Spectrum and Utility Communications Networks: How Interference Threatens Reliability

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Executive Summary

This paper provides a fundamental explanation of the importance of highly reliable and available telecommunications for electric utility operators and examines the impact of potential interference in the 6 GHz spectrum band to utility point-to-point microwave systems. It begins with an overview of how the electric grid is structured, the associated applications required to make it function, and telecommunications technologies required to control the grid. It provides insight into how grid technologies are evolving and the associated telecommunications technologies necessary for this evolution to be successful. In each area, this paper underscores utility reliability and the essential role telecommunications play in the management and stability of the grid. It discusses the impact resulting from a loss of telecom services and the compensatory measures that are required to account for the potential for interference. Additionally, the paper describes an overview of the utility telecom architecture, including the specific telecom transport technologies employed, how they function, and a discussion of related weaknesses, strengths, and cybersecurity concerns.

This paper provides a background regarding the utility telecom landscape, from the data center to remote distribution devices and meters in the field; its key objective is to explain and justify the need for "Five-9's" of availability within the utility telecommunications backbone, and specifically the potential impact of interference on point-to-point microwave systems in the 6 GHz spectrum band under a petition being considered by the Federal Communications Commission (FCC, the Commission)[1]. As this paper demonstrates, unlicensed operations in the 6 GHz band could have profound impacts on the reliability of utility communications networks, which, in turn, will likely threaten grid reliability.

The utility telecommunications network backbone is typically a combination of fiber optics and microwave point-to-point transport technologies that aggregate and transport all critical utility applications used to manage and control the grid. This includes the highly critical transmission-system protection requiring the detection of fault disturbances in millisecond detection that, if compromised due to interference, would result in system instability and potential blackouts as well as federal regulatory violations. *This is the crux of the necessity for extreme levels of availability within utility telecom systems.*

Microwave systems are a key component of the utility telecommunications infrastructure and any potential challenges to its operating integrity could have a negative impact on electricity reliability. Utilities predominantly use systems in the 6 GHz band due to its optimal propagation characteristics and data capacity or throughput. Under the typical deployment scenarios—with links stretching up to 50 miles in length--higher frequencies are quickly attenuated beyond the required signal margin, especially during inclement weather. Therefore, these microwave systems in the 6 GHz band are a primary component of the utility telecommunications

[1] FCC 6 GHz proposal

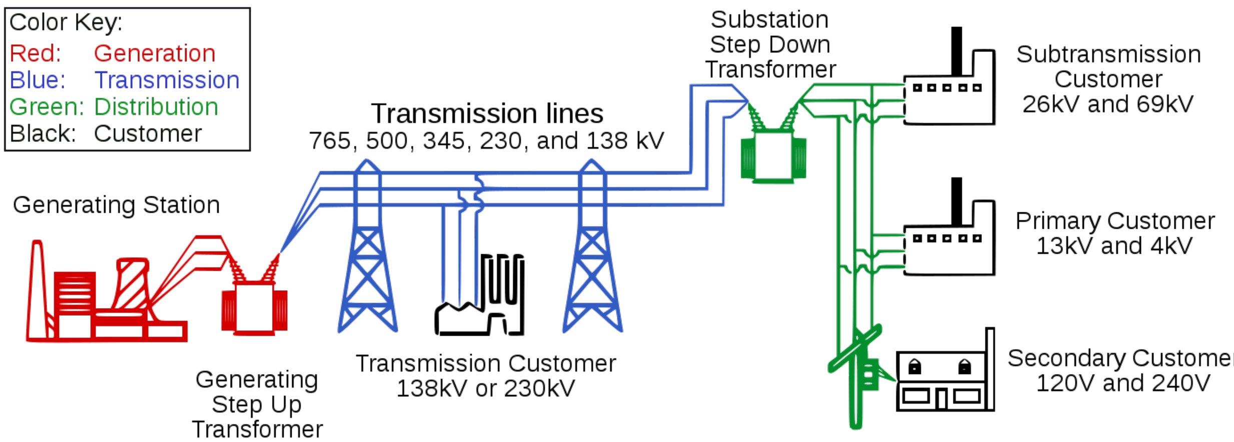
infrastructure and any potential challenges to its operating integrity could have a negative impact on electricity reliability.

