Backhaul for Public Safety Networks

Abstract:

Public safety is undergoing a revolution in situation awareness due to the inclusion of multimedia. Unfortunately, many public safety communication networks were not designed or envisioned to support multimedia and the wealth of other data intensive applications. The increasing use of data and multimedia applications to enhance first responder situation awareness requires that the backhaul network must be capable of supporting this demand. This paper will explore several options available for backhauling large amounts of data in real time.

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Public safety is undergoing a revolution in situation awareness due to the inclusion of multimedia. Unfortunately, many public safety communication networks were not designed or envisioned to support multimedia and the wealth of other data intensive applications. The increasing use of data and multimedia applications to enhance first responder situation awareness requires that the backhaul network must be capable of supporting this demand. The use of media rich applications brought upon by technology advances, places pressure not only on the backhaul but on the public safety operating budgets to take advantage of these critical advances.

One of the daunting tasks for public safety personnel involved with the design, deployment and operations of a communications network is what backhaul technology should be used today and provide future proofing, so you do not continue to have stranded assets. The three main backhaul technologies which can be used for addressing the backhaul requirements for public safety are fiber optics, wireless transport and satellite. However, the reality is that no single technology can fully support all public safety's communications' requirements. It is a combination of different technologies based the requirements, budgets and network topology which will determine the what, when and where decisions.

In this brief article what will be discussed are some of the essential backhaul design considerations that need to be included with a backhaul network for public safety. The backhaul design considerations include design guidelines which are based on needs and traffic analysis as well as the desired network topology. Then a general description of the three primary technology choices for backhaul starting with a basic description, their typical uses and a brief listing of some pro and cons for each.

Backhaul Design Considerations:

The Backhaul configuration for a public safety network can consist of terrestrial circuits, copper and fiber, wireless transport and satellite or a combination of all three. The backhaul itself can either be for a single path or a complete network topology design depending on the what the requirements are.

However, when designing a backhaul network whether it is for a single or multiple path it is essential that you know first what your objective is. The objective is simply your design goal or desired outcome. Specifically, for the objective you should define what you are solving. Is this backhaul being put in for connectivity, capacity, resiliency, performance, budgetary reasons or any combination of these. The next step is to determine when the circuit or circuits need to be in service. Then you need to define how you will get this task done through the establishment of a plan.

Sometimes the first part of the process is the hardest. The design process involves the creation of a system architecture that provides the interconnection capabilities to support the various elements of the public safety network(s) which includes both wired and wireless nodes.

The backhaul design process needs to include the following items as part of the process.

- Obtain your existing network backhaul topology
- Identify the connectivity requirements for the network and individual links
- Obtain the existing capacity and functionality requirements, latency, redundancy and reliability objectives
- Compare the existing backhaul topology against your design/performance criteria
- Obtain the existing OpEx costs as well as CapEx for the current network or link.
- Project what the needs will be over a defined period of time as well as future growth.

Now that you have the current network backhaul topology if there are no gaps or additional needs then everything is fine. However, if you determine that there are some gaps or additional needs to support the public safety broadband requirements for backhaul then a design process needs to begin either for the link, portion of the network or the entire network. The backhaul design process can be organized into three functional step which are:

- HDR – high-level design review
- PDR – preliminary design review
- CDR – critical design review

The adherence to the three-step process should be structured so that it creates a logical review process but does not impede the ability to improve the network or lengthen timescales.

As an example, the HDR would cover the objectives for backhaul design – technology options, architectures for enhanced reliability, long term growth plans etc. The PDR and CDR would focus, in progressing detail, on the specifics of the design and assumptions, QoS objectives and impact, and construction impediments. The PDR and CDR would also review the impact to other processes impacted by the backhaul design result, as well as construction budgets. The CDR would be the final review defining the resulting infrastructure that is required.

The High-Level Design Review (HDR) is the first step in the design process. The objective is to review the overall solution for the backhaul network. Issues that will be addressed involve the interface, capacity, quality and availability specifications of the network designed and integrating this into the system management, end users, financial, legal and regulatory requirements.

Some of the major topics that need to be addressed in the technical HDR are:

- Network Topology and Architecture selected
- Availability, capacity and quality levels supported
- Technology Strategy
- Integration into existing network architecture
- Interconnect Plan for all services supported
- Vendor and equipment/system selections
- Network management architecture
- Growth concepts
- System Availability and fall back requirements
- Disaster recovery
- Future Services/Platforms concept

The Preliminary Design Review (PDR) process bridges the gap between the high-level design and final critical design for the system or platform offerings. The preliminary design ensures all the technical details are presented in a formal process with one distinction. The preliminary design is not the final design and the design presented is intended to be a tentative baseline solution based on all available information. The preliminary design result can be a direct move to the Critical design or lead to revisions to the fundamental design requiring a revisit to key business and technical assumptions utilized in the creation of the preliminary design.

