT SHA should request MDOT IT to explore this option.
3. Initial network planning to verify MDOT POP tie-in locations at the Radio Shop. The same NID equipment needed for TSMO System 1 may be used for this connection as well.
4. Identify all existing ITS equipment along I-695 that would be moved onto this new fiber and perform initial planning for integration to the new MDOT POP location.

4.4 Mid-Term Phased Implementation Roadmap

This section provides a listing of mid-term, defined as a 5-10 years outlook, project descriptions and includes a mix of network specific enhancements as well as ITS project deployments. Any dependencies or relative priorities between these projects, if any, are identified in the descriptions.

4.4.1 TSMO System 10

TSMO System 10 is comprised of I-83 and parallel MD-45 corridors just south of Pennsylvania until the I-695 interchange shown in **Figure 4-14**. The project requires connection of the following devices to the MDOT/ MDOT SHA network:

- Vehicle Detection
- DMS
- CCTV
- Traffic Signals
- ATM (HSR LUS, DSA, QWS)

The communications schemes are shown in a single phase. Depending upon how the project is developed it may be more cost and time efficient to upgrade field communications in multiple phases. Detailed schematics of each phase are provided in **Appendix VIII**.

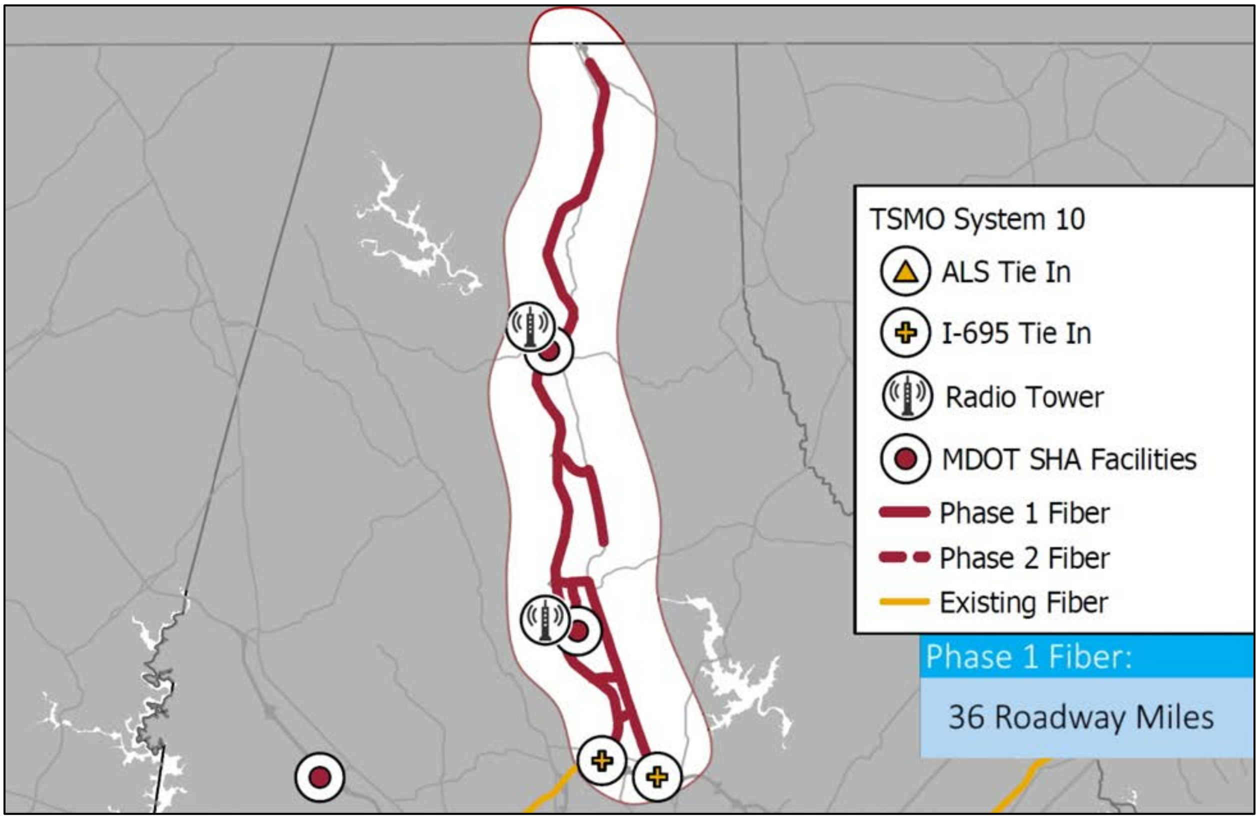


Figure 4-14 TSMO System 10 Map

Details of the communications scheme include the following:

- New fiber along the entire length of I-83 from just south of the Pennsylvania state line to the I-695 beltway with tie-in points at the District 4 Office on Warren Rd., the Hereford Maintenance Shop on MD-138, and the I-695 beltway. The District 4 office and maintenance shop are both MDOT POP locations. The I-695 fiber tie-in is dependent upon the I-695 HSR project.
- Radio towers at both the District 4 Office and the Hereford Maintenance Shop are used to host a wireless master radio which may be used to interconnect field cabinets within line-of-sight of these towers.

- New fiber along MD-45 in two sections. The southern section begins at Shawan Rd and goes to the I-695 beltway with a fiber tie-in. This tie-in is dependent upon the I-695 HSR project. A northern section starts with an I-83 tie-in at Belfast Rd and continues down to MD-45.
- Equipment north of the Hereford Maintenance Shop has limited collapsed ring redundancy within a single fiber cable, while equipment south of this location will have true route diversity redundancy.
- Any existing T-1 circuits along any of the fiber routes may be removed.

The cost estimate for the TSMO System 10 Communications is **$18.7M** and includes all planning, design, construction and commissioning costs. Cost details are provided in **Appendix IX**.

Next steps for the TSMO System 10 Communications design and deployment include the following:

1. Refine the communications design in coordination with overall project development to maximize cost efficiencies of the Dig Once policy and supplementing with leased line services as a temporary measure where needed. Note that the current cost estimate is independent of any other project construction considerations.
2. Investigate potential AT&T RSA service use and tie-in point at the northern end of I-83. This may provide an alternative route to the new fiber being installed. MDOT SHA should request MDOT IT to explore this option.
3. Initial network planning to verify MDOT POP tie-in locations at both the District 4 Office and the Hereford Maintenance Shop and identify NID requirements.
4. Investigate existing copper interconnect alignment along MD-45 (aerial or conduit) and inspect conduit to support new fiber cable.
5. Investigate District 4 Office and the Hereford Maintenance Shop radio towers to support master radio equipment and perform wireless communications survey to existing ITS and traffic signal cabinets in the region.
6. Identify all existing ITS and traffic signal cabinets along I-83 and MD-45 that would be moved onto this new fiber and perform initial planning for integration to the new MDOT POP location.

4.4.2 Major Highway Programs

Major highway construction programs provide unique opportunities to construct communications infrastructure at reduced costs along corridors to connect identified gaps or to provide network access to new device deployments or an opportunity to consolidate infrastructure to existing devices. Many of MDOT SHA's major highway construction programs are delivered through alternative project delivery methods, P3, design-build, and construction management at risk (CMAR or CM/GC). These programs provide opportunities to shift the design of communications infrastructure to the design-builder through the use of performance specifications. This master plan provides the roadmap for identifying the needs to target inclusion of communications infrastructure in major highway construction programs. The following are two major planned programs for opportunities to construct communications infrastructure at reduced costs along major corridors.

4.4.3 I-495 & I-270 P3

The I-495 and I-270 public-private partnership (P3) project is part of a statewide Traffic Relief Plan that is currently in the planning and preliminary engineering stage. The project includes major roadway improvements along I-495 (Capital Beltway) and along I-270 which will also provide opportunities for additional conduit and/or fiber installation.

Recommendation: while this is being implemented as a P3 project, it may be possible to use the developer's fiber under an RSA or participate in a partnership-based overbuild opportunity to install additional MDOT SHA fiber.

At a minimum, MDOT SHA will coordinate for the installation of conduits, utilizing the Dig Once strategy, for future fiber installation. This provides a unique opportunity to reduce the overall costs of fiber installation along these congested corridors. Potential telecommunications opportunities for this corridor should be defined later as project details are clarified. Provisions of this master plan and any future design guides should be used to the greatest extent.

4.4.4 Baltimore-Washington Parkway

As part of the statewide Traffic Relief Plan, the Baltimore-Washington Parkway project, which is in its initial planning stage, will add four new lanes to the entire length of the Parkway and MD-295 from Baltimore City to Washington, D.C.

Recommendation: The planned level of roadway construction provides an excellent opportunity to install additional fiber optic cable along the [Baltimore-Washington Parkway] corridor.

MDOT SHA owned fiber along this corridor would present opportunities to enhance state telecommunications capabilities, provide possible RSA opportunities to other entities, eliminate expensive leased circuits, and resource sharing. Potential telecommunications opportunities for this corridor should be defined later as project details are clarified. Provisions of this master plan and any future design guides should be used to the greatest extent.

4.5 Comprehensive Design Strategies

The following design strategies are intended to compliment the overall MDOT SHA ITS Communications roadmap identified in this Plan.

4.5.1 All IP-Network

Recommendation: Continue to ensure all ITS field devices are natively IP-enabled to support a complete IP-based network design.

An all IP-network will serve to support MDOT and MDOT SHA's scalability, flexibility and redundancy objectives. Additionally, this approach facilitates a more efficient use of the limited and expensive roadside fiber assets. Adhering to this approach for future ITS systems and solutions simplifies design and deployments and reduces the "time-to-deployment". As increasing numbers of field devices are added, the continued use of IPv4 may become limited in terms of scaling, and a transition to IPv6 may be required. This may be experienced first with CAV as supporting standards are based on IPv6 to not only support the number of potential vehicles but also enhanced security capabilities. MDOT SHA should begin efforts with MDOT to plan support for IPv6 in the mid-term (5 to 10-year) horizon. This may be coupled with the network virtualization solutions permitting IPv6 virtual networks to leverage the core IPv4 transport networks permitting some IPv6 support to be introduced without wholesale enablement on the backbone but the actual implementation strategy should be co-developed with MDOT.

4.5.2 Intelligent Network Equipment

Recommendation: Use of intelligent, edge-computing field network devices can enhance control and visibility of the network and reduce network traffic.

The ability to remotely monitor and troubleshoot network equipment is critical as the number of devices and their importance to the overall system operation increase. The capability of field equipment in this regard is directly related to centralized remote network management capabilities.

This includes to the greatest extent possible field network equipment with zero-touch provisioning capability to allow newly deployed field devices to automatically configure with minimal manual intervention once they are identified on the network. This requires a centralized controller to authenticate the device and then “push” the appropriate configuration to the device. To do this at scale it is also desirable therefore that the network be able to perform device level authentication to determine what type of device is being connected and then dynamically apply the standardized security profiles governing its communication capabilities.

In a network with potentially thousands of network infrastructure devices and tens of thousands of individual operational ports a controller-based solution is needed to permit centralized policy definition with distributed enforcement.

4.5.3 Increase Network and Route Diversity

Recommendation: Designing network rings with cable route diversity will greatly improve field network resiliency by providing physically independent paths to support these communication links.

Some CCTV field devices are still configured using point-to-point IP circuits limiting their resiliency against single point failures. MDOT SHA should create network rings rather than electronic diversity over a common fiber path (collapsed ring) topology with cable route diversity to improve field network resiliency. Lacking infrastructure to support a physically independent path then utilizing electronic diversity over a common fiber path (collapsed ring) topology may be used. Redundant hardware architectures of key network components are recommended to reduce single point failures. The designs implemented at William Preston Lane Jr. (WPL) Memorial Bridge as well as the Intercounty Connector (ICC) have leveraged diverse fiber paths along both sides of the roadways and have proven resiliency during fiber disruptions (both planned and unplanned). It is recommended that where possible MDOT SHA continue to construct fiber assets along both sides of the roadways/bridges to support such resiliency.

4.5.4 Develop Isolated Test Environment

Recommendation: Create an isolated test environment for verification and validation.

A separate test environment representing the production communication network provides a method by which firmware or configuration updates, equipment changes, operations, and maintenance procedures can be validated before deployment to the operational environment. Verification and validation would include all systems under MDOT SHA ownership including communications network equipment, connected field devices, application servers, workstations, and related software. Additionally, the test environment can be leveraged to provide a safe mechanism to perform third party vulnerability scanning of representative devices. Care should be taken in the design and instantiation of the test network to include all production aspects of including leased and cellular based services. A close representation of the field conditions will permit pre-deployment and post-deployment testing that will provide a satisfactory baseline performance expectation for applications and network services.

4.5.5 Standardized Deployment Models

Recommendation: Develop a standard methodology for deploying the underlying IT communications architecture.

Following a standard physical and logical network configuration philosophy will aid in network understanding and simplify monitoring and troubleshooting. Where possible, the standardized methodology should extend to the actual equipment types, configuration, and code revisions deployed. This will ensure that appropriate levels of complexity are allocated to the OT vs IT supporting infrastructures. Once developed the standard model should be documented and validated continuously against best practices.

4.5.6 Transportation Data Portal

Recommendation: Creation of a connected vehicle data portal.

As more transportation management and connected vehicle technology is deployed allowing for greater data collection and control capability, there will be a need to share this information with the larger transportation community. This is typically done through a data portal where third parties can remotely access this information over the public Internet. In the IT world these public facing interactions are typically supported through the deployment of a DMZ network segment. DMZs are specialized network segments and infrastructures that are purposely designed with inherent security controls to govern what communications are permitted to/from the DMZ. These DMZ segments are typically separated from both the public Internet and the internal network infrastructure or “Enterprise” network using a security boundary or firewall. Only devices inside the DMZ are permitted to be accessed directly by the Internet. The systems inside the DMZ are typically “Front End” processing systems only designed to facilitate interactions between the end clients and the “back end” application services and datastores. Often the application servers are also then placed into a second DMZ protected network segment. The application DMZ is permitted to interact with the front-end processing DMZ and "back end" data store. Typically, there are very tight communication constraints and exposed programmatic interfaces permitted to communicate between these DMZ segments. Data exchange transactions between public facing untrusted and unsecure segments and more secure internal backend data stores and application services are brokered and proxied by systems under the control of the operating entity. Personally Identifiable Information (PII) must also be protected, sanitized, or anonymized when shared with external partners. This capability would most likely be managed at the MDOT level and the needed timeframe is uncertain at this time. As the need becomes clearer than this capability will require further definition.

4.5.7 Secure Network Design

Recommendation: Security control features should be made available as close to the device end points as possible within the design using defense-in-depth security strategy.

Secure Network Design ensures that a defense-in-depth security strategy is followed to provide multiple layers of protection so that even if one layer is breached or bypassed, there are other systems in place to provide sufficient protection consistent with the nature and risk of a given system. This affects all aspects and every layer (physical and logical) of the network.

Physical security includes measures, such as locked and limited access field cabinets; alarm and monitoring of field cabinets; disabling unused network ports; possible Media Access Control (MAC) address network port filtering and network authentication models. Logical security includes access control lists (IP address, protocol and port) and deep inspection filtering at key subnetwork peering points. Policies restricting physical access to work areas and equipment to only pre-approved visitors through the use of locks or escorts should be followed.

Logical security measures include access control lists (IP address, protocol and port) and deep inspection filtering at key subnetwork peering points, with boundary security policies in place between OT segments and IT environments. Higher layer security controls should be implemented such as intrusion detection software, antivirus software, network monitoring, log audits, and file integrity checking software.

Policy changes on these devices should require formal approval by the appropriate Authority dependent upon the OT devices and their operational roles. Periodic penetration testing is recommended; however, general IT security scanning and automated zero-day discovery systems should be restricted to representative “test” environments only as such intensive scans can often have adverse effects on the field devices. Any vulnerabilities discovered should be addressed and rolled into the production environments using change control processes.

Current industry best practices, guidelines, and recommendations from the National Institute of Standards and Technology (NIST), National Electrical Manufacturers Association (NEMA), and National Cooperative Highway Research Program (NCHRP) should be followed such as:

- SP 800-82 Guide to Industrial Control Systems Security.
- NEMA TS 8-2018 Security Standard for Cyber and Physical Security in Transportation System.
- NCHRP 03-127: Cybersecurity of Traffic Management Systems (due 4qtr 2019) Security.

As a best practice, security policies, procedures, training, and educational material should be developed for every newly implemented control system.

Recommendation: For each expansion strategy, security should be evaluated from the very beginning of its implementation to the very end of its life cycle.

4.5.8 Documentation Updates

Recommendation: Update reference documents and related manuals.

