A Telecommunication Transport Approach for the Island of Puerto Rico

Melvyn Santiago Maldonado
Master in Engineering Management
Dr. Hector J. Cruzado
Graduate School
Polytechnic University of Puerto Rico

Abstract *— This project identifies and studies different telecommunications methods and their specific application for the island of Puerto Rico. This project aims to contribute to building a reliable and robust network, resilient to inclement weather while alleviating construction challenges. This project concluded that for flat areas such as metropolitan areas, a fiber optic ring is the ideal network topology option due to its capability of traveling long distances and transporting data reliably at very high speeds. Microwave links are optimal access or aggregation nodes in rural areas where fiber optic construction is not viable. They can be installed much faster than fiber optic, making them a preferred redundancy solution for fiber optic links and emergency deployments.*

Key Terms *— Fiber optic, microwave link, network topology, collocation.*

INTRODUCTION

Telecommunication services have evolved from being an exclusive service for small businesses and big corporations to becoming an essential service. During the previous years, the island has suffered natural disasters that have negatively impacted the telecommunications infrastructure on the island. The recuperation of this essential service depends on a well-designed, robust, and redundant network.

The main objective of this project is to define transport networks and methods of transporting telecommunication services and explore the viability of different transport networks to improve the reliability of telecommunications in Puerto Rico. Additionally, it aims to improve the island's telecommunications backbone and support the decision-making process to ensure faster and easier deployment of data links, while prioritizing network resilience, redundancy, cost-effectiveness, and efficiency.

The data for this project was collected by reviewing specialized literature on networks, fiber optic links, and microwave links. Construction challenges, costs, and reconstruction timeframes were collected by interviewing subject matter experts and contractors who are currently active in the telecommunication industry on the island.

This project shows a review of the different methods of telecommunication transport, specifically fiber optic and microwave links, and compares the different network configurations and how they can be used together to improve the reliability and resilience of telecommunications services in Puerto Rico.

METHODOLOGY

This project studied the different network connectivity means such as wireless microwave, and fiber optics, and their contribution to improving the efficiency and resiliency of a telecommunication network. To determine the most optimal and efficient methods for constructing a telecommunications network tailored to Puerto Rico's specific needs, a selected body of literature has been examined. This literature focuses on addressing the inherent challenges faced by the island, which are outlined below:

- Island topography
- Network redundancy
- Resilience through natural disasters

This project presents different points of view on two main telecommunications transport methods, optical communication or fiber optics, and wireless microwave communication links.

This project provides quantitative and qualitative research methods to answer the most important challenges addressed in this project, network resilience and construction challenges due to the island's topography. The literature examined presented information that provided many of the theoretical aspects of the project. A supplementary investigation was completed to review additional quantitative and qualitative aspects of the project. This was accomplished by interviewing subject matter experts to include data on construction costs, and network link recovery and to cover any limitations in the literature research.

RESULTS AND DISCUSSION

Fiber Optic Links

A fiber optic link can be established by running fiber optic cables using utility poles (aerial) or by running underground cables. Assuming a proper installation was built, a fiber optic communication link reliability will mainly depend on the physical stability and integrity of the construction. This will be dependent on the probability of a fiber cut accident or inclement weather that can destroy utility poles or damage the fiber terminal equipment by flood. Fiber optics offers the longest distance achievable for a communication link. One popular example is the use of fiber optics to establish communication links between islands and continents by deploying submarine cables. The device that illuminates the fiber optic between two points is called an optical transducer. An optical transducer device converts electromagnetic waves into light pulses that will be transmitted through a glass fiber strand. These electromagnetic waves are measured by their wavelengths, and they have different attenuations per kilometer as a function of the wavelength [1]. This relationship is depicted in Figure 1. To prevent attenuation due to the length of the link, a transducer is selected during the fiber link design process. The transducers are chosen depending on the link distance which dictates their signal transmission power.

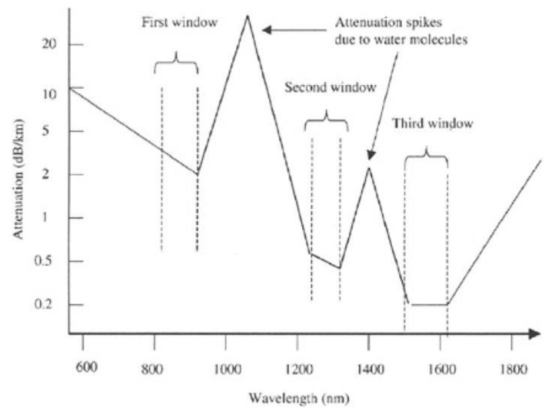

Figure 1
Attenuation Per Kilometer as a Function of Wavelength [1]

The data rate will be defined by the capabilities of the network device (such as a router) and its transducer. To increase the link speed, it would be required to just replace a network interface card in the router and/or the transducer. This makes fiber optic a future-proof solution compared to microwave where to increase the speed in a microwave link, it will reach a point where the whole link will need to be replaced.