For the preliminary design to be effective the following are the general items, which need to be included in the design process. Depending on the specific network element and the design objective some of the general topics can be removed. However, the list is not all inclusive and is not rank ordered.

- Design Criteria
- Traffic Design
- Capacity forecast per node (1,2,5 yr.)
- Network Topology/Architecture
- Path Analysis
- Backhaul technology Platforms Chosen
- Service Treatment Methods (features/capabilities)
- Service Level Agreements (SLA)- by type including QoS, KPI and restoration
- Resiliency and Availability Objective (99.XXX%)
- Interconnection requirements (PSTN, Internet, Private Network)
- Available interconnect options (Fiber, Microwave, Copper, satellite)
- Synchronization Plan
- IP Address Plan
- Facility Diversity Plan
- Power Plant (AC/DC and Generator) design
- Disaster Recovery Plan/Requirements
- Implementation Plan (key dates and requirements)
- Personnel Resources
- Equipment Ordering and Delivery Schedule
- Installation and Commissioning
- Legacy System Plan
- Monitoring Plan (NOC)
- Regulatory Requirements (FCC licenses)
- Activation
- Budget (CapEx and OpEx)

The Critical Design Review (CDR)'s objective is to lock down the design. The lock down is important for several reasons related to logistics for not only securing and configuring the physical property locations, ordering and commissioning facilities and ordering the necessary equipment so that it will arrive in the required time frame for service delivery.

The chief (main) difference between the PDR and the CDR is that during the PDR open issues could be identified and left for refinement while in the CDR there can be no open issues left for debate.

The design process or review should take place on a regular basis. The specific interval should be chosen so it facilitates a healthy backhaul network. The performance of the backhaul links and network should be monitored on a continuous basis. However, a review of the backhaul network design and topology should be done at least once a year.

A difficult step in any backhaul design process and especially in public safety is determining the specific needs for each of the various departments and agencies which will be using the backhaul.

Therefore, it is important to obtain a brief needs assessment from each. The questions at a high level involve

- What – what is the objective or current needs, i.e. what are you trying to accomplish?
- When – when does it need to be realized, implemented?
- How – how is the resolution going to be achieved, i.e. the plan?
- Constraints – What constraints are to be placed on the design?

Answering these four questions will ensure that the objective, prioritization and actualization are achieved in an organized and planned method.

The system traffic analysis directly defines the transport requirements for the backhaul design. The traffic and transport requirements for overall backhaul and the specific link requirements for each path is defined by the expected usage and applications that are needed to be delivered to and from the end terminal devices.

- Projected traffic and types of service offerings (launch, 6mo, 1,2 and 5yr)
- IP and circuit switch traffic blends with growth including potential migration of existing legacy systems (i.e. possible traffic mixture implications with VoIP and H.265)

The cost effectiveness of an architecture can be determined only on a case-by case basis, since it depends on many case-specific considerations and conditions.

The topology of the backhaul network is directly linked to the transport requirement. The topology design will most likely a combination of topologies due to legacy issues. However, the backhaul topology ideally should migrate toward a flat architecture whenever possible.

Therefore, the backhaul topology and architecture needs to ensure that traffic, both voice and data, can be sent and received between the desired elements in the network. While the design will be unique for each network there are some general concepts and topologies which are applicable. Typically, a design involves multiple sites and nodes which utilize several types of connectivity methods including leased T1/E1's, fiber, wireless transport and satellite.

Before the topology design can commence the existing infrastructure, which is owned, leased or available for potential use needs to be reviewed and included in the design process to ensure that the most efficient use of available resources while reducing the overall Total Cost of Ownership (TCO) has been achieved. It is suggested that the existing infrastructure used or available for use be mapped on the network diagram if it has not been done already.

Topology:

The backbone topology in support of broadband demands can and does take on many different configurations and in most cases has a combination of different topologies. The following are the more general topologies that are used either by themselves or as part of the overall backbone topology. The four basic topology types are flat, star, mesh and ring. These links can be from a service provider or be directly owned by public safety.

The topology used for the public safety broadband network can be a single link also referred to as a point to point link or involve multiple links. For example, a star configuration, also called a hub and spoke is a configuration that exists in many wireless broadband networks. With the star configuration there are concentration nodes, or rather aggregation points where many nodes or devices are directly connected to a common element. With a star configuration a failure with an aggregation node, depending on the protection scheme employed, will isolate the node from the rest of the network. All the other nodes that are not connected through the aggregation node will continue to operate normally.