The following should be updated to ensure consistent deployment of ITS communication systems in support of the MDOT SHA transportation network:

MDOT SHA ITS Design Manual

The existing manual should be updated to include ITS communication design guidelines to include fiber infrastructure (conduit, pull boxes, vaults, inner duct, hub facilities); fiber cable (size and type, splicing); private wireless and public carrier cellular data solutions; network equipment and any other elements necessary to ensure consistent design and deployment of the ITS communications network.

MDOT SHA Office of Traffic and Safety (OOTS) Traffic Control Devices Design Manual (2017)

The existing manual should be updated to reflect the communication standards for arterial traffic signal control possibly referencing the MDOT SHA ITS Design Manual for these details.

4.6 Research and Long-Term Recommendations

This section provides recommendations that require additional research and long-term action to support the needs detailed in the Road Map and Action Plan. Through the development of the ITS Strategic Plan and in meetings with officials from MDOT and MDOT SHA, items for further research have been identified that were not included in this Master Plan. Those items are mentioned here in addition to recommendations and requirements that were developed in the workshop meetings.

4.6.1 Operations and Maintenance

Operations and Maintenance (O&M) needs will increase substantially as the network expands and becomes more complex. The criticality of the ITS network to daily MDOT SHA operations and the safety of the traveling public necessitates a defined strategy to ensure all O&M needs are met. The remainder of this section identifies general O&M needs, provides recommendations regarding O&M approach, and presents options and considerations for O&M service delivery in the future. Existing and future high-level O&M needs include the following:

- Flexible and adaptable O&M personnel and tools to accommodate existing and future ITS network needs and ongoing expansion projects while maintaining daily operations.
- Efficient and effective O&M standard operating procedures to maintain network resiliency and security, provide high levels of service and availability, and resolve network related incidents quickly.
- Comprehensive O&M plan that incorporates best practices to maximize benefit-cost ratios and return on investment (ROI) of the ITS network.
- Adoption of OT tools and alerting to continually enhance the OT landscape and service delivery.

At the task level, the ITS network O&M approach must include regular preventative maintenance, corrective maintenance, and a variety of operations tasks. Operations tasks include activities such as fault monitoring, field dispatch, configuration management, change management, warranty management, leased-line management, service provider management, hardware/software management, security management, and general on-site operational support.

An O&M program capable of maximizing and maintaining the operational value of the ITS network is required to support mission critical applications and ensure ROI of the substantial costs and investment associated with ongoing network expansion projects.

Recommendation: A performance-based approach to O&M is desirable to meet the needs identified above and maintain the quality and longevity of the ITS network now and into the future.

As part of a performance-based approach, existing and future performance objectives and Key Performance Indicators (KPI) must be analyzed and structured specifically to meet organizational needs. In terms of network and O&M performance, performance objectives and KPI should include the following, at a minimum:

- Network availability
- Network throughput, utilization, and packet loss
- Acknowledgment and resolution of network related incidents
- Acknowledgment and resolution of cybersecurity incidents
- Mean Time to Repair
- Mean Time Between Failures

Actively monitoring and managing established KPI will bolster the ability to continually improve O&M processes and enhance the effectiveness of daily operations. Likewise, performing regular testing and validation of communications resiliency through production testing and failure simulation will help ensure the network is operating as intended. Also, when issues are observed, root cause analysis is performed and audits of the rest of similar production solutions are performed to address other potential issues. Additionally, KPI will enable MDOT SHA to better quantify and assess the health of the ITS network, the performance of O&M activities, and the overall success of ITS network expansion efforts.

Recommendation: To support a performance-based O&M approach, a centralized system (or system of integrated systems) is recommended to manage all aspects of O&M.

Aspects of O&M management via the centralized system include service delivery and ticketing; asset inventories; warranties; performance objectives and KPI; knowledge and documentation; configurations; changes; and reporting. Essentially, this proposed system would be a "one-stop-shop" for all aspects of O&M to be used by in-house staff and potential contracted O&M resources. A variety of Commercial Off the Shelf (COTS) solutions exist specifically for these purposes, some of which have the potential for integration and/or use in conjunction with network management systems such as SolarWinds and agency ATMS. Although procuring, implementing, and/or integrating a centralized system may be a substantial upfront effort, the need for such a system to manage O&M effectively will only continue to grow as the ITS network increases in size/geographic scope and complexity.

The systematic use of a centralized system to manage O&M activities has many initial and long-term benefits. First, use of such a system will enhance ability to manage asset life cycles and will provide greater visibility into daily O&M activities, performance, and recurring issues. If this system is utilized by in-house staff as well as O&M entities, there is potential to enhance communication and coordination among O&M resources and reduce response/repair times. Additionally, service ticketing will allow for comprehensive maintenance histories, tracking of work progress, and other O&M service-related items.

Over time, data created, collected, and stored within the central system will allow MDOT SHA to further develop and execute a life cycle-based approach to O&M, asset management, and network management. For instance, KPI data could be utilized to justify, identify, and support continual improvement of O&M practices; historical service ticketing data, performance data, and cost data could be utilized to produce accurate O&M and asset life-cycle cost projections to manage ongoing capital expenses and properly allocate funds for future projects; and maintenance service ticketing records could be used to identify recurring issues, manage spare parts inventories, and enhance future designs.

The O&M strategy must also account for all resources and work necessary to perform regular preventative maintenance, corrective maintenance, and operations. The extent to which external O&M support will be needed from additional contracted entities will be based upon the availability, skillsets, and ability of internal MDOT SHA staff currently performing O&M functions as well as the ability and/or willingness for existing contracted O&M entities to scale to meet additional needs resulting from network expansion.

Recommendation: develop a comprehensive O&M Work Breakdown Structure (WBS) and perform a gaps analysis to identify existing roles/resources and determine additional roles/resources needed to accomplish O&M work and meet performance objectives.

Maintenance responsibilities are currently performed by a mixture of in-house staff, service providers, and other contracted entities:

- Field Networking equipment is maintained by the radio shop.
- Leased line (including T1 connections) and POTS line maintenance is performed by the appropriate service provider.
- Interconnected traffic signals are maintained by TOD and OOTS.
- Fiber is currently maintained on a contracted time and materials basis.

Considering the rapid growth of ITS networks and near-constant change in technologies, it is prudent to explore potential options to operate and maintain the complete ITS network in the future. Generally, O&M options based on performance and complete asset life cycle management will enhance MDOT SHA's ability to properly manage future needs and ongoing capital expenses. There are two possible options for establishing O&M for ITS and communications:

- **Option 1** involves utilizing existing internal O&M resources and existing contracted entities to the greatest extent possible. Option 1 may also involve the procurement of additional contracted services or initiating negotiations with existing maintenance providers to modify contracts to address existing service gaps and limitations in contract scope(s) and resources. This option represents the least organizational change in the current O&M regimen; however, it may present challenges in the future to readily adapt to changes in technology. Additionally, this option may not easily scale as the network expands and becomes more complex without consistently negotiating contractual changes and additions. Additionally, there is potential for "finger pointing" and other issues with managing disparate resources across multiple O&M entities.

- **Option 2** involves the procurement of a single long-term performance-based O&M contract to provide complete ITS network maintenance and supplementary operational support for MDOT SHA operations staff. This option would represent a more substantial change in how ITS network assets are currently maintained; however, this option is generally recommended as a long-term initiative to simplify/consolidate O&M responsibilities and requirements; leverage economy of scale through competitive procurement; and establish a performance based O&M model that is readily scalable through contractual mechanisms that can be developed specifically for that purpose. Additionally, this option may provide long-term viability without placing undue burden on internal MDOT SHA staff to manage multiple contracts and procure additional services as organizational needs change over time.

These options are not intended to be an all-inclusive list of O&M models for the ITS network; however, they represent practical methods to secure the additional support that will be needed to operate and maintain the network in the future. **Table 4-1** summarizes and proposes high-level MDOT SHA and contracted service partner responsibilities under Option 1 and Option 2.

Table 4-1 O&M Options Responsibility Matrix

Option	Operations	Maintenance	Warranty Management	Service Provider Management
#1	• MDOT SHA	• MDOT SHA • Existing O&M Entities	• MDOT SHA	• MDOT SHA
#2	• MDOT SHA • New Contract	• New Contract	• New Contract	• New Contract

4.6.2 Asset Management

A robust ITS asset management program should primarily serve the needs of those responsible for operating and maintaining the network while also functioning within the context the larger MDOT asset management program and other stakeholder needs. The OPPE manages the MDOT Transportation Asset Management Plan (TAMP). The initial focus has been on bridge and roadway assets, but the ultimate goal is to include all transportation assets. As ITS takes on a more significant role in operating the transportation network, the digital infrastructure representing communication assets should role up and support the greater TAMP.

The following subsections describe components and issues of an ITS asset management program that will need to be further defined and resolved.

4.6.2.1 Stakeholder and Need Identification

It is critical to begin by identifying the various stakeholders, information users, and possible user needs of information that may be derived from a communication asset management program. Stakeholders of the asset management system would include:

- MDOT SHA OPPE – summary information to assist with capital improvement planning and programming efforts.
- MDOT SHA Office of CHART ITS Development – similar to OOTS for ITS assets supporting freeway and arterial ITS operations.
- OOTS – detailed asset information to assist with maintenance management, troubleshooting, conditions assessment, and cost control analysis to determine replacement lifecycle of ITS assets supporting arterial traffic signal control operations.
- Collaboration with other Maryland entities to assure efficiency, redundancy, and interoperability.

4.6.2.2 Asset Identification and Inventory

Recommendation: Identify and define what devices and components are capital assets that need to be managed based on stakeholder needs.

There is a point of diminishing returns where the necessary staffing and resources may not justify the tracking and managing of all assets. For example, with fiber optic network equipment, a switch or router may be considered a capital asset while the fiber transceiver modules may be considered consumable components. Likewise, a wireless radio would be a capital asset, but the external antenna and cable components may not. Assets used by MDOT SHA but owned by others (i.e. RSA assets) may also need to be identified. Determine how assets will be identified, tagged, and tracked (i.e. by product make, model, and type serial number or by separate MDOT SHA tag). Develop asset management measures and targets for acceptable asset condition and replacement strategies by asset type. Identify at risk devices and prioritize for relocating or decommissioning. Identify risk types – such as environmental, age, and maintenance to assist with data driven decision making.

4.6.2.3 Condition Assessment and Data Collection

Recommendation: label asset condition to establish a baseline from which to build on.

This includes an initial inventory process to locate, collect and identify asset information, tag assets, and perform initial condition assessment. This would also include detailed location identification of buried cable assets and possible installation of warning markers and signs. Periodic audits may be subsequently performed as part of a quality control program to ensure accurate information management. Leased services data collection would also include identification of circuits no longer in use and reconciliation of account information against this inventory.

4.6.2.4 Technology Systems Identification

Recommendation: determine the correct suite of tools needed to establish a reliable, integrated, accessible and user-friendly asset management technology system.

It is likely that multiple tools may be used so determining the relationship, possible information sharing, and capabilities of various tool sets to satisfy all stakeholder needs will be important. The following is a listing of possible systems and related issues:

- **ArcGIS** – MDOT SHA OPPE currently uses a GIS database with individual layers to manage location and type all MDOT assets, including ITS. Only fiber cable is currently identified. Other ITS assets may need to be considered for inclusion and the relationship to other assets such as ITS field devices may need to be defined. The assets are not typically managed at this level but merely identified for programming and planning reporting purposes. Other tools may simply need to report up summary information in compatible GIS format (i.e. Shape files showing location, route, and other attribute information of fiber cable) based on assets needs at this level.
- **Fiber Cable Management** – MDOT SHA currently uses the OSPInsight tool to plan, design, operate and maintain the fiber optic cable network. This is a GIS-based tool that can summarize cable location information for higher level reporting. Cable attribute information tracking should agree with user needs. An example use case may be ability to determine cable replacement strategy based on installation date, cable size/type and condition (percentage of good fiber, number of splices, etc.). It may also be possible to extend the use of this tool to manage copper TWP cable as well.
- **Leased Services Management** – these assets may currently only be tracked within spreadsheets. Stakeholder needs should be evaluated to determine if spreadsheets or similar tools are adequate or more purpose-built tools are better. MDOT uses the Maximo enterprise asset management tool for all TBU needs. Other DOTs have used custom built database tools to manage this type of information.
- **Network and Element Management Tools** – other tools used to actively monitor, troubleshoot, and manage communication network may also have inventory management capabilities that could be utilized. The use of intelligent IP-capable equipment allows for auto-discovery and active condition monitoring of equipment (i.e.

firmware version) under management and could be used as the asset management tool or to supplement another tool.

4.6.2.5 System Deployment

Recommendation: Develop a prioritization strategy based on immediate needs, available resources, project opportunities, and possible leveraging of existing technology systems.

A critical piece of the ITS planning will be to identify how the ITS asset management program will be rolled out. It may not be practical or feasible to implement all components at one time. An initial process should be identified and in place to capture ITS communications as-built information correctly and accurately for any future projects. Before all the tools and processes have been defined, ITS asset management systems will make documentation of these assets easier. For example, construction projects may install communications infrastructure such as conduit that would be documented for use by MDOT SHA for expansion of the Enterprise Network in a future project. Properly identifying, projecting, and maintaining these assets for future use is a critical component of future iterations of this *ITS Communications Master Plan*.

4.6.3 Rural Broadband

Maryland has not limited the ability for private companies to build in their Right of Way. As a result, most of the areas where broadband services are likely to result in profit have already been built-out. However, the State has a few options where they can assist in facilitating cost reduction to private companies:

Recommendations:

(1) Promote and support Grant Funding to entice private industry to expand their footprint in rural areas.

(2) incorporate excess underground conduit capacity in their ITS and or road improvement projects.

The largest cost to anyone building fiber is the cost to install the conduit underground. It incorporates roughly 60% of the cost per mile to build fiber. Incorporating policies like "Dig Once" or including subsurface conduit installation with other "ground opening" highway improvement and or ITS projects, they can change the largest portion of the private sector formula used to build fiber. While the increase in cost to the State could be roughly 10-15 percent, the spare conduit capacity could be shared or leased to the private sector. Private companies would then be able to justify the expense of building fiber for network services in disadvantaged areas. The increased construction costs to the state would be recovered over time in the form of lease payments by the private industry to utilize the conduit for fiber installation. To begin exploring opportunities with network expansion and support of rural broadband, outreach should be performed to the Office of Rural Broadband (kenrick.gordon@maryland.gov). Additional information regarding rural broadband and RSA can be found online[1].

[1] Rural broadband information is available at the following URL: https://www.roads.maryland.gov/mdotsha/pages/Index.aspx?PageId=872

5 Closing Statement

Advancements in technology are changing the way we travel, including how we think about projects, from the smaller ITS deployment to the system-of-systems TSMO projects, or the advent of connected and automated vehicles. As population increases in Maryland, more drivers access our roadways, and more pedestrians and bicyclists utilize our facilities, MDOT SHA is more determined than ever to deliver the best customer experience and keep Maryland moving forward as safely and reliably as possible.

Throughout MDOT, staff continuously strive to ensure deliverables support our core mission: Connecting Marylanders to life's opportunities. As part of that mission, stakeholders engaged in the development of this ITS Communications Master Plan created a sustainable path forward to support existing and future transportation technologies to ensure the safety of our customers and the economic vitality of the State. No matter what the future of transportation ends up looking like, MDOT SHA will continue to lead to build a resilient and adaptable network of communications for our customers. This ITS Communications Master Plan establishes a robust strategy to ensure the strategic execution of the substantial efforts involved in achieving MDOT SHA's ITS vision:

"*To implement a statewide ITS network capable of supporting existing and future technologies, while ensuring resiliency, efficiency, and equity***."**

This plan and its associated analyses, architectural overview, roadmap and action plan, recommendations, and appendices provide MDOT SHA with an adaptable strategy to bolster specific ITS network expansion projects and spearhead success. Through strategies developed in this plan, MDOT SHA is better equipped to meet its current and future needs while remaining agile, consistent, and cooperative in its approach to both funding and performing the planning, design, operations, and maintenance of future ITS networks. We look forward to sharing our future successes as this document is revised (bi-annually) in the years to come and offering our customers a roadway network and communications infrastructure that can support the world of tomorrow.

If you have any questions related to this report, please contact ITS Division Chief at jfrenkil@mdot.maryland.gov or CATS Division Chief at cdelion@mdot.maryland.gov .