Introduction

The electric power grid is one of the most critical resources within the United States and is essential to enable society to function. The grid is a complex system composed of equipment built to deliver centrally generated power to homes and businesses across a utility's territory. For purposes of this paper, the grid will be broken down into two functional systems: the transmission system, which operates at high voltages, approximately 69 kV up to 765 kV; and the distribution system, which functions between 4 kV up to 46 kV. The distribution system is the most recognizable as it can be viewed as poles going down streets or along the roadway, commonly referred to as "distribution feeders." Pole-top transformers are then used to reduce the voltage further to provide power into homes and businesses.

The transmission system is commonly characterized as the large lattice structure or monopole towers with wire conductors stretching across the territory landscape. The transmission system– sometimes called the Bulk Electric System (BES)--typically originates at a power generation facility and transmits power at high voltages across long distances. The transmission system interfaces with the distribution system at "substations" where switchgear and transformers reduce the voltage to levels that allow the safe distribution of electricity to serve businesses, communities, and homes.

Note: this is a simplistic description of the power grid. In reality, it is a highly complex fabric of copper wires and switchgear woven together across the utility territory. Underscoring the complexity is the need to monitor and control the grid. Similar to air traffic control, utilities have control rooms with monitors or mimics of the grid within their territory, typically one control center for the transmission system and one for the distribution system. The operators monitor critical parameters controlling the flow of power throughout the grid, fundamentally matching power supply with demand as it varies throughout the day, thus ensuring the system remains stable. *The need for continuous and instantaneous balancing of power demand with supply is foundational to grid management, establishing the strict requirement for highly reliable telecommunications. In order to maintain this balance, utilities must have highly reliable telecommunications to monitor and control the flow of electricity on the grid. Reliable telecommunications and the associated network infrastructure are the critical enablers in providing visibility in maintaining the balance and must be available within milliseconds of resolution.* This will be commonly referred to as "visibility to the grid" throughout this paper. Loss of visibility to the grid means the operators cannot monitor or control the supply and demand of power.



Regulatory Reliability Requirements for the Grid

Because of the essential services supplied by the power grid, its reliability extends beyond convenience for utility customers; in fact, grid reliability on the transmission system is regulated by the federal government. Congress in the Energy Policy Act of 2005 established a regulatory regime which requires all electric utilities to follow reliability standards proposed by the North American Electric Reliability Corporation (NERC) and approved by the Federal Energy Regulatory Commission (FERC). Under the law, NERC develops standards specifically for the Bulk Electric System (BES). The BES includes centralized generation plants and extends to the transmission system, but notably does not include the distribution system. Once FERC accepts the standards as final, it has the authority to fine utilities if they are out of compliance with the standards for up to a million dollars a day for a given violation. The reliability standards address two functional areas. First is the adequacy of supply (power) to be delivered to customers at any time. Utilities must ensure their systems are capable of adequately meeting the demand for energy at any given time. Second is the security of the BES to withstand disturbances and unforeseen equipment failures while maintaining full functionality, this includes maintenance of grid and telecommunications infrastructure, as well as potential cybersecurity vulnerabilities which are directly tied to the telecommunications infrastructure. This further underscores the need to ensure telecommunications reliability and the significant role utility telecom systems play in supporting the reliability of the BES. As will be discussed throughout this paper, reliable telecommunications are an essential component in managing the availability of the BES.