The loop or ring network topology is another configuration which usually two paths for connectivity for nodes. This path diversity scheme provides a higher resiliency if one node has failure affording an alternative path for the other nodes to transport their traffic. Many loop, ring, topologies operate in the U.S. utilizing SONET. While SONET affords greater resiliency than a star configuration to facilitate an alternative path, typically only half of the available bandwidth or carrying capacity is used in this configuration to facilitate the path resiliency.

The third type of network topology that is being more readily deployed is the flat architecture. A flat network topology, also referred to as Metro Ethernet, utilizes an IP only backbone to achieve connectivity. The flat network topology affords high resiliency and is effectively a large LAN. A flat architecture is desired to improve latency in any backbone design.

When determining which topology design best supports the connectivity needs a lot of information needs to be considered. Depending on the actual configuration the list of nodes requiring connectivity can and will vary based on the system requirements. Therefore, when selecting the type of topology or topologies that will be used the following items need to be considered.

- Network size (number and location of network nodes)
- Capacity and traffic growth between each node
- Interface and signaling requirements
- Preferred locations for effective interconnect to OMC, PSTN, Internet, etc.
- Availability of existing fiber optic capacity; cost and reliability
- Availability of microwave spectrum
- Availability of leased lines and related cost, reliability issues.
- Availability of public and private right-of-way permits to construct or extend a fiber network.
- Cost and budget constraints
- Requirements of design scalability and flexibility
- Multi-vendor environment issues related to problem isolation
- Space and power requirements
- Recurring costs

Technology:

Three types of transport technology will be briefly discussed next. The three transport technologies are Fiber Optics, Wireless Transport and Satellite.

Fiber Optics:

Fiber optics communication networks utilize pulses of light to send data over a glass cable. Fiber optics are superior to typical copper connections since they provide high capacity connectivity with very low latency. Fiber optics facilities can support any transport protocol like TDM, ATM, IP as well as proprietary transport protocols.

Fiber optics connectivity are typically provided by leased lines from the LEC or CLEC. However, depending on the amount of fiber links needed or the requirements, public safety can deploy its own fiber optic network.

Fiber optic facilities are grouped into three basic categories, lit, dim and dark. If the fiber optic link is lit, then it is transporting traffic on it and operated by a service provider. If the fiber link is dim, then the operator or lessee has control of the fiber link itself from the service provider. If the fiber is dark, then you are normally responsible for providing the circuitry to enable the fiber to transport traffic.

All fiber optic circuits utilize either a single mode (SM) or multimode (MM) fiber optic cable. The choice of which fiber type to use is dependent upon the application it is being used for. Specifically, SM uses an optical frequency that is modulated by use of a laser allowing it to transmit the data over a long transmission path. MM however uses LED's for sending and receiving data and is meant for short distance communication links, typically within a building and has a lower bandwidth than single mode.

SM has less attenuation than MM due to the characteristics of the fiber optic cables properties. Additionally, SM fiber is used in many applications where data is sent at multi frequency Wave-Division-Multiplexing (WDM) and Dense Wave-Division-Multiplexing (DWDM).

Therefore, if you are connecting two nodes or multiple nodes across the state of city then you are most likely going to utilize SM fiber. However, if you are connecting fiber between racks of equipment within a building or between floors you will probably use MM fiber. MM is cheaper than SM since it uses diodes instead of lasers and does not require the higher-grade optical cable characteristics.

A typical leased service for fiber optics is referred to as Metro Ethernet network (MEN). A MEN is an IP network using a fiber optic backbone and is usually established as a ring topology. MENs however are not available everywhere. There are two types of MEN connectivity: Ethernet-Line (E-Line) and Ethernet-LAN (E-LAN). E-line is a point to point service that is done by setting up a VPN between the two nodes. While E-LAN is a multipoint connection where the E-LAN appears as a LAN connection to the Node.

One important note is that just because fiber is on the street where you have a node does not mean it is available. For connectivity with fiber an optical multiplex unit (OMU) needs to be present to facilitate the data entering and exiting the fiber network itself. The OMU uses lasers and there are different frequencies that can be used based on the selection of the laser itself.

Fiber optics used for a backhaul network can be deployed as point to point, multi-point or ring architecture in any broadband backhaul network. Fiber optics can and should also be part of an overall network survivability strategy. Specifically, if resiliency though diverse routes are important, the diverse routes of the two fiber paths take have no common elements or transverse the same conduit.