6 Appendices

Table 6-1: Appendices List

Appendix	Title
I	Terms and Acronyms
II	Existing MDOT SHA Backbone Architecture
III	Proposed Backbone Network Architecture
IV	Field Network Examples
V	RSA Tie-In Details
VI	Freeway Segment Example
VII	District Backbone Build Details
VIII	TSMO System Details
IX	Cost Estimates
X	Verizon Leased Services
XI	Communications Resource Sharing

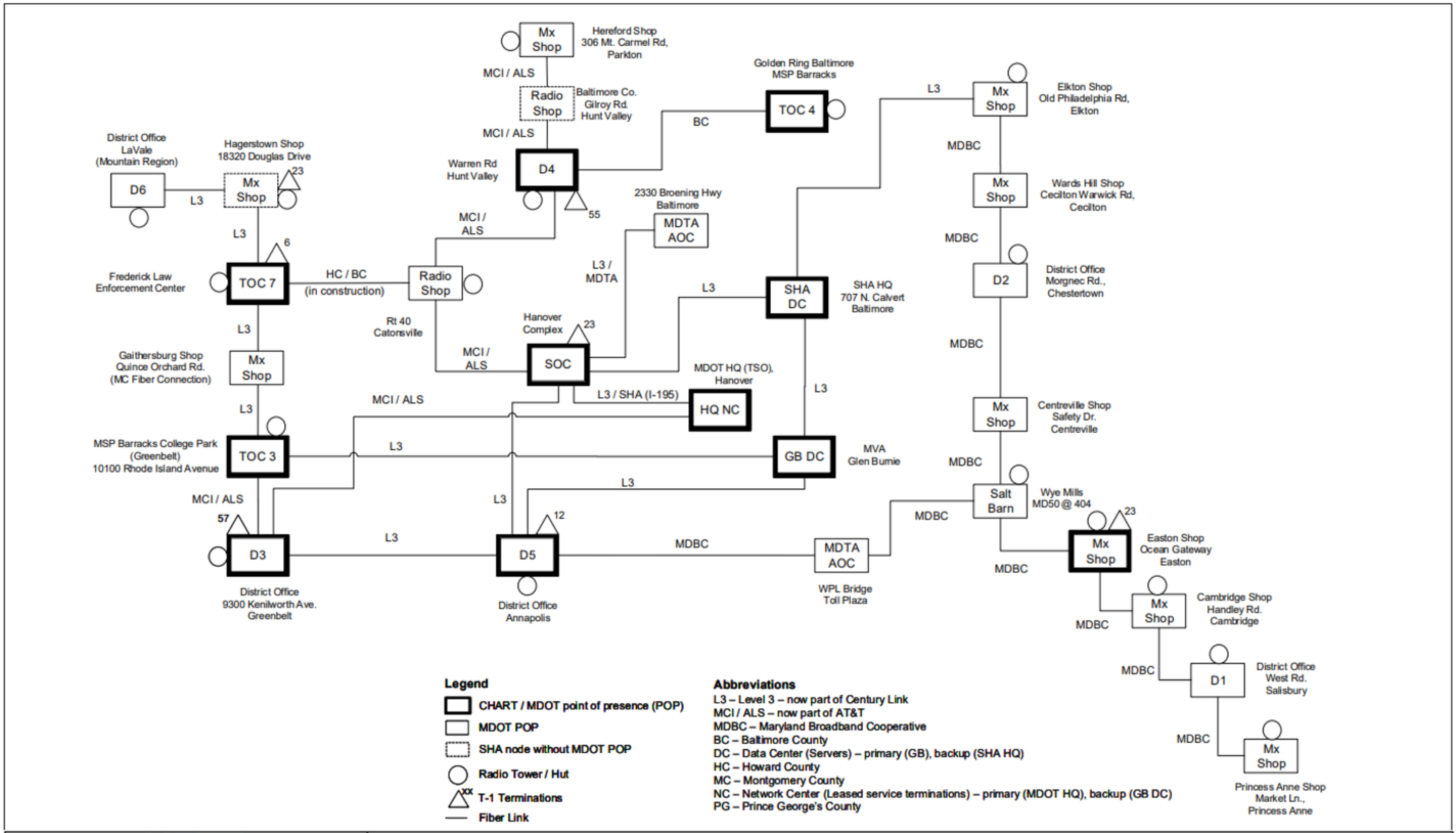
Appendix I: Terms and Acronyms

Table I Terms and Acronyms

ATR	Automated Traffic Recorder	**LATA**	Local Access and Transport Area	**POP**	Point of Presence
CATS	Connected and Automated Transportation Systems	**LUS**	Lane Use Signals	**POTS**	Plain Old Telephone Service
CCTV	Closed-Circuit Television	**LRSDP**	CHART Long Range Strategic Deployment Plan	**RTMS**	Remote Traffic Microwave Sensor
CHART	Coordinated Highways Action Response Team	**MDOT**	Maryland Department of Transportation	**RWIS**	Roadway Weather Information System
CMAR or CM/GC	Construction Management at Risk	**MDTA**	Maryland Transportation Authority	**SLA**	Service Level Agreement
COTS	Commercial Off the Shelf	**MOU**	Memorandum of Understanding	**SHA**	State Highway Administration
DMZ	Demilitarized Zone	**MPLS**	Multi-Protocol Label Switching	**SOC**	MDOT SHA Statewide Operations Center
DoIT	Department of Information Technology	**MTA**	Maryland Transit Administration	**TAMP**	Transportation Asset Management Plan
DSL	Digital Subscriber Line	**MVA**	Motor Vehicle Administration	**TBU**	Transportation Business Units
EMS	Element Management System	**NCHRP**	National Cooperative Highway Research Program	**TOC**	Traffic Operations Center
FAHP	Federal-Aid Highway Program	**NEMA**	National Electrical Manufacturers Association	**TOD**	MDOT SHA Traffic Operation Division
FHWA	Federal Highway Administration	**NID**	Network Interface Device	**TLS**	Transparent LAN Service
FRED LEC	Frederick Law Enforcement Center	**NIST**	National Institute of Standards and Technology	**TSMO**	Transportation Systems Management and Operations
GB	Glen Burnie	**NMS**	Network Management System	**TWP**	Twisted Wire Pair
GIS	Geographic Information System	**NOC**	Network Operations Center	**VPN**	Virtual Private Network
HAR	Highway Advisory Radio	**O&M**	Operations and Maintenance	**VSLS**	Variable Speed Limit Sign
HQ	Headquarters	**OPPE**	MDOT SHA Office of Planning and Preliminary Engineering	**VWS**	Virtual Weigh Station
ICC	Intercounty Connector	**OOTS**	MDOT SHA Office of Traffic and Safety	**WAN**	Wide Area Network
KPI	Key Performance Indicators	**OT**	Operations Technology	**WBS**	Work Breakdown Structure
LAN	Local Area Network	**POP**	Point of Presence	**WPL**	William Preston Lane Jr. Memorial Bridge

Appendix II: Existing MDOT SHA Backbone Architecture

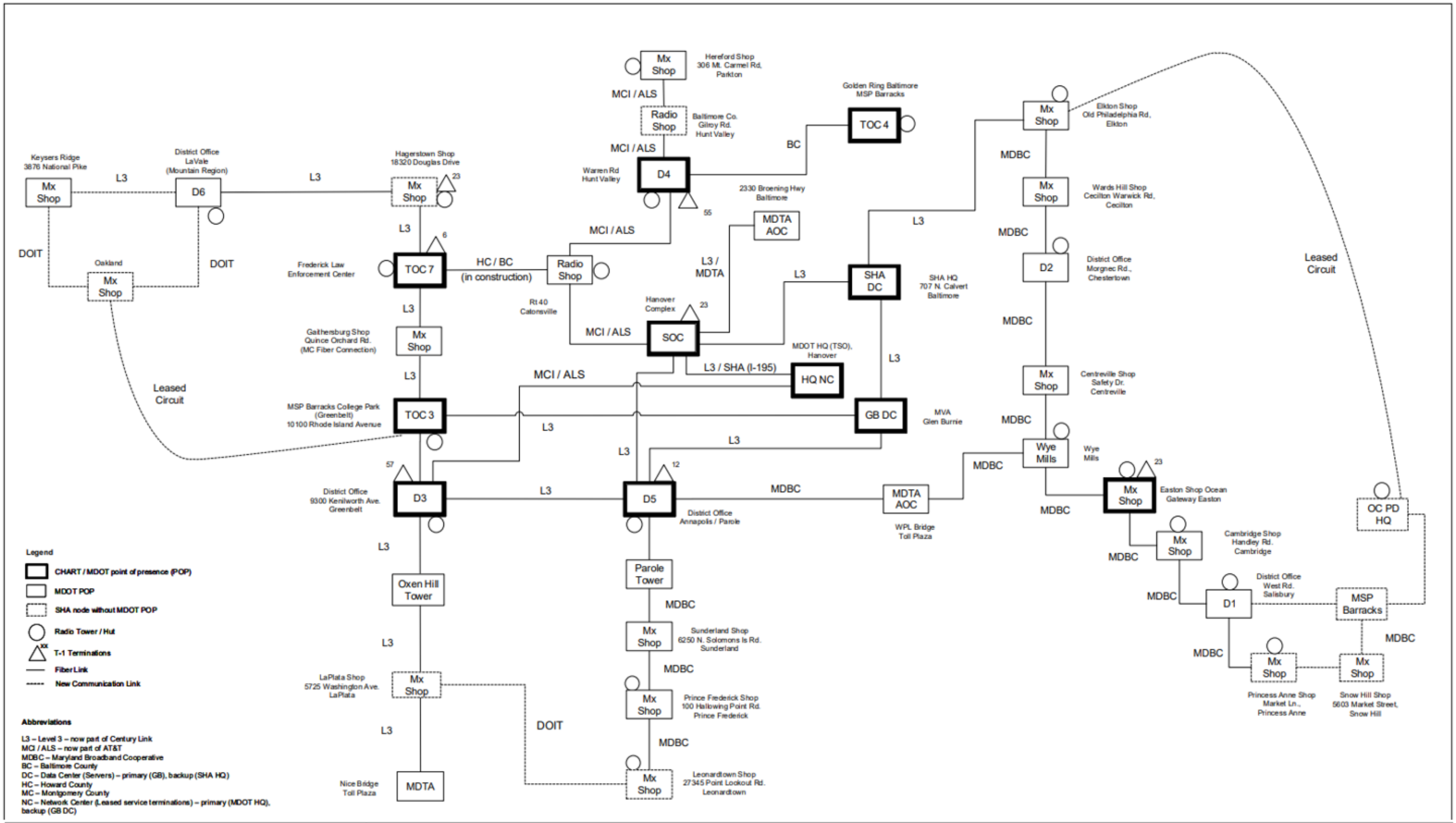
Figure II Existing MDOT SHA Backbone Architecture



MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Existing SHA Backbone Architecture		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 4/2/2020

Appendix III: Proposed Backbone Architecture

Figure III Proposed Backbone Architecture



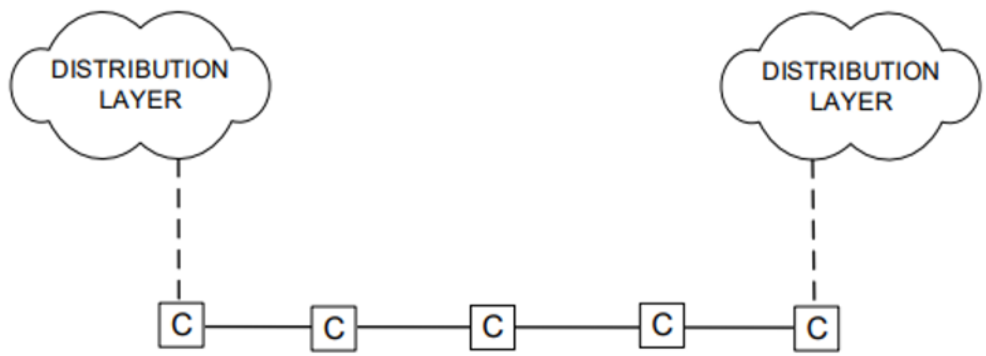
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Proposed Backbone Architecture		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 4/2/2020

Appendix IV: Field Network Examples

Table IV: Summary of Field Network Examples

Figure	Figure Name
1	Access Layer Field Network
2	Field Network Example 1
3	Field Network Example 2
4	Field Network Example 3

Figure IV-1 Access Layer Field Network



Legend

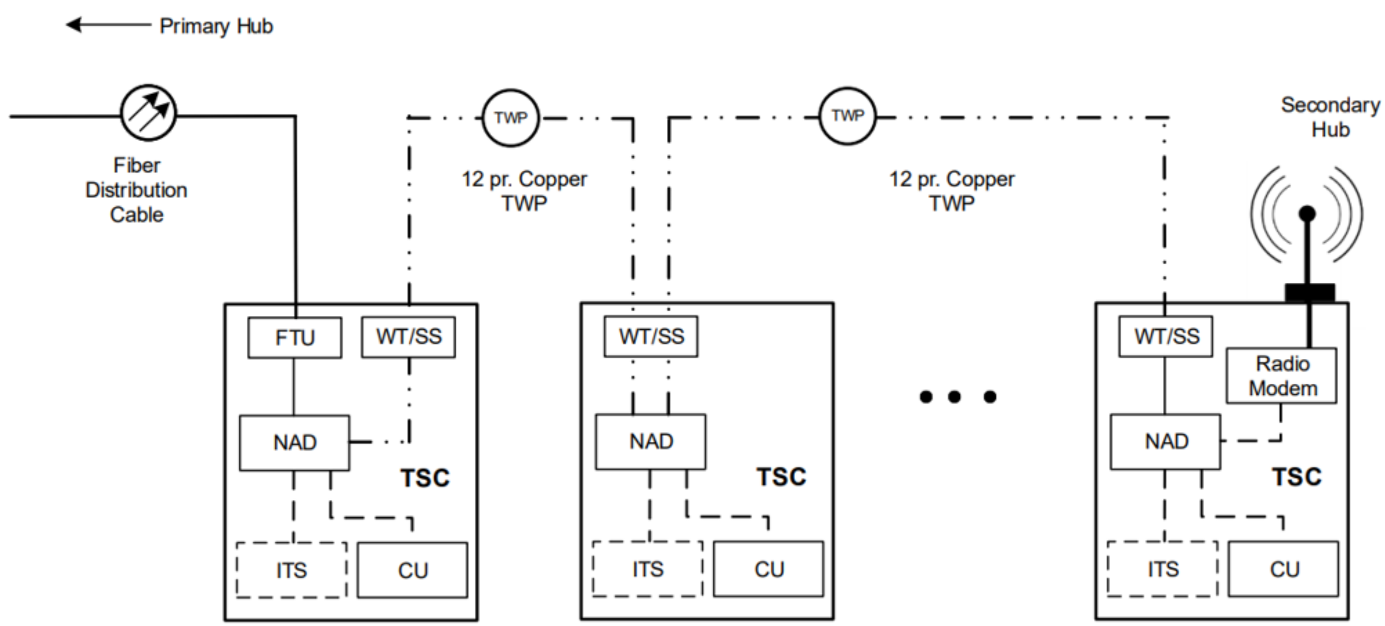
—— Field Network (FO, TWP/DSL, Wireless). In order of preference. Each link may be different

------ Distribution Uplink (FO, Wireless, Cellular, Leased Line). In order of preference

FO	Fiber Optic Cable
TWP/ DSL	Copper Twisted Wire Pair / Digital Subscriber Line
C	ITS or Traffic Signal Cabinet

MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Access Layer Field Network			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	2/12/2020

Figure IV-2 Field Network Example 1



Legend

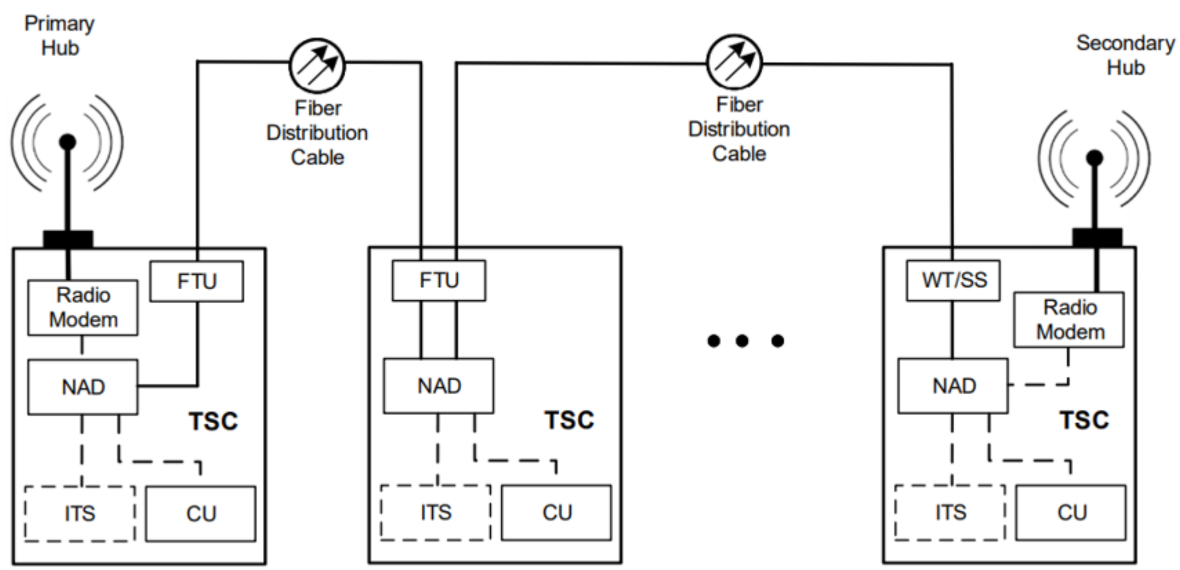
- Fiber Optic Cable
- TWP Cable
- Ethernet Cable