The Evolution of Utility Communications

It has been said that grid technology has remained unchanged for generations, with only minor enhancements over time to improve efficiency and reliability, but fundamentally still delivering power at a 60 Hz A/C waveform to the customer. Today, the utility industry is in a state of transformation. Grid modernization has evolved to provide sensor and control devices to enhance the reliability and efficiency of the grid, popularly termed as the “Smart Grid.” The Smart Grid introduced advancements in technologies for both the customer and grid management, including the deployment of smart meters, now referred to as Automated Metering Infrastructure (AMI), capable of providing distinct, detailed customer-energy usage information on hourly or shorter interval reads. On the grid-management and control side commonly referred to as "Distribution Automation" (DA), utilities have been adding switches into the distribution system referred to as "reclosers" or "sectionalizers." These devices enable the utility to isolate powerline faults along a given distribution feeder and to route electricity around trouble spots. As more and more reclosers are added, the size of a given fault domain can be reduced which lowers the potential number of customers impacted by a particular fault. Additional DA devices and applications are being utilized that will enable utilities to manage feeder voltage to meet regulatory requirements (minimum voltage level), resulting in improved demand efficiency, thus optimizing overall generation capacity requirements.

Additionally, the introduction of Ethernet and Internet Protocol has altered the entire utility telecom landscape, providing innovative capabilities. The remainder of this paper enumerates the congruency of telecommunications reliability with grid reliability.

Utility Telecom Applications Supporting Grid Operations

There are numerous utility telecommunications applications or use cases employed to provide command and control of the grid. The following discussion is not all inclusive, but highlights the major applications required to manage the power grid.

SCADA Systems

Supervisory Control and Data Acquisition (SCADA) systems are prime examples of the types of command-and-control applications utilized over a utility telecommunications network. SCADA systems send telemetry (information) from substation switchgear or field devices over communications transport networks to a headend application, where the information is processed, analyzed, and presented to the control room operators. Until the advent of the "Smart Grid," the majority of this information came from substations and was transmitted through Remote Terminal Units (RTUs) over 1200 baud serial RS232 data streams. The modems operated over telecommunications carrier-based so-called Plain Old Telephone (POTs) lines (i.e., copper, narrowband wirelines) with very low bandwidth devices and carried very basic information about the status of the device, i.e., voltage, current, power, environmental temperature, etc. using proprietary bit-oriented protocols. In large measure, these POTs lines were unreliable due to frequent outages and utilities had little control over service restoration if these systems failed. This is why utilities prefer to use their own private network infrastructure to ensure higher levels of reliability and availability.

SCADA systems poll or request information on a predefined interval such as every minute or every five minutes, depending on the nature of the information. While this is bare bones, it provides the required visibility to manage the grid. As technology has improved, the RTUs can be programmed in such a way that they can gratuitously send messages indicating a parameter is outside its defined boundary or specification. Newer devices being introduced in the "Smart-Grid" era with improved telecommunications will enable pushing more intelligence further into the field, providing additional detail to the health of the grid and improving overall situational awareness.

Teleprotection

Teleprotection serves both transmission and distribution functions. On the transmission grid, teleprotection is a system of relays located in a substation connected to both ends of a transmission line, monitoring the health of the transmission span between the connected relays. If a fault was to occur on the transmission span, the relay senses the fault and quickly open breakers at the substation to clear the fault. The communications channel must function within 10 milliseconds <u>or less.</u> If the relay fails to operate within the prescribed time, which is derived from one 60 Hz A/C cycle, i.e., significant damage will result when a 500 kV line is grounded coupled with the inrush of current to a connected transformer. In addition to transformers catching fire or worse, the utility's overall transmission system can become unstable and cause possible blackout scenarios. Overall, while the teleprotection system is fairly simple and requires low bandwidth telecommunications to function, it needs the highest level of reliability and lowest level of latency of any other system within the grid. Also, it possesses local intelligence to function, only requiring status and management through the control center.

Given its importance, utilities build multiple redundancies into the teleprotection system through several telecom pathways as well as redundant relays on both ends of the span to ensure the reliability of the system. As an illustration of the importance of network redundancy, if a utility loses a functioning path and its redundancy--and is thus operating in single contingency--the utility may take the transmission line out of service completely until the telecommunications are restored, rather than risk a potential problem on the transmission line. Utilities generally design for Five-9's or more of reliability in these systems. Therefore, the preferred teleprotection transport technologies are private