The capacity of a fiber optic system depends on many factors however the following have a direct say in the capacity:

- The bit rate capacity of the Fiber Optic Electronics
- Quality/Characteristics of the Fiber Optic Cable
- Protection ratio employed

When designing or configuring a fiber network some of the key requirements for the design include:

- Network Architecture requirements including topology
- Network capacity projections at every level

- Protection Scheme options
- Type of construction (buried, aerial)
- Fiber grade and manufacturer
- Cable reel lengths, splice/repeater locations
- Connector type
- Laser type
- Fiber Terminating and Interconnecting equipment availability and cost
- Location of existing fiber terminal equipment
- Proposed/ultimate equipment requirements for all locations
- Type of multiplex equipment required for interface between networks and network elements

A fiber optic system will normally be used as a backbone transport to connect major network locations either as point to point systems or with a ring configuration. The decision to use a fiber optic system as part of the overall backhaul design will depend on the following:

- Service Cut-over schedule
- Capacity needs
- Link distances and size of network
- Type of construction (aerial, buried)
- Ability to secure property to house equipment (leased or acquired)
- Ability to secure permit and licenses to build infrastructure
- Vendor and equipment availability
- Available CAPEX

Wireless Transport

Wireless transport uses a radio link to connect one node to another node. A node can be a broadband wireless site, or it can be a network operating center. Wireless transport utilizes microwave frequencies for its radio link. These links can be deployed as a last mile or access connection, backbone or a combination of both. Wireless transport links can support both TDM and IP traffic. These links(s) can be constructed as a single hop of less than 2 Km or as a backbone route (backhaul) that includes multiple hops spanning 15-20 Km each. Wireless transport link paths require line-of-sight and are often limited in use by building or terrain blockage or existing use of the licensed spectrum within urban areas.

Frequency bands used for wireless transport is recommended by the ITU. Each band is defined for the frequency range, the channel spacing, and the bit rate. However, restrictions are placed on the link distance so that the lower frequency bands are reserved for the longer hops. Some of the microwave frequency bands used are 2 GHz, 6 GHz, 11 GHz, 18 GHz, 23 GHz, 36 GHz, etc. The higher frequencies have greater bandwidth however they also have less range.

With wireless transport it is preferable to utilize licensed frequencies for mission-critical networks to protect the network from unintentional interference from other users. Several license exempt frequency bands are available depending on geographic area.

License exempt wireless transport links, can be implemented more rapidly and are well suited for temporary solutions. However, it is not recommended as a long-term solution due to the risk involved to the reliability.

The wireless transport network can be established as a point to point link meaning it connects one node to another. Wireless transport can also be configured for a star connection where a group of nodes all concentrate their traffic to one place. Another typical configuration for wireless transport is a ring topology used primarily for resiliency. However due to network topology all these configurations can be utilized in different parts of the system.

Wireless transport can have a variety of resiliency alternatives from providing N+1 or 1 to 1 hardware. It can also utilize link redundancy by having another link established between the nodes for backup purposes.

Some of the key requirements or support information needed when designing wireless transport enabled backhaul network or link are:

- Overall Network Architecture / Topology Plan
- Interface Requirements (Cat5/6, T1-E1)
- Link Details (per link)
    - Link capacity required
    - Frequency of operation
    - Polarization
    - Antenna size requirement
    - Antenna height
    - Antenna azimuth
    - Hop length
    - Line of sight survey report for link
    - Protection scheme (hot standby, loop, etc.)

Wireless transport enabled networks can be constructed with path redundancy in a ring/loop configuration or connected to fiber optic system (hybrid). The decision to use wireless transport as part of the backhaul architecture will depend on the following:

- Spectrum (licensable channels) availability
- Construction cost and schedule (includes licensing and frequency coordination time)
- Capacity requirements vs. available channel bandwidths
- IP capability and availability of specific interfaces
- Links distances and line of sight issues
- Ability to secure permit and licenses to build infrastructure (includes zoning)
- Vendor and equipment availability

The high-level Microwave Backbone design steps are:

1. Needs Analysis
2. Traffic Analysis
3. Topology Design
4. Preliminary Path Profiling
5. Field Path Surveys
6. Final Path Profiling
7. Path Propagation Performance Analysis
8. RF Interference Analysis and Channel Selection

9. Prior Frequency Coordination Notification
10. FCC License

Wireless transport links (point to point and more recently, point to multipoint) are often used in conjunction with fiber optic and/or wire line services to interconnect communications network equipment.