Abbreviations

CU	Controller Unit
FTU	Fiber Termination Unit
ITS	ITS Equipment
NAD	Network Access Device
SS	Surge Suppressor
TWP	Twisted Wire Pair
TSC	Traffic Signal Cabinet
WT/SS	Wire Termination/Surge Suppressor

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Field Network Example 1			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	2/12/2020

Figure IV-3 Field Network Example 2



Legend

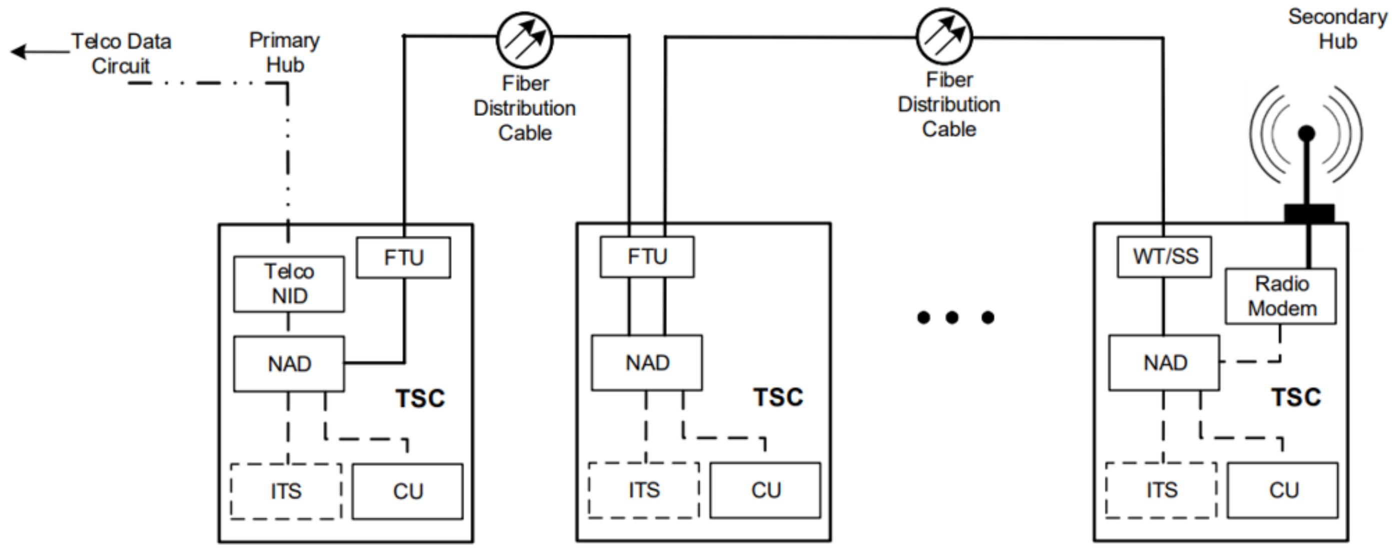
- Fiber Optic Cable
- TWP Cable
- Ethernet Cable

Abbreviations

CU	Controller Unit
FTU	Fiber Termination Unit
ITS	ITS Equipment
NAD	Network Access Device
SS	Surge Suppressor
TWP	Twisted Wire Pair
TSC	Traffic Signal Cabinet
WT/SS	Wire Termination/Surge Suppressor

MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Field Network Example 2		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 2/12/2020

Figure IV-4 Field Network Example 3



Legend

- Fiber Optic Cable
- TWP Cable
- Ethernet Cable

Abbreviations

CU	Controller Unit
FTU	Fiber Termination Unit
ITS	ITS Equipment
NAD	Network Access Device
SS	Surge Suppressor
TWP	Twisted Wire Pair
TSC	Traffic Signal Cabinet
WT/SS	Wire Termination/Surge Suppressor

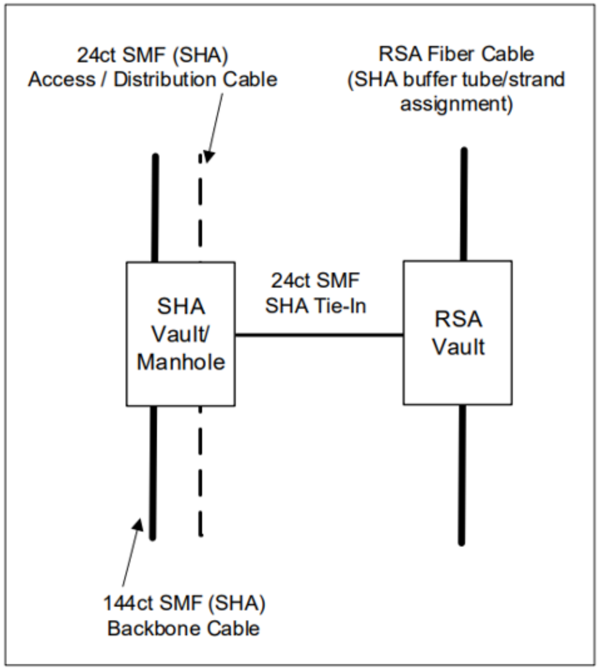
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Field Network Example 3			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	2/12/2020

Appendix V: RSA Tie-In Details

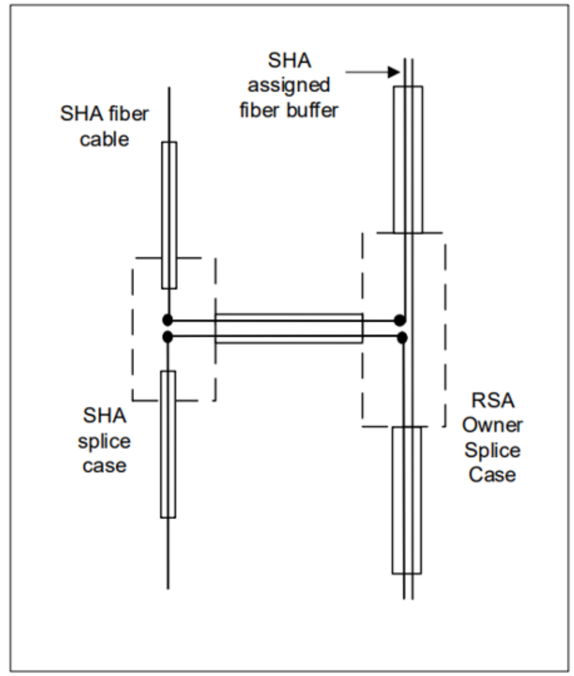
Table V: Summary of RSA Tie-In Details

Figure	Figure Name
1	RSA Fiber Tie-In Details
2	RSA Service Tie-In Details

Figure V RSA Fiber Tie-In Details



RSA Vault Colocation



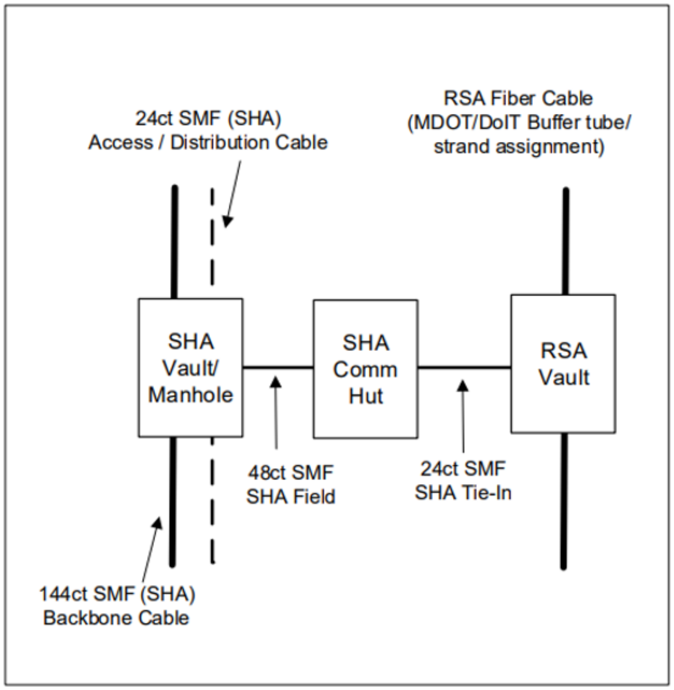
RSA Splice Tie-In

Notes:

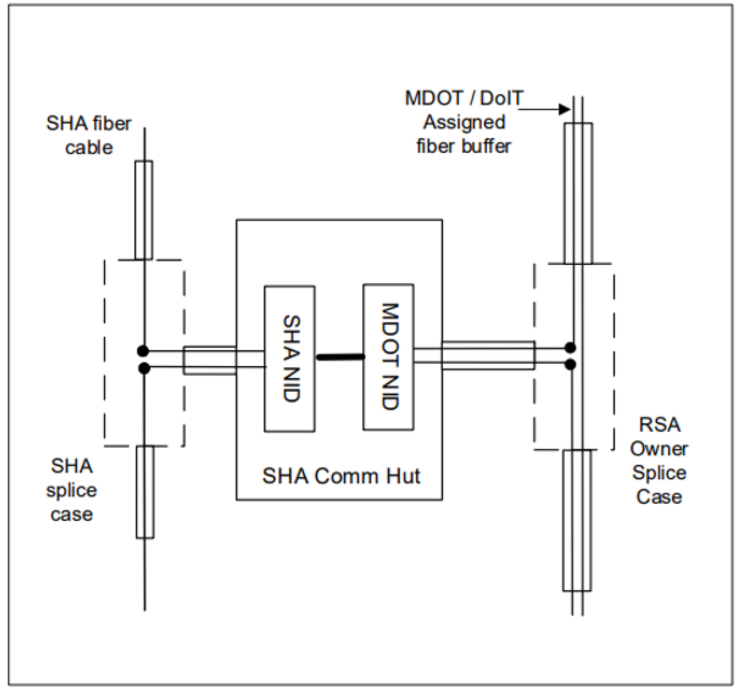
1. RSA fibers carry SHA field network directly from field to local SHA facility with MDOT NID
2. RSA vault/splice case enter/configure once. Maintain static configuration. Limited access points along RSA backbone. Typically no back-back splices points (between successive RSA vaults) are allowed.
3. SHA vault/splice case enter as needed to modify distribution configuration.

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	RSA Fiber Tie-In Details			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	3/18/2020

Figure IX RSA Service Tie-In Details



RSA Vault Colocation



RSA Splice Tie-In

Notes:

1. RSA fibers carry MDOT network. MDOT NID POP in field SHA fiber shelter to terminate SHA field network directly onto MDOT network.

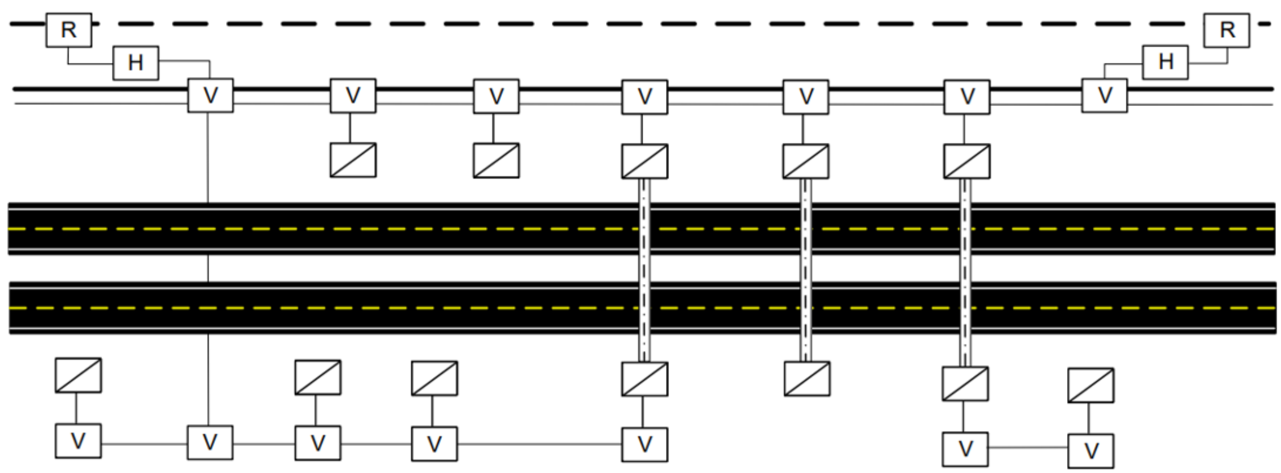
2. RSA vault/splice case enter/configure once. Maintain static configuration. Limited access points along RSA backbone. Typically no back-back splices points (between successive RSA vaults) are allowed.

3. SHA vault/splice case and field fiber hut enter as needed to modify distribution configuration.

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	RSA Service Tie-In Details			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	3/18/2020

Appendix VI: Freeway Segment Example

Figure VI Freeway Segment Example



Legend

- Backbone FO Cable
- RSA FO Cable
- Distribution FO Cable
- Wireless
- H Comm Hut
- V FO Vault
- R RSA FO Vault
- ITS Cabinet

Notes:

1. RSA vault tie-in locations limited by agreement. Includes colocated comm hut network interface device equipment to adapt SHA field network to MDOT virtualized network connection to GB and SHA HQ DC.

2. Redundant routing and protection provided for cabinets between RSA tie-in locations

3. Cabinets on other side of road connected to main distribution line via fiber and/or wireless point-to-point. Various configurations possible to provide simple point-to-point or redundant connections.

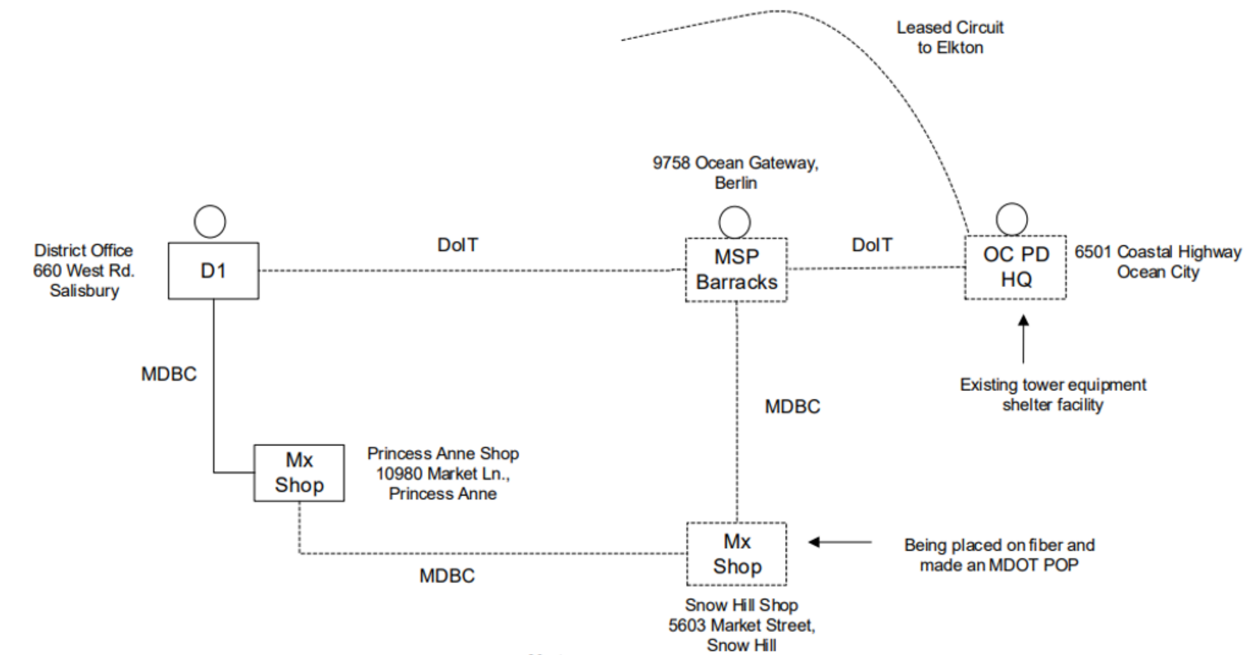
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Freeway Segment Example		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 3/18/2020

Appendix VII: District Backbone Build Details

Table VII: Summary of District Backbone Build Details

Figure	Figure Name
1	Eastern District Backbone Build
2	Southern District Backbone Build
3	Western District Backbone Build

Figure VII-1 Eastern District Backbone Build



Legend

- CHART / MDOT point of presence (POP)
- SHA node without MDOT POP
- SHA node without MDOT POP
- Radio Tower / Hut
- Fiber Link – existing MBDC RSA
- Proposed new communications link

Notes

1. DoIT and MDBC cable already extends past Snow Hill, Berlin MSP and to OCP HQ. New Connection from the DoIT/MDBC Backbone cable would need to be constructed to the Snow Hill Mx Shop. Additional splicing/termination will be required. Establish MDOT RSA with DoIT for these locations.