Microwave Links

Microwave links have the best reliability compared to the destruction of utility poles during natural disasters or human errors such as fiber cuts during construction activities. A microwave link that is correctly designed and properly installed is 99.999% reliable. A microwave link reliability also depends on a clear unobstructed line of sight, the operating frequency band, and signal interference. From these variables sometimes the most challenging one is having a clear line of sight between the desired link ends, and the operating frequency of the link. The operating frequency of the microwave link will depend mostly on the distance of the link. The longer the link distance, the lower the operating frequency. Additionally, lower operating frequencies tend to be less prone to attenuating environmental factors such as rain and fog. Another challenge for microwave links is signal interference. Signal interference or electromagnetic interference (EMI) is usually caused by other devices in the area operating at the same or adjacent frequencies. This can be avoided by obtaining frequency utilization licenses from the FCC. This will ensure the frequencies utilized by the microwave link will not interfere with other frequencies and other frequencies in the area will not interfere with the wireless path. These frequencies can range from 6 to 80 GHz.

The design process to determine if both ends of the wireless communication path will be capable of transmitting and receiving with the intended link reliability is called the link budget. This is one of the first design steps to determine the components of a microwave [2].

This process takes into consideration the antenna transmits power, the gain of both transmitting and receiving antennas, signal attenuation due to coupling, and the link distance. These factors are shown in Figure 2.

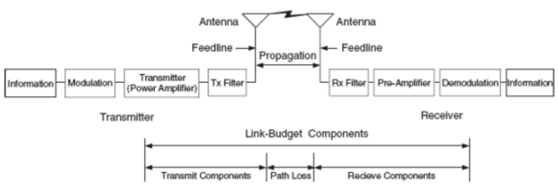

Figure 2

Link Budget Components [2]

Construction Challenges and Costs

The construction challenges can include the link distance that can be achieved by each connectivity method. This link distance span is mainly dictated by the island topography and any existing infrastructure that could facilitate the installation.

Fiber optic connectivity represents the preferred method of network connectivity due to its long-distance coverage [1], high speeds and low latency. However, the island's topography presents several challenges due to the abundant rural and remote areas. These areas rely on existing infrastructure to run fiber optics in poles which most of the time are in questionable conditions due to the lack of proper maintenance, and building new fiber optic infrastructure tends to be costly compared to a microwave link. This type of link can be used to overcome these challenges, especially the cost of building a link. Figure 3 shows a comparison of building a fiber optic link versus a microwave link as a function of the link distance. Even though microwave links are robust and commonly designed with a reliability of 99.999%, they offer lower data rates than fiber optic links at high distances. A conscious network design is desired to balance these tradeoffs between the best link medium and the required data rate.

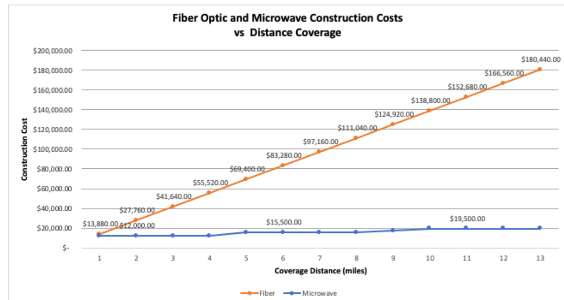

Figure 3

Fiber Optic and Microwave Construction Costs vs Coverage

The installation speed is more favorable for microwave links. As an example, once the design, site surveys, and permits are completed, one 10-mile wireless microwave communication link can be installed in at most one week while 10 miles of construction in fiber optic can take months. For a fiber optic link, construction costs and its challenges would determine the distance of the link whereas for microwave, as the cost doesn't vary as much per distance, the main consideration would be having a clear line-of-sight between both ends.

Network Resilience

Network resilience refers to a network's ability to quickly recover or maintain service during unexpected failures such as adverse weather or a natural disaster. Resilience can be achieved by utilizing different strategies. From energy backup systems to maintain the devices operating in case of power outages to having physical devices in place for immediate replacement, or devices that offer the capability of failover to redundant controllers or service cards. The installation speed is significantly faster than fiber optic construction. Microwave link installation speed makes it a great solution to temporarily replace a fiber optic link that would need a lengthy repair. Another application is to establish a microwave link in parallel to a fiber optic link for redundancy [3]. All of these are subsets of network engineering design, but from a connectivity perspective, the most important phase of the design is to choose the network topology.

Network Topology

Network topology refers to the interconnectivity of network devices or in this case, network nodes. There are six different network topology types such as point-to-point, bus, ring, star, mesh, and hybrid [1]. A point-to-point network, as the name implies, connects one site to another. In terms of network resilience, this provides the least amount of protection because it has a single point of failure and does not provide alternate data traffic routes. The bus network type connects multiple sites through a common main network link or bus. The vulnerability of this network type depends on the localization of the outage. The ring network interconnects each node with two alternate routes. In the event of a link failure or degradation, the traffic switches direction to an alternate route. The star network topology interconnects the nodes to a central node. This topology provides good redundancy, but it is dependent on the central node's redundancy. In the mesh network topology, each node interconnects to each other. This network topology offers the best level of redundancy at a very expensive cost. A hybrid network topology integrates two or more network topologies. For example, it can connect a ring network to a star network, two ring networks connected through a bus, or a mesh network with a ring network, etc.