Satellite

Satellite communication systems come in many varieties and depending on your specific requirements for coverage and bandwidth the proper system can be selected for your needs. Satellites can be low earth orbit (LEO), medium earth orbit (MEO) or geosynchronous earth orbit (GEO). However, all satellite communication systems utilize line of sight between the satellite and the end device.

Satellite communications involves both fixed and mobile devices. The mobile satellite services (MSS) either are portable satellite phone or terminals. The MSS satellite phones are narrowband and provide voice services allowing for reach back to either another satellite phone, cellular phone, or landline. Another type of MSS is a Broadband Global Area Network (BGAN) satellite terminal which can be mounted on a vehicle or in a backpack and are quick to set up and can support data rates of up to 256kbps.

MSS is excellent for immediate setup however the Fixed Satellite Service (FSS) enables higher bandwidth. FSS systems typically operate in the C or Ku Bands. The Ku band typically requires a 3 to 8-foot dish and the C band needs a dish of 12 feet or more in diameter.

High Throughput Satellite (HTS) is the next generation satellite telecom. HTS systems use spot beam technology which greatly enhances its throughout giving it the ability to provide broadband services. HTS falls within the MSS and FSS satellite spectrum assignment.

Whether the satellite system is fixed or mobile it relays its signal through a satellite that can go to another satellite device or to the internet or landline service. Satellites are equipped with multiple repeater units called transponders and some satellites can be linked together to form a meshed network.

Satellite communication has the unique ability to deliver bandwidth exactly where and when it is needed independent of the geography and local infrastructure. GEO Satellites are typically used for backhaul requirements. For a Public Safety backhaul network each node would require its own satellite connectivity link and most likely utilize the same satellite for all its communication needs.

Some of the advantages with using satellite communication for backhaul include:

- Broad coverage area
- Independent of Terrestrial Facilities
  - Ideal for remote connections
  - Disaster Recovery
  - Mobile incident command setup
- Transmission cost is independent of the coverage area
- Able to provide load sharing and surge capacity
- Redundancy though providing path diversity

Some of less advantage would include:

- Bandwidth limited to satellite transponder capability and available bandwidth
- Cost inhibitive

Satellite communication systems should be part of a public safety communication system helping to protect critical links by providing a communication path in times of emergency or in establishing a mobile communication system. Satellite communication should be used along with fiber optic, wireless transport and/or wire line services to interconnect communications network equipment.

Brief comparison:

The table 1 is a brief comparison of the three transport technologies for broadband backhaul.

	Fiber Optic	Wireless Transport	Satellite
Bandwidth	Unlimited	In Gb/sec	limited
Latency	Low	Low	High (need PEP accelerator)
Reliability	High	High	High
Climate Effect	Immune except when Rx or Tx hardware is damaged by flood	Weather affected	Weather affected
Terrain	Not effected	Need LOS	LOS
Deployment time	Increases with distance	Quick	Fast
Mobility	Not possible	Possible	Vary MSS- is portable
Reusable	Typically, cannot be relocated once deployed	Can be removed and relocated if required	FSS - Can be removed and relocated if required
Regulation	Right of way	Spectrum regulation (even for license exempt)	Spectrum regulation
Cost	By distance in $/Ft or $/Meter a) Number of channels required b) Point to point link distance c) Type of install (in ducts or overhead)	Cost per link (by distance)	Independent of distance

Table 1: Backhaul Transport Technology Comparison

Conclusion:

The requirements and needs of public safety continue to evolve wireless transport for backhaul can and will continue to play a critical role in meeting their communication needs.

Since there is no single technology or network topology that will meet all public safety's requirements a hybrid approach is needed.

Each technology discussed in this article clearly has its pros and cons depending on the specific demands of a situation and geographical area. Thus, every public safety agency needs to choose a combination of backhaul technologies that best aligned with their needs both currently and into the near future.

Through following a best practices approach for backhaul design the proper combination of backhaul technologies can be achieved meeting the short term and long-term needs of public safety.

I trust that you found this article useful.

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Who we are:

NGC is a consulting team of highly skilled and experienced professionals. Our background is in wireless communications for both the commercial and public safety sectors. The team has led deployment and operations spanning decades in the wireless technology. We have designed software and hardware for both network infrastructure and edge devices from concept to POC/FOA. Our current areas of focus include 4G/5G, IoT and security.

The team has collectively been granted over 160 patents in the wireless communication space during their careers. We have also written multiple books used extensively in the industry on wireless technology and published by McGraw-Hill.

Feel free to utilize this information in any presentation or article with the simple request you reference its origin.

If you see something that should be added, changed or simply want to talk about your potential needs please contact us at info@nextgconnect.com or call us at 1.845.987.1787.