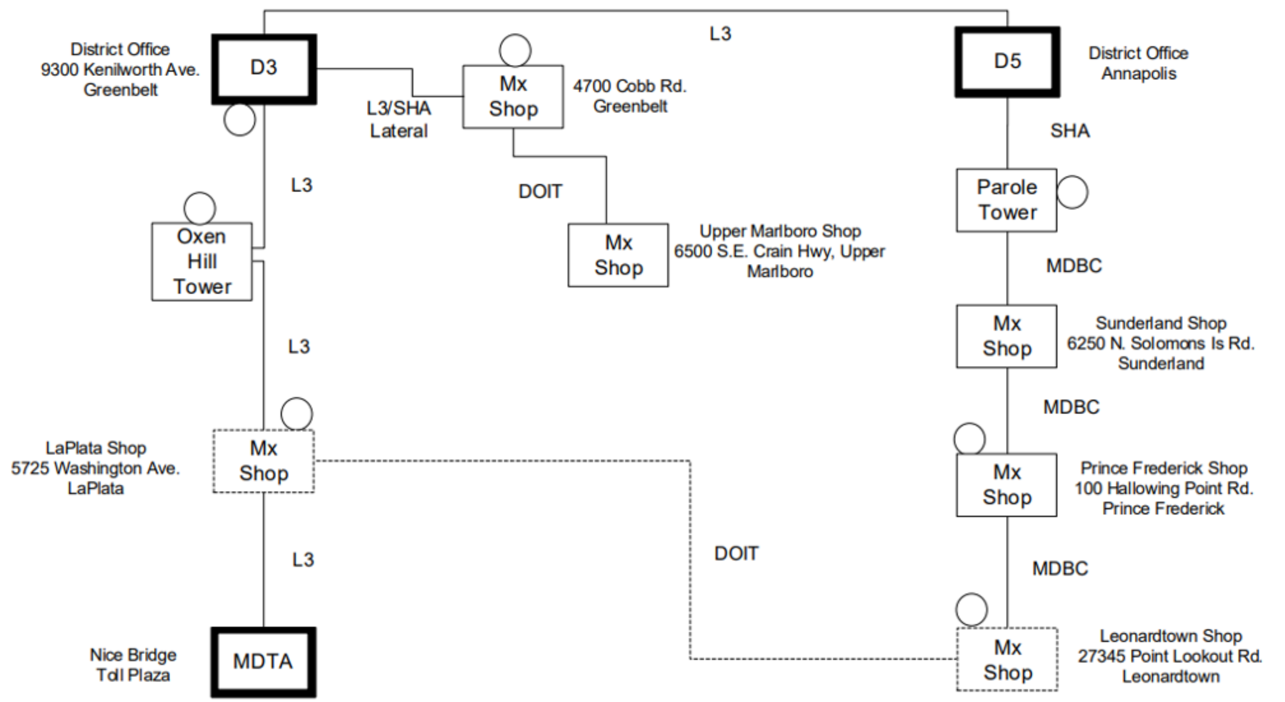
2. Establish SHA presence via new MDOT POP at Snow Hill Shop, Berlin MSP and OC PD HQ. Use as communication hub to aggregate all OC arterial traffic signals.

3. Establish new backup communications link between Princess Anne Shop, Snow Hill Shop, Berlin MSP OC PD HQ and D1 office in Salisbury to provide improved resilience for Eastern District. Details of this link would need to be engineered.

4. Redundant leased circuit from OC PD to Elkton eliminates the single-thread vulnerability to Wye Mills.

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Eastern District Backbone Build			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	4/6/2020

Figure VII-2 Southern District Backbone Build



Legend

- CHART / MDOT point of presence (POP)
- SHA node without MDOT POP
- SHA node without MDOT POP
- Radio Tower / Hut
- Fiber Link – existing MBDC RSA
- Proposed new communications link

Notes

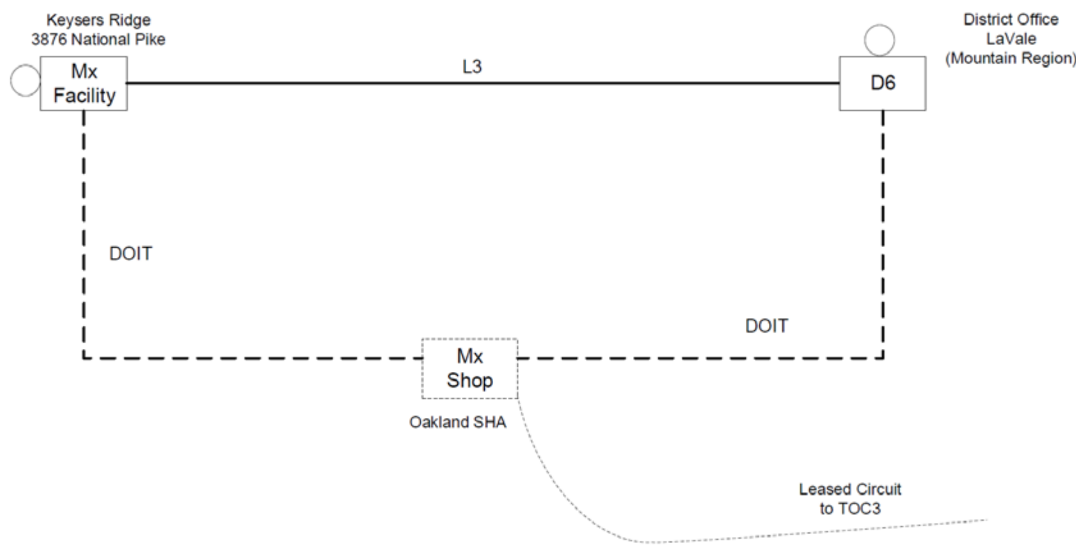
1. Verify/establish DoIT fiber connection from Upper Marlboro Shop, to Cobb Rd Shelter. Verify /establish MBDC fiber connection from Parole to Sunderland, Sunderland to Prince Frederick, Prince Frederick to Leonardtown. Some splicing/ termination may be required.

2. Establish SHA presence via new MDOT POP at these locations. Use as communication hub to aggregate all Southern District arterial traffic signals.

3. Establish new backup communications link between Leonardtown Shop and LaPlata Shop via DoIT Fiber to provide improved resilience for Southern District. Details of this link would need to be engineered.

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	Southern District Backbone Build			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	4/6/2020

Figure VII-3 Western District Backbone Build



Legend

- CHART / MDOT point of presence (POP)
- SHA node without MDOT POP
- SHA node without MDOT POP
- Radio Tower / Hut
- Fiber Link – existing MBDC RSA
- Proposed new communications link

Notes

1. Establish DoIT / Level 3 fiber connection from Levale SHA, to Oakland SHA to Keysers Ridge SHA. Some splicing/termination may be required.

2. Establish SHA presence via new MDOT POP at Oakland Shop. All three locations can be used as a communication hub to aggregate Western District devices.

3. Redundant leased circuit to TOC3 eliminates the Hagerstown to FRED LEC single-thread vulnerability.

4. Details of this link would need to be engineered.

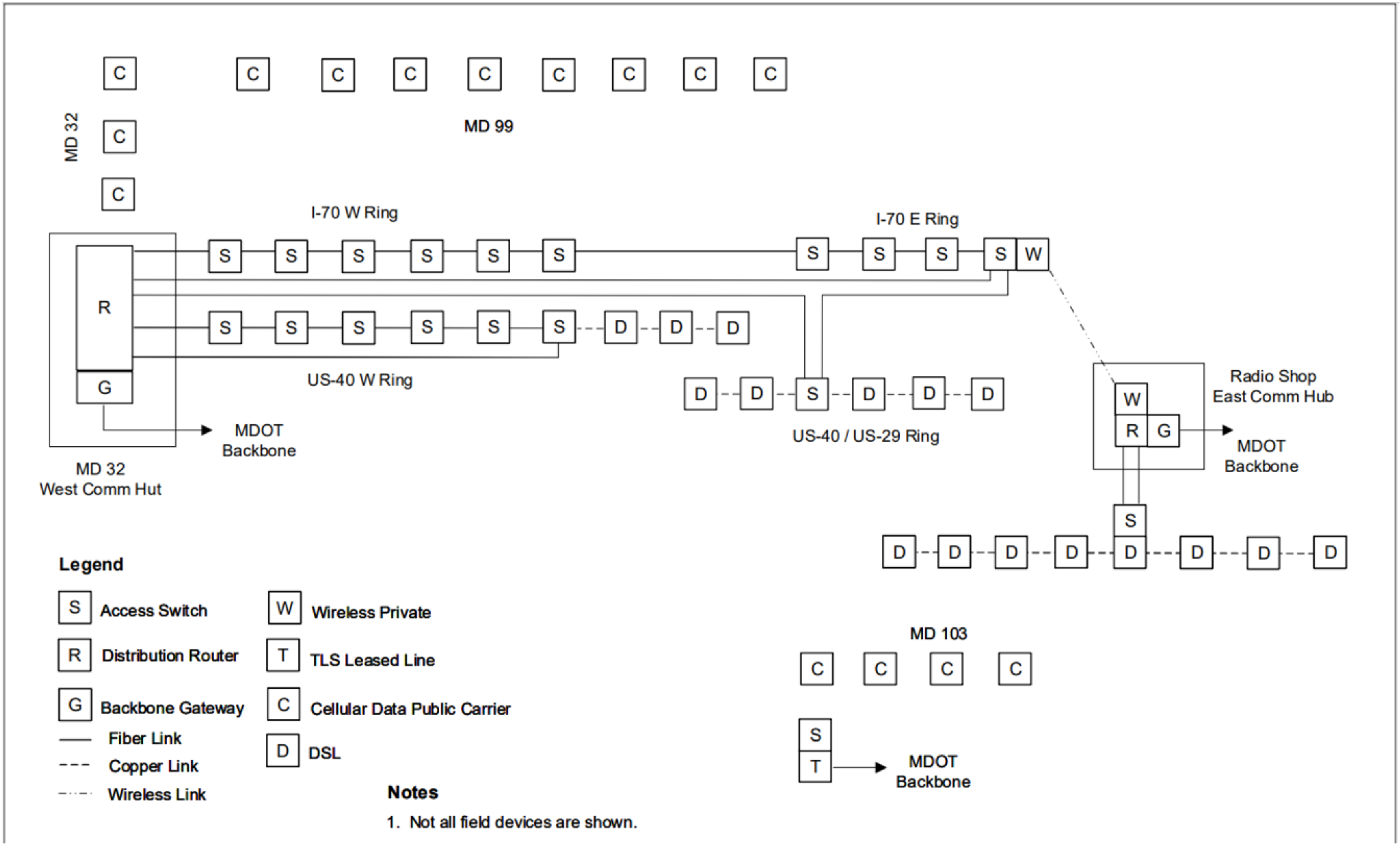
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title : Western District Backbone Build		
	File Name : SHA ITS Communications Architecture	Revision :	Date : 4/6/2020

Appendix VIII: TSMO System Details

Table VIII: Summary TSMO System Details

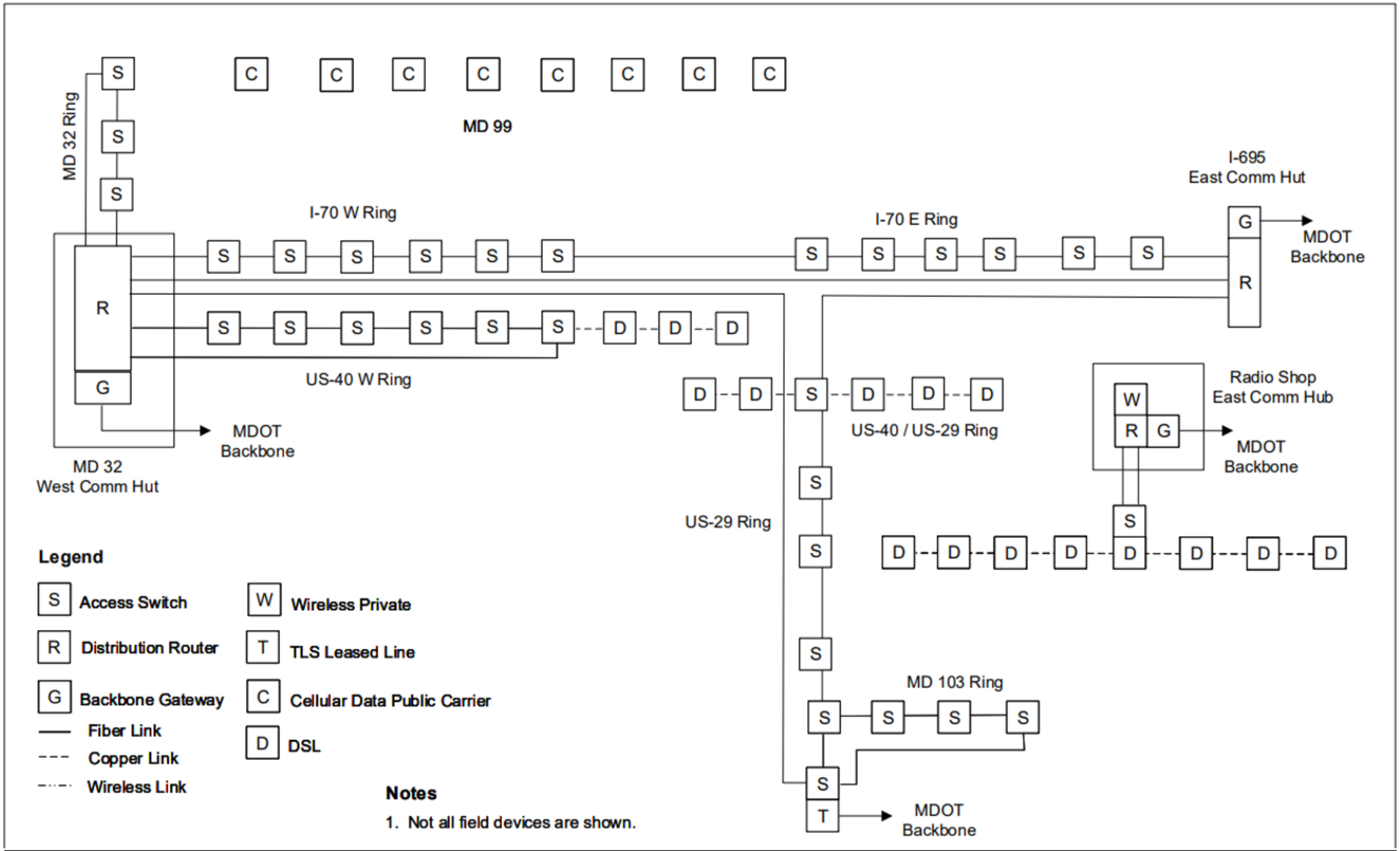
Figure	Figure Name
1.1	TSMO System 1 – Phase 1
1.2	TSMO System 1 – Phase 2
2.1	TSMO System 2 – Phase 1
2.2	TSMO System 2 – Phase 2
3.1	TSMO System 10