There are six main network topology options, and they depend on the specific service availability needs of the network. In practice, choosing the network topology is more of an economic decision due to the high cost of implementation and construction challenges. The network can change over time depending on how the network needs and bandwidth changes over time. The different network topologies are shown in Figure 4.

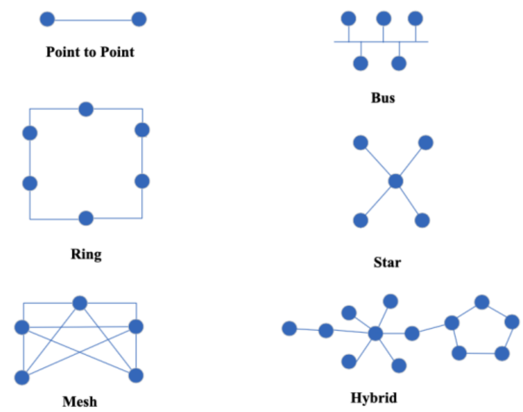

Figure 4
Network Topologies

Network Categories & Collocation

There are three different types of network categories based on coverage area [1]. The smallest network type is the local-area network (LAN) which covers a minor area such as a home, office, or building. A metropolitan area network (MAN) ranges from several blocks to a whole city or metropolitan area, and the largest is the wide area network (WAN) which could interconnect network elements between different cities, and countries. Puerto Rico would fall in the WAN category, and, to support resilience in case of a natural disaster, each node that aggregates traffic from several small areas should be collocated in the incumbent local exchange central offices [4]. These offices are equipped with redundant power generators, redundant air conditioners, and uninterrupted access to the facilities. An incumbent local exchange carrier is the carrier that established the first large-scale telecommunication infrastructure on the island and the FCC enforces the incumbent local exchange carrier to allow other competitors to reach collocation agreements.

CONCLUSIONS

Fiber optic and microwave both have their benefits and disadvantages. Fiber optics have higher speeds and longer distance coverage, but construction cost starts to double after two miles compared with a microwave link and grows linearly with distance, reaching 10 times the cost in a 10-mile coverage. Microwave links still have good speeds and great cost-effectiveness, the installation speed is much faster than the fiber optic, but its connection speed is still lower than fiber and is not as future proof as fiber. The topology configuration options are endless however, if cost is not an issue, the mesh network topology offers the best network redundancy option, but the hybrid one is the most applicable in real life.

Due to the diverse topography of the island, a combination of fiber optic and wireless links offers the best and most cost-effective option.

For rural or remote areas, a wireless link could be optimal if the areas are not densely populated and data traffic is not expected to be high, or as a redundancy for fiber optic links.

Ring nodes will carry traffic from aggregate nodes, they will have multiple routes connected with fiber optic and some of them could have a redundant link, for example, an aerial fiber optic route using an underground fiber optic with an alternate geographic route or a microwave link as a backup. These nodes would be installed as collocations in the incumbent telecommunication central offices throughout the island. Aggregation nodes are nodes that would receive traffic from access nodes. These nodes are going to have medium traffic and would be connected to a ring node preferably through a fiber optic connection and could be considered to have a microwave link as a backup. These would be installed in collocations of the incumbent central office, cell towers, or other competitive carrier central offices. Access nodes are endpoint nodes with low traffic. This type of node would use a microwave link as its primary method of transport and would not have a transport backup. These nodes can be installed in small central offices such as remotes.

For planning purposes, these nodes should be monitored to consider them to be upgraded to a higher tier or to build a backup route. For example, upgrade an access node to aggregation nodes and aggregation nodes to ring nodes depending on the traffic and the importance of the nodes attached to them (hospitals, airports, schools, enterprises etc). As an example, a ring star network can be built in each municipality either using wireless links or fiber and have one aggregation node connected to the island's main ring. Each ring will be interconnected with a fiber optic link and a wireless link can be installed in parallel for redundancy purposes as shown in Figure 5.

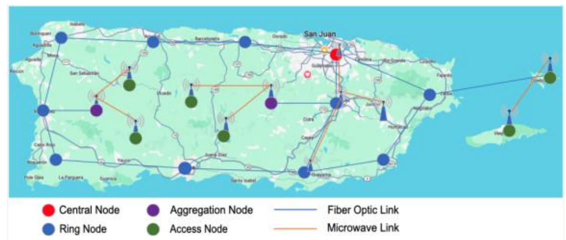

Figure 5
Example of Proposed Transport Network

A traffic engineering design would be needed to determine the bandwidth need of the link and how data will be prioritized in case of an outage, for example, voice traffic versus internet data. Selecting the network topology that better suits the island is both a strategic and economic decision and having the proper technical and economic resources could determine the success of a robust and state-of-the-art telecommunications network.

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