Figure VIII-1.1 TSMO System 1 – Phase 1



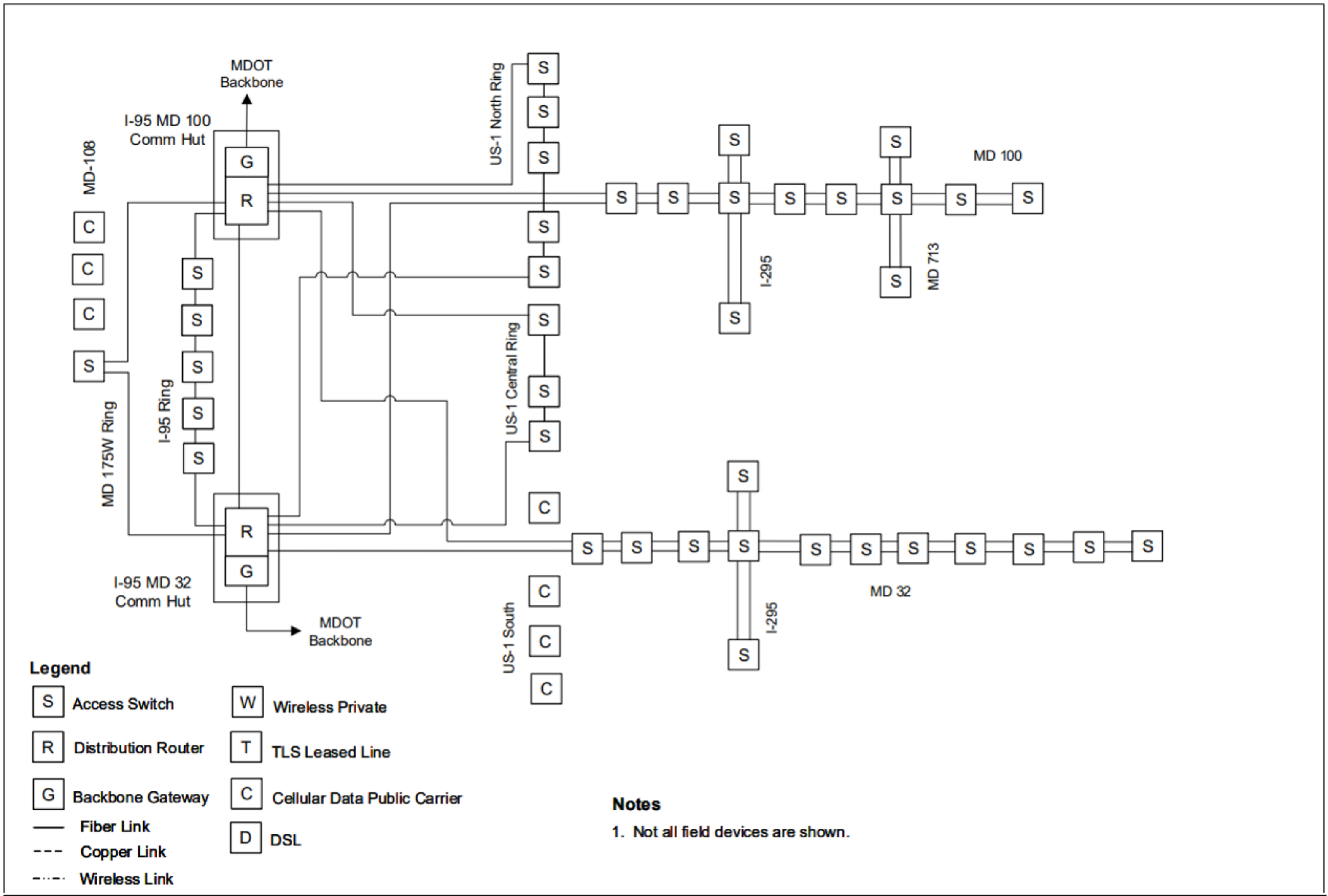
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title: TSMO System 1 – Phase 1
	File Name: SHA ITS Communications Architecture | Revision: | Date: 4/6/2020

Figure VIII-1.2 TSMO System 1 – Phase 2



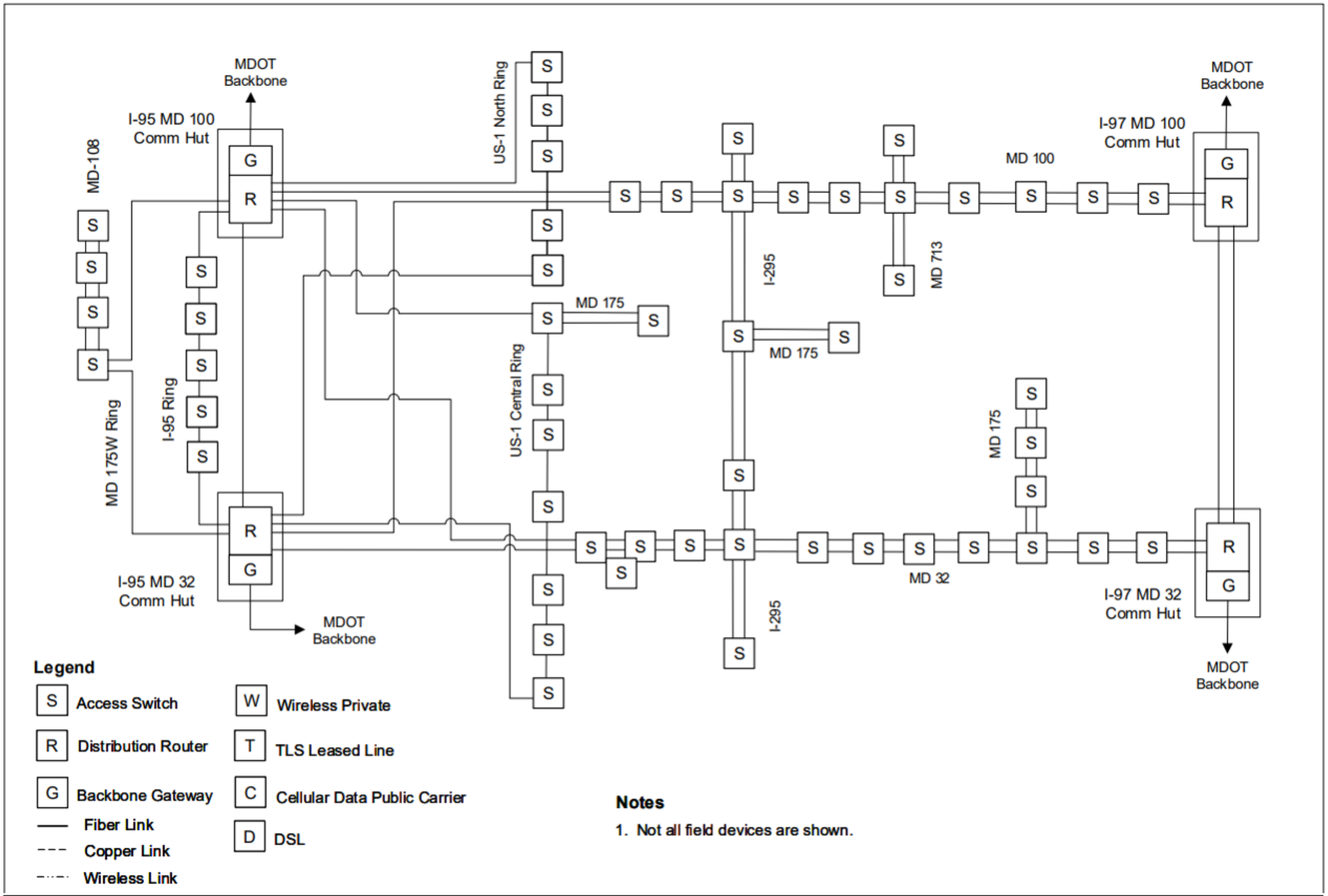
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	TSMO System 1 – Phase 2		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 4/6/2020

Figure VIII-2.1 TSMO System 2 – Phase 1



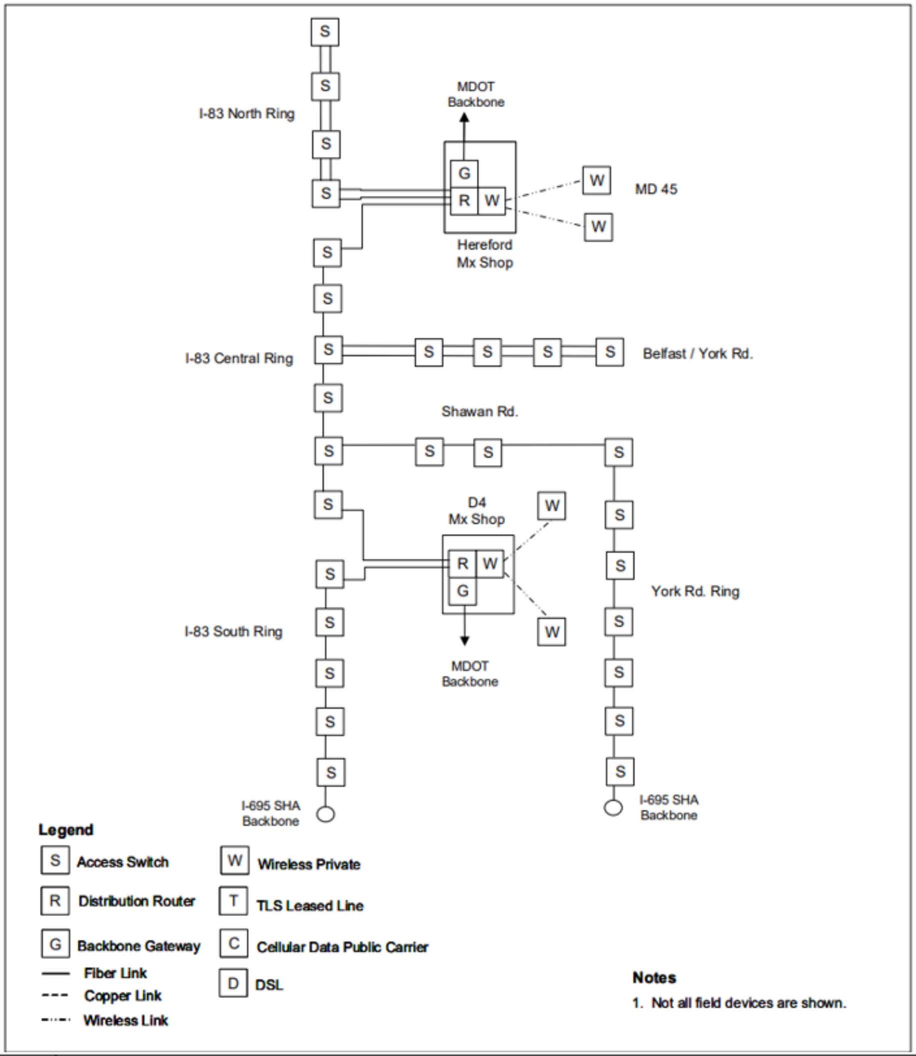
MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	TSMO System 2 – Phase 1			
	File Name:	SHA ITS Communications Architecture	Revision:	Date:	4/6/2020

Figure VIII-2.2 TSMO System 2 – Phase 2



MDOT Maryland Department of Transportation State Highway Administration	Title:	TSMO System 2 – Phase 2		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 4/6/2020

Figure VIII-3 TSMO System 10



MDOT MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION	Title:	TSMO System 10		
	File Name:	SHA ITS Communications Architecture	Revision:	Date: 4/6/2020

Appendix IX: Cost Estimates

Table IX: Summary of Cost Estimates

Table	Table Name
Component Cost Estimate	
1.1	Freeway Fiber Installation Per Mile
1.2	Arterial Rural Fiber Installation (Underground New Conduit) Per Mile
1.3	Arterial Urban Fiber Installation (Underground New Conduit) Per Mile
1.4	Arterial Fiber Installation (Underground Existing Conduit) Per Mile
1.5	Arterial Fiber Installation (Aerial) Per Mile
1.6	Communication Hut (New Tie-In Facility)
1.7	Communication Hut (Existing Tie-In Facility) - Radio Shop, Tower Fiber Huts)
1.8	Radio Tower Wireless Hut (4.9G 360 deg Master Radio Site)
Core Network Virtualization Estimate	
2	Core Network Virtualization Cost Estimate
TSMO System 1 Cost Estimate	
3.1	TSMO System 1 Phase 1 Cost Estimate
3.2	TSMO System 1 Phase 2 Cost Estimate
TSMO System 2 Cost Estimate	
4.1	TSMO System 2 Phase 1 Cost Estimate
4.2	TSMO System 2 Phase 2 Cost Estimate
TSMO System 10 Cost Estimate	
5	TSMO System 10 Cost Estimate
I-695 Cost Estimate	
6	I-695 Cost Estimate
District Backbone Build Cost Estimates	
7.1	Eastern Region Backbone Improvements Cost Estimate
7.2	Southern Region Backbone Improvements Cost Estimate
7.3	Western Region Backbone Improvements Cost Estimate

Table IX-1.1 Component Cost Estimate: *Freeway Fiber Installation Per Mile*

Freeway Fiber Installation Per Mile					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Main Trench Type 1	LF	5280	$ 20.00	$ 105,600.00	Primary side of road
Secondary Trench Type 1	LF	3960	$ 20.00	$ 79,200.00	Opposite side of the road includes lateral boring - 75% of main
Main Conduits (2x3") includes innerduct	LF	5280	$ 4.00	$ 21,120.00	
Secondary Conduit (1x3") includes innerduct	LF	3960	$ 2.00	$ 7,920.00	Opposite side of the road includes lateral boring - 75% of main
MOT Traffic Control	DY	12	$ 2,600.00	$ 31,200.00	
JB / Vault	EA	10	$ 2,000.00	$ 20,000.00	5 JB/Vaults per mile main + 5 per mile secondary
Delineator / markings	EA	10	$ 100.00	$ 1,000.00	Both sides of freeway
Fiber (144 SMFO backbone)	LF	5650	$ 6.00	$ 33,900.00	One side of freeway, includes 7% slack
Fiber (24 SMFO distribution)	LF	9887	$ 3.50	$ 34,604.50	Both sides of freeway, includes 7% slack
Splice Enclosure	EA	10	$ 3,000.00	$ 30,000.00	One enclosure, and splicing, at each cabinet @ about 10 per mile
Total Cost Per Mile				**$ 364,545.00**	
Total Cost Per Foot				$ 70.00	

Table IX-1.2 Components Cost Estimate: *Arterial Rural Fiber Installation (Underground New Conduit) Per Mile*

Arterial Rural Fiber Installation (Underground New Conduit) Per Mile					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Main Trench Type 1	LF	5280	$ 20.00	$ 105,600.00	
Lateral Trench Type 1	LF	500	$ 20.00	$ 10,000.00	Cabinets on opposite side of road
Conduit (3") includes innerduct	LF	5780	$ 2.00	$ 11,560.00	
MOT Traffic Control	DY	5	$ 2,600.00	$ 13,000.00	
JB / Vault	EA	3	$ 2,000.00	$ 6,000.00	About 3 signals per mile
Delineator / markings	EA	5	$ 100.00	$ 500.00	
Fiber (48 SMFO distribution)	LF	6185	$ 4.00	$ 24,740.00	Includes 7% slack
Splice Enclosure	EA	3	$ 3,000.00	$ 9,000.00	One enclosure, and splicing, at each cabinet @ about 3 per mile
Total Cost Per Mile				**$ 180,400.00**	
Total Cost Per Foot				$ 35.00	

Table IX-1.3 Components Cost Estimate: *Arterial Urban Fiber Installation (Underground New Conduit) Per Mile*

Arterial Urban Fiber Installation (Underground New Conduit) Per Mile					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Trench Type 1	LF	5280	$ 20.00	$ 105,600.00	
Lateral Trench Type 1	LF	600	$ 20.00	$ 12,000.00	Cabinets on opposite side of road
Conduit (3") includes innerduct	LF	5880	$ 2.00	$ 11,760.00	
Surface Repair and Restoration	LF	5880	$ 6.00	$ 35,280.00	
MOT Traffic Control	DY	7	$ 2,600.00	$ 18,200.00	
JB / Vault	EA	5	$ 2,000.00	$ 10,000.00	About 5 signals per mile
Delineator / markings	EA	5	$ 100.00	$ 500.00	
Fiber (48 SMFO distribution)	LF	6292	$ 4.00	$ 25,168.00	Includes 7% slack
Splice Enclosure	EA	5	$ 3,000.00	$ 15,000.00	One enclosure, and splicing, at each cabinet @ about 5 per mile
Total Cost Per Mile				**$ 233,508.00**	
Total Cost Per Foot				$ 45.00	

Table IX-1.4 Components Cost Estimate: *Arterial Fiber Installation (Underground Existing Conduit) Per Mile*

Arterial Fiber Installation (Underground Existing Conduit) Per Mile					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Conduit Cleaning, Rod, Rope	LF	5808	$ 6.00	$ 34,848.00	includes 10% for laterals to opposite side of road
Conduit Repair	LF	1162	$ 28.00	$ 32,536.00	Assume 20% includes surface restoration
MOT Traffic Control	DY	7	$ 2,600.00	$ 18,200.00	
JB / Vault	EA	5	$ 4,500.00	$ 22,500.00	5 Intersections and New Fiber JB/Vaults per mile, tie into conduit
Delineator / markings	EA	5	$ 100.00	$ 500.00	
Fiber (48 SMFO distribution)	LF	6215	$ 5.00	$ 31,075.00	Includes 7% slack
Splice Enclosure	EA	5	$ 3,000.00	$ 15,000.00	One enclosure, and splicing, at each cabinet @ about 7 per mile
Total Cost Per Mile				**$ 154,659.00**	
Total Cost Per Foot				$ 30.00	

Table IX-1.5 Components Cost Estimate: *Arterial Fiber Installation (Aerial) Per Mile*

Arterial Fiber Installation (Aerial) Per Mile					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
MOT Traffic Control	DY	5	$ 2,600.00	$ 13,000.00	
Fiber (48 SMFO distribution)	LF	5650	$ 10.00	$ 56,500.00	Self-supporting, utility pole attachments, includes 7% slack
Splice Enclosure	EA	5	$ 4,000.00	$ 20,000.00	One enclosure, and splicing, at each cabinet @ about 5 per mile
Total Cost Per Mile				**$ 89,500.00**	
Total Cost Per Foot				$ 17.00	

Table IX-1.6 Components Cost Estimate: *Communication Hut (New Tie-In Facility)*

Communication Hut (New Tie-In Facility)					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
10x10ft Telecommunications Shelter	EA	1	$ 45,000.00	$ 45,000.00	Includes concrete pad, racks, electrical, UPS, BU Gen hookup, HVAC
Telecommunications Equipment	LS	1	$ 40,000.00	$ 40,000.00	SHA Aggregation switch, MDOT Network equipment
Fiber Infrastructure	LS	1	$ 10,000.00	$ 10,000.00	Fiber terminations, ingress drop cable, patch panels/cables
Total Cost				**$ 95,000.00**	

Table IX-1.7 Components Cost Estimate: *Communication Hut (Existing Tie-In Facility) - Radio Shop, Tower Fiber Huts)*

Communication Hut (Existing Tie-In Facility) - Radio Shop, Tower Fiber Huts					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Telecommunications Equipment	LS	1	$ 40,000.00	$ 40,000.00	SHA Aggregation switch, MDOT Network equipment
Fiber Infrastructure	LS	1	$ 10,000.00	$ 10,000.00	Fiber terminations, ingress drop cable, patch panels/cables
Total Cost				**$ 50,000.00**	

Table IX-1.8 Components Cost Estimate: *Radio Tower Wireless Hut (4.9G 360 deg Master Radio Site)*

Radio Tower Wireless Hut (4.9G 360 deg Master Radio Site)					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Wireless Master Radio	EA	6	$ 3,200.00	$ 19,200.00	Cambium 60deg radios hardware, software license, warrantees
Brackets, Power Supply, Materials, Cables, Misc.	LS	1	$ 10,000.00	$ 10,000.00	
Installation	LS	1	$ 14,000.00	$ 14,000.00	
Total Cost				**$ 43,200.00**	

Table IX-2 Core Network Virtualization Cost Estimate

Core Network Virtualization					
Item	**Unit**	**Quantity**	**Unit Cost***	**Total Cost**	**Notes & Assumptions**
Data Center Network Equipment	EA	3	$ 45,000.00	$ 135,000.00	Assume Cisco Core Switch/ Firewall/ SFPs (GB, TSO, SHA HQ)
Operations Center Network Equipment	EA	5	$ 45,000.00	$ 225,000.00	Assume Cisco Core Switch/ Firewall/ SFPs (SOC and TOCs)
Other SHA / CHART Facility Network Equipment	EA	4	$ 25,000.00	$ 100,000.00	Assume Cisco Switches
Contingency	EA	40%		$ 184,000.00	
Construction Subtotal				***$ 644,000.00***	
Planning, Engineering & Detailed Design	LS	20%		$ 128,800.00	Detailed design, technology/product eval and selection, RFP dev.
Construction Phase Services	LS	10%		$ 64,400.00	Integration, cutover support, commissioning, as-built, asset mgt.
Total Cost				**$ 838,000.00**	

Table IX-3.1 System 1 Phase 1 Cost Estimate

System 1 Phase 1					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
I-70 Fiber	ML	10	$ 364,545.00	$ 3,645,450.00	Type = Freeway
MD 32 Fiber	ML	0.5	$ 180,400.00	$ 90,200.00	Type = Arterial rural underground new
MD 40 Fiber	ML	2.5	$ 180,400.00	$ 451,000.00	Type = Arterial rural underground new
US 29 Fiber	ML	1.5	$ 364,545.00	$ 546,817.50	Type = Freeway
Field Communications Equipment	EA	46	$ 5,000.00	$ 230,000.00	ITS Cabinets I-70 and US29, est. 4 per mile
Field Communications Equipment	EA	22	$ 5,000.00	$ 110,000.00	Signal Cabinets US40
Communication Hub	EA	1	$ 95,000.00	$ 95,000.00	New Tie-In facility MD32 @ 144
Communication Hub	EA	1	$ 50,000.00	$ 50,000.00	Existing Tie-In facility Radio Shop
Radio Tower Wireless Hub	EA	1	$ 43,200.00	$ 43,200.00	Radio Shop tower
Contingency	LS	40%		$ 2,104,667.00	
Construction Subtotal				***$ 7,366,334.50***	
Planning, Engineering & Detailed Design	LS	10%		$ 736,633.45	
Construction Phase Services	LS	5%		$ 368,316.73	
Total Cost				**$ 8,472,000.00**	

Table IX-3.2 System 1 Phase 2 Cost Estimate

System 1 Phase 2					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
I-70 Fiber	ML	1.5	$ 364,545.00	$ 546,817.50	Type = Freeway
MD 32 Fiber	ML	1	$ 180,400.00	$ 180,400.00	Type = Arterial rural underground new
MD 40 Fiber	ML	0	$ 180,400.00	$ -	Type = Arterial rural underground new
US 29 Fiber	ML	2	$ 364,545.00	$ 729,090.00	Type = Freeway
Field Communications Equipment	EA	14	$ 5,000.00	$ 70,000.00	ITS Cabinets I-70 and US29, est. 4 per mile
Field Communications Equipment	EA	4	$ 5,000.00	$ 20,000.00	Signal Cabinets US103
Communication Hub	EA	1	$ 95,000.00	$ 95,000.00	New Tie-In facility I-695
Contingency	LS	40%		$ 656,523.00	
Construction Subtotal				***$ 2,297,830.50***	
Planning, Engineering & Detailed Design	LS	10%		$ 229,783.05	
Construction Phase Services	LS	5%		$ 114,891.53	
Total Cost				**$ 2,643,000.00**	

Table IX-4.1 System 2 Phase 1 Cost Estimate

System 2 Phase 1					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
I-95 Fiber	ML	6.5	$ 364,545.00	$ 2,369,542.50	Type = Freeway
MD 32 Fiber	ML	10	$ 364,545.00	$ 3,645,450.00	Type = Freeway
MD 100 Fiber	ML	5	$ 364,545.00	$ 1,822,725.00	Type = Freeway
MD 295 Fiber	ML	4.75	$ 364,545.00	$ 1,731,588.75	Type = Freeway
MD 175 Fiber	ML	1.5	$ 180,400.00	$ 270,600.00	Type = Arterial rural underground new
US 1 Fiber	ML	4.5	$ 154,659.00	$ 695,965.50	Type = Arterial underground existing conduit
Field Communications Equipment	EA	105	$ 5,000.00	$ 525,000.00	ITS Cabinets I-95, MD32, MD100, MD295, est. 4 per mile
Field Communications Equipment	EA	21	$ 5,000.00	$ 105,000.00	Signal Cabinets US-1, MD 175
Communication Hub	EA	1	$ 95,000.00	$ 95,000.00	New Tie-In facility I-95/MD32 or I-95/MD100
Contingency	LS	40%		$ 4,504,348.70	
Construction Subtotal				***$ 15,765,220.45***	
Planning, Engineering & Detailed Design	LS	10%		$ 1,576,522.05	
Construction Phase Services	LS	5%		$ 788,261.02	
Total Cost				**$ 18,131,000.00**	

Table IX-4.2 System 2 Phase 2 Cost Estimate

System 2 Phase 2					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
MD 32 Fiber	ML	4	$ 364,545.00	$ 1,458,180.00	Type = Freeway
MD 100 Fiber	ML	4.5	$ 364,545.00	$ 1,640,452.50	Type = Freeway
MD 295 Fiber	ML	2	$ 364,545.00	$ 729,090.00	Type = Freeway
MD 175 Fiber	ML	5	$ 180,400.00	$ 902,000.00	Type = Arterial rural underground new
US 1 Fiber	ML	3	$ 154,659.00	$ 463,977.00	Type = Arterial underground existing conduit
Field Communications Equipment	EA	42	$ 5,000.00	$ 210,000.00	ITS Cabinets MD32, MD100, MD295, est. 4 per mile
Field Communications Equipment	EA	17	$ 5,000.00	$ 85,000.00	Signal Cabinets US-1, MD 175
Communication Hub	EA	1	$ 95,000.00	$ 95,000.00	New Tie-In facility I-97/MD32 or I-97/MD100
Contingency	LS	40%		$ 2,233,479.80	
Construction Subtotal				***$ 7,817,179.30***	
Planning, Engineering & Detailed Design	LS	10%		$ 781,717.93	
Construction Phase Services	LS	5%		$ 390,858.97	
Total Cost				**$ 8,990,000.00**	

Table IX-5 System 10 Cost Estimate

System 10					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
I-83 Fiber	ML	24	$ 364,545.00	$ 8,749,080.00	Type = Freeway
MD 45 Fiber (North - Belfast)	ML	3.5	$ 180,400.00	$ 631,400.00	Type = Arterial rural underground new
MD 45 Fiber (North - Shawan to Warren)	ML	2.5	$ 180,400.00	$ 451,000.00	Type = Arterial rural underground new
MD 45 Fiber (South - Warren to I-695)	ML	2.5	$ 233,508.00	$ 583,770.00	Type = Arterial urban underground new, est. half
MD 45 Fiber (South - Warren to I-695)	ML	2.5	$ 154,659.00	$ 386,647.50	Type = Arterial underground existing conduit, est. half
Field Communications Equipment	EA	96	$ 5,000.00	$ 480,000.00	ITS Cabinets I-83, est. 4 per mile
Field Communications Equipment	EA	30	$ 5,000.00	$ 150,000.00	Signal Cabinets MD 45
Communication Hub	EA	2	$ 50,000.00	$ 100,000.00	Existing Tie-In facility Hereford Shop & D4 Warren Rd.
Radio Tower Wireless Hub	EA	2	$ 43,200.00	$ 86,400.00	Hereford Shop & D4 Warren Rd. radio tower
Contingency		40%		$ 4,647,319.00	
Construction Subtotal				***$ 16,265,616.50***	
Planning, Engineering & Detailed Design	LS	10%		$ 1,626,561.65	
Construction Phase Services	LS	5%		$ 813,280.83	
Total Cost				**$ 18,706,000.00**	

Table IX-6 I-695 Cost Estimate

I-695 HSR					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
I-695 Fiber (I-70 to MD43)	ML	19	$ 364,545.00	$ 6,926,355.00	Type = Freeway (main HSR project)
I-695 Fiber (I-70 to Radio Shop)	ML	1.5	$ 364,545.00	$ 546,817.50	Type = Freeway (western tie-in)
I-695 Fiber (MD43 to I-95)	ML	2.5	$ 364,545.00	$ 911,362.50	Type = Freeway (eastern tie-in)
Field Communications Equipment	EA	92	$ 5,000.00	$ 460,000.00	ITS Cabinets I-695, est. 4 per mile
Communication Hub	EA	1	$ 95,000.00	$ 95,000.00	New Tie-In facility I-695/I-95
Contingency		40%		$ 3,575,814.00	
Construction Subtotal				***$ 12,515,349.00***	
Planning, Engineering & Detailed Design	LS	10%		$ 1,251,534.90	
Construction Phase Services	LS	5%		$ 625,767.45	
Total Cost				**$ 14,393,000.00**	

Table IX-7.1 Eastern Region Backbone Improvements Cost Estimate

Eastern Region Backbone Improvements					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
New Fiber	FT	1500	$ 35.00	$ 52,500.00	New construction at Snowhill
Fiber Splicing Backbone	EA	9	$ 2,800.00	$ 25,200.00	Existing aerial and underground splice cases entry
Fiber Splicing Lateral	EA	5	$ 2,800.00	$ 14,000.00	Existing underground splice case entry
Fiber Testing	EA	4	$ 1,600.00	$ 6,400.00	Bi-Directional OTDR and Power Meter
MOT Traffic Control	DY	9	$ 2,600.00	$ 23,400.00	Attenuator Set up Required 55+ MPH
Leased Line Circuit	EA	1	$ 7,500.00	$ 7,500.00	OC PD to Elkton, Verizon TLS or similar L2 service
Network Equipment	EA	5	$ 25,000.00	$ 125,000.00	Assume Cisco Switch/ Firewall / SFP's
Contingency	LS	40%		$ 101,600.00	
Construction Subtotal				***$ 355,600.00***	
Planning, Engineering & Detailed Design	LS	20%		$ 71,120.00	Initial fiber testing/audit, RSA, network design
Construction Phase Services	LS	5%		$ 17,780.00	Integration, commissioning, as-built, asset mgt.
Total Cost				**$ 445,000.00**	

Table IX-7.2 Southern Region Backbone Improvements Cost Estimate

Southern Region Backbone Improvements					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
New Fiber	ML	0	$ -	$ -	No New Construction Needed
Fiber Splicing Backbone	EA	4	$ 2,800.00	$ 11,200.00	Existing aerial and underground splice cases entry
Fiber Splicing Lateral	EA	3	$ 2,800.00	$ 8,400.00	Existing underground splice case entry
Fiber Testing	EA	2	$ 1,600.00	$ 3,200.00	Bi-Directional OTDR and Power Meter
MOT Traffic Control	DY	4	$ 2,600.00	$ 10,400.00	Attenuator Set up Required 55+ MPH
Network Equipment	EA	3	$ 25,000.00	$ 75,000.00	Assume Cisco Switch/ Firewall / SFPs
Contingency	LS	40%		$ 43,280.00	
Construction Subtotal				***$ 151,480.00***	
Planning, Engineering & Detailed Design	LS	20%		$ 30,296.00	Initial fiber testing/audit, RSA, network design
Construction Phase Services	LS	5%		$ 7,574.00	Integration, commissioning, as-built, asset mgt.
Total Cost				**$ 190,000.00**	

Table IX-7.3 Western Region Backbone Improvements Cost Estimate

Western Region Backbone Improvements					
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**	**Notes & Assumptions**
New Fiber	ML	0	$ -	$ -	No New Construction Needed
Fiber Splicing Backbone	EA	6	$ 2,800.00	$ 16,800.00	Existing aerial and underground splice cases entry
Fiber Splicing Lateral	EA	3	$ 2,800.00	$ 8,400.00	Existing underground splice case entry
Fiber Testing	EA	2	$ 1,600.00	$ 3,200.00	Bi-Directional OTDR and Power Meter - 2 links
MOT Traffic Control	DY	6	$ 2,600.00	$ 15,600.00	Attenuator Set up Required 55+ MPH
Leased Line Circuit	EA	1	$ 7,500.00	$ 7,500.00	Oakland to TOC3, Verizon TLS or similar L2 service
Network Equipment	EA	3	$ 25,000.00	$ 75,000.00	Assume Cisco Switch/ Firewall / SFPs
Contingency	LS	40%		$ 50,600.00	
Construction Subtotal				***$ 177,100.00***	
Planning, Engineering & Detailed Design	LS	20%		$ 35,420.00	Initial fiber testing/audit, RSA, network design
Construction Phase Services	LS	5%		$ 8,855.00	Integration, commissioning, as-built, asset mgt.
Total Cost				**$ 222,000.00**	

Appendix X: Verizon Leased Services

The Jacobs team conducted several working sessions with the State of Maryland Verizon sales team to determine what options are available in addition to the current TDM (time division multiplex) based T1 facilities that SHA currently leverages to support roadside communication. Of specific interest for SHA are the following services:

- TLS – Transparent LAN Services
- PiP – Private IP

This appendix highlights the Project Team's findings through discussions with Verizon.

X.1 TLS – Transparent LAN Services

TLS services are MEF (Metro Ethernet Forum) based service that operate at layer 2 of the OSI model and are provided by the CLEC side of the Verizon company. Since these services are offered by the CLEC organization, they are restricted to LATA regions of which Maryland has 4 defined (Baltimore, Washington, Eastern, Western). The TLS service offerings come in 2 basic formats:

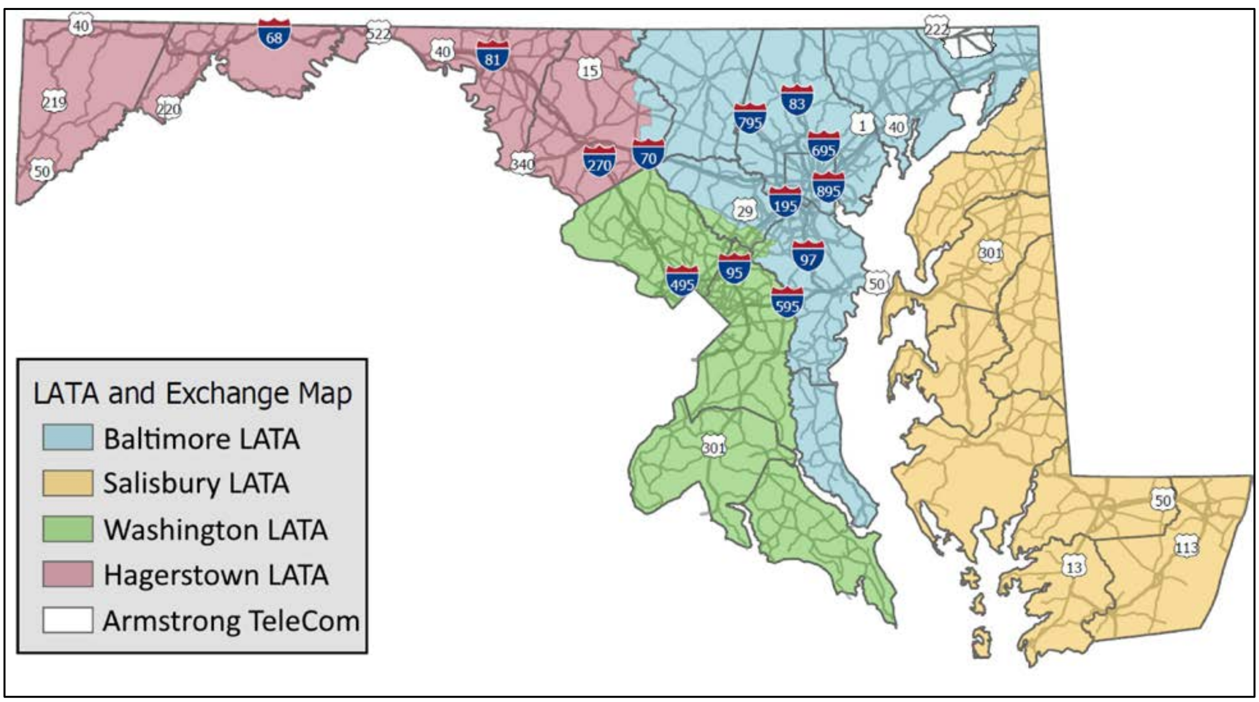


Figure X-1 Maryland LATA Boundaries

1. **EvPL – Ethernet Virtual Private Line**

   EVPL services are basic P2P services delivered over an Ethernet based UNI physical handoff. These UNI interfaces can be 100Mbps, 1Gbps, or 10Gbps in speed and each EvPL service is delivered via a VLAN tagged service each with an associated bandwidth contract. Class of Service (CoS) can also be offered where required to ensure end-to-end frame delivery guarantees around both packet loss and latency. The services are point-to-point in nature in that each EvPL service connects 1 UNI to another UNI with a common VLAN tagged circuit and each service is individually metered for bandwidth contracts. The available Committed Information Rate (CIR) bandwidth contracts are fixed however they range from 5Mbps to 10Gbps.

2. **ELAN – Ethernet Local Area Network**

   ELAN services are a multipoint-to-multipoint any-to-any switched communication service where any physical connection UNI can communicate directly to another UNI integrated into the same logical ELAN service. The ELAN services can support broadcast and multicast forwarding and are also available in the same physical UNI and CIR logical service bandwidth subscriptions as described above for EvPL.

X.2 PiP – Private IP

PiP services operate at Layer 3 of the OSI model and are provided by the Verizon Business side of the organization. As such, they are not restricted to LATA regional boundaries like the above TLS based offerings. The PiP services are similar to the ELAN services in that they are a multipoint-to-multipoint service, offering providing direct communication between any UNI services with a subscription to the same PiP service. These services provide a routed solution whereby the Verizon network appears as a routed hop between any two (2) locations participating in the same logical PiP service instantiation. PiP services leverage the same Ethernet based UNI physical connections as described above and come in predefined service bandwidth subscription options. The PiP services also offer Quality of Service (QoS) options and features to ensure traffic delivery can adhere to required Service Level Agreement (SLA) characteristics if required. PiP service integration can be statically defined within the Verizon cloud or the customer edge devices and can use a dynamic protocol such as Border Gateway Protocol (BGP) to integrate with the service and dynamically influence the routing behaviors. PiP services can also support multicast routing and participate in a sparse-mode operational environment to ensure only subscribing sites receive the multicast traffic flows.

X.3 Recommendations

The existing TDM services used by MDOT SHA are aging and limiting in service features. It is recommended that MDOT SHA begin to migrate to one of the above service offerings from Verizon. Verizon is the current DoIT statewide Master Telecommunications contract owner, but most service providers support similar services. The Ethernet PiP services offers several advantages to SHA:

- Bandwidth capacity is increased from 1.5M to 100M/1G/10G
- Bandwidth can be soft-provisioned and adjusted to each site up to the full UNI service bandwidth as required (flexibility)
- These services are switched/routed in that a single site can communicate to more than 1 remote site. This allows SHA to establish redundancy for each field site without incurring the cost of 2 separate field site circuits. Logical provisioning can permit each field site to connect to multiple aggregation sites
- Services are fiber-optic based and as such will likely be more resilient compared to the current aging copper-based wiring that Is more susceptible to environmental corrosion.
- CoS and QoS features are available to ensure the traffic deliver SLAs associated with CCTV and ITS systems can be maintained.
- Services are NOT distance dependent with respect to pricing (see LATA restrictions above).
- ELAN and PiP provide carrier side multicast support allowing replication to occur within the carrier network which can save bandwidth; however, the EvPL point-to-point offerings are also viable in MDOT SHA’s use case. Currently traffic flow requirements for MDOT SHA are client service models, where consumer end points

are generally inside the network core and not within the field sites. Field site to Field site communication is currently not in high demand; however, future ITS applications may change this paradigm.

It is recommended that SHA conduct a pricing exercise to determine which of the available services represent the best solution to adopt. The PiP services are attractive as they do not incur the same LATA boundary restrictions and as such SHA could reduce the number of Field site aggregation sites to 2 (primary and secondary); therefore, PiP may result in a lower capital and operational expenditure requirement as compared to the current regional aggregation based on the current distance-based services. The TLS based services are LATA restrictive which will require at least 2 aggregation hubs to be established in each LATA for redundancy. The TLS services are generally less expensive than the PiP services, which given the scale on which MDOT SHA operates for existing field sites, the future expansion may prove cost effective. It is also important to note that these higher speed services can also be used to connect regional fiber optic based network "islands" that are built to establish field site communications to connect back to a hub site as a stop gap temporary solution as the fiber infrastructure is extended to eventually connect back to a backbone node.

X.4 Responses to Verizon's Questions

The following are the current state of the project's correspondence with Verizon regarding their leased services.

1. **What does MDOT SHA mean by regional point of presence?**

   MDOT SHA traffic flows from its field sites are generally client server in operation whereby the various field site devices communicate with command and control services running within the MDOT SHA Enterprise backbone. This requires that communication from each field site be brought back into the backbone at aggregation site facilities where connectivity to the backbone private fiber-based infrastructure and connectivity to the leased provider network can coexist. MDOT SHA desires to reduce these aggregation sites as much as possible and as such will look to establish regional aggregation sites (redundant) to perform this action. The "regions" will be defined by the operational capabilities of the leased service provider (LATA bounded, transported mileage considerations if applicable etc).

2. **Can Skyline /Jacobs elaborate on the need for Ethernet interfaces vs DS1, and increases in bandwidth to support High-Def video?**

   Currently MDOT SHA is limiting its video CCTV services to low resolution based on the limits on bandwidth available on the current T1 based communication services. The video and majority of the other ITS applications are either already IPv4 based or are moving towards this standard communications protocol suite. To that end as more applications are introduced there will likely be a desire to increase the resolution and framerates for the CCTV video services that will likely exceed the current 1.5Mbps capacity of the existing services. Exactly what resolution/framerate and resulting bandwidth are unknown at this time as these newer technologies and use cases are being developed. It is the desire of the Jacobs team to identify to SHA an alternative to the current model that will permit them to more easily scale the communications services so this restriction is no longer a consideration in adoption of new network based applications into the business.

3. **Is Multicasting required?**

   Yes – MDOT SHA currently operates a multicast network (PIM-SM) to support distribution of its CCTV video feeds and potentially simulcasting of future application communications as well in the future. A network solution that can participate in their multicast-based infrastructure is desired where by smart data replication can occur in the provider network efficiently. Currently the network is IPv4 based however there will likely be a transition to IPv6 in the future to support the additional device growth on the edge.

   Caveats: Depending on the design the carrier network may or may not need to participate directly in the MC services. For example the EvPL (TLS) solution doesn't need to be MC aware as the circuits are P2P in nature so the SHA equipment on either end takes care of things. The L3VPN however is P2MP any to any so it must participate in MC.

4. **Has MDOT SHA reviewed any recent intelligent traffic network systems models, involving traffic management and public safety**

   Yes – Such a review was conducted as a part of the Jacobs efforts to support the current communications plan development.

5. **Aside from supporting camera video what other applications might be shared or collaborated on this network?**

   There are several application and services however from a provider perspective they represent both real-time transactional data as well as bulk data uploads/download for logging info etc. Examples include Dynamic Message Sign control/updates, sensor polling (speed/temp etc.), land controls, and signal controls and data collection.

6. **What is the estimated timeline for network design development, budgeting and implementation?**

   As stated during discussion the Jacobs team is tasked with the development of a strategic planning document not actual design or implementation. MDOT SHA is expected to leverage the document deliverable to determine which recommendations to pursue and assign timelines for their project-based execution.

7. **Can Skyline / Jacobs elaborate on MDOT SHA's plans relative to resource sharing as a part of this network and beyond?**

   No. As stated previously the project deliverable will merely provide conceptual ideas and areas where MDOT SHA should focus additional efforts in the future and in no way will directly guide the RSA/PPP negotiation process. It will merely influence those processes.

8. **LOA for information sharing?**

   Any such request will need to be directly with SHA and not the Jacobs team using their official channels.

X.5 Follow-up Questions for Verizon

1. Do both TLS services support VLAN-in-VLAN tagging? We anticipate that field L2 traffic will be segmented by VLAN which will need to remain in tack until reaching the MDOT backbone
2. Are there any restrictions on the IPv4 or v6 addresses used for this service? Is there support for CIDR?
3. What are the various cost components associated with each service and estimated costs?
    - Local loop (fixed and variable). If we terminate multiple field TLS services at a MDOT SHA shop/maintenance facility is there only one local loop charge with an aggregated bandwidth supporting the total of all TLS services, or a separate loop for each.
    - Service – is there a basic EvPL or ELAN service charge
    - CIR / bandwidth – is this aggregate or by VLAN
    - CoS – aggregate or by VLAN
    - If as part of the Network Transformation Project a current T1 circuit is upgraded to fiber is the incremental cost to upgrade to TLS less
    - How are local loop construction costs handled? Is there a cost for buildout, does SHA incur all costs from closest Verizon cable POP to the service location or is this shared or part of an agreed service time period?
4. What is typical field equipment?
    - ONT (optical network terminal) what is typical size, environmental and power requirements. Does this serve as the Verizon local loop demark and testing point? Is this provided by Verizon?
    - NID (network interface device) – typical Canoga Perkins model 9145E or similar? Is this needed in addition to the ONT or does it serve both. Looks like a hardened model is available (-40° to +65°C). This would be provided by MDOT SHA?

Appendix XI: Communications Resource Sharing

The information provided in this section is available on Maryland.gov regarding RSA with MDOT SHA[1].

The Maryland Department of Transportation State Highway Administration (MDOT SHA) employs two overall strategies in achieving its communication objectives. These are Inter-Governmental Partnering and Resource Sharing. The benefits are significant cost savings and improved operational efficiencies. MDOT SHA's communication objectives support multiple statewide applications including MDOT SHA's Intelligent Transportation System (ITS); Coordinated Highways Action Response Team (CHART); Network Maryland; data and voice communications; video teleconferencing; and other broadband services.

MDOT SHA permits non-exclusive use of its rights of way, other MDOT SHA real estate; and its existing communications infrastructure by a Public/Private entity for the installation, operation and maintenance of communications systems for themselves in exchange for providing communications equipment, services, and/or monetary revenue/compensation to the MDOT SHA. Resource sharing undertaken by MDOT SHA and a Public/Private entity may include installation of conduit and fiber optic cabling facilities; construction of new wireless communication facilities; collocation of wireless communication facilities on existing towers or allocation of fiber strands acquired from previous Resource Sharing projects; or other transportation technologies such as data sharing.

Resource Sharing Proposals

Submit resource sharing proposals to:

MDOT SHA Statewide Utility Engineer

7450 Traffic Drive

Building #4

Hanover, Maryland 21076

or via email to RSA_Utilities@sha.state.md.us.

[1] https://www.roads.maryland.gov/mdotsha/pages/Index.aspx?PageId=872

Proposal Format

Part I - Executive Summary

1. Condense and highlight the contents, including the benefits to Maryland's economy and the Value to the State Estimate. The Executive Summary should provide an overview of the entire proposal.
2. Add examples of benefits to the State of Maryland's economy. You may include:
    - o The estimated percentage of contract dollars to be recycled into Maryland's economy in support of this proposal, through Maryland subcontractors, suppliers and joint venture partners.
    - o The estimated number and types of jobs for Maryland residents resulting from this proposal.
    - o Tax revenues to be generated for Maryland and its political subdivisions as a result of this proposal.
    - o The estimated percentage of subcontract dollars committed to Maryland small businesses and minority business enterprises (MBEs).

Part II - Value to the State Estimate

1. Submit a "Value to the State Estimate." It should be a full itemization (monetary compensation, equipment, services, etc.) of the items in the total value of its offer to the State.
2. MDOT SHA may ask you to hire an independent, third-party firm or consultant to provide a certified statement of the economic value for the Value to the State Estimate. MDOT SHA will alert you if you need to provide this third-party certification. This certification should include a detailed explanation of how you calculated value.

Longitudinal Installation Proposals

1. When formulating Longitudinal Installation proposals, address the following:
    - Request Statewide Utilities have DoIT value the fiber path(s) by route and termini by way of:
        - o Proposed route map with enough detail to see intersecting streets and names

  - Supporting equipment, cabinets, shelters (above ground facilities). Explain any special considerations
  - Preliminary cross sections and details
  - Requested term of the agreement
  - Monetary compensation or in-kind exchange offered to the MDOT SHA
2. Refer to the Department of Information Technology's rate sheets for the formula as well as rates.[2]

Macro Wireless Telecommunications Proposals[3]

1. When formulating Macro Wireless Telecommunications proposals, address the following:
   - Proposal site location with physical address and latitude & longitude
   - "Collocate" or "new build"
   - Height of existing or proposed tower
   - Number, model, size of antennae to be installed on the tower
   - Number and size of feed lines
   - Power and telecommunications availability/requirements including any special considerations
   - Preliminary site plan showing tower, requested ground space, equipment pad for the shelter or cabinets, and proposed access to the site
   - Requested term of the agreement
2. Determine the monetary value for new macro wireless telecommunication using the Maryland Department of Information Technology's (DoIT) Tower Resource Sharing - Standard Pricing Schedule and Matrix (latest revision), of antenna types and Average Daily Traffic (ADT) volumes.
   - Determine the ADT using data from the Maryland highways surrounding the proposed macro wireless telecommunication location.
   - ADT's for Maryland highways are at Traffic Volume Maps by County.

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[2] Rate sheet can be found online at the following URL: https://www.roads.maryland.gov/OOC/Fiber-Resource-Sharing-Standard-Pricing-Schedule.pdf

[3] Additional information can be found online at the following URL: https://www.roads.maryland.gov/OOC/Macro_Cell_on_Tower_Resource_Sharing-Standard_Pricing_Schedule_Ver_03-29-2019.pdf

- The DoIT's Tower Resource Sharing - Standard Pricing Schedule may be found on the webpage
- Use the monetary value determined from this matrix in your Value to the State Estimate for Macro Wireless Telecommunication proposal.

3. Determine the monetary value for the collocation of wireless telecommunications on an existing tower from the current monetary compensation received from the tower's telecommunications carrier. Use this monetary value in your Value to the State Estimate for Macro Wireless Telecommunication Collocation proposal.

Micro Wireless (Small Cell) Telecommunications Proposals

1. Micro Wireless (Small Cell) may be attached in the following ways:
   - Attachment to existing wooden utility pole
   - Replacement of streetlight to own and maintain by wireless provider
   - Attachment to structure or streetlight owned by others
   - Placement of new structure in the Clear Zone or behind traffic barrier
   - Placement with stand-mounted antennae
2. KMZ location is vetted with MDOT office(s) that may be affected.
3. Fees include an annual fee of $270 in addition to applicable one-time review fees[4].

Part IV - Concept Plans/Technical Drawings

1. Once location is vetted, engineering drawings may be required.

[4] Additional information can be found online at the following URL: https://www.roads.maryland.gov/OOC/Small_Cell_Resource_Sharing_FCC_Standard_Pricing_Schedule_rev_Aug2019.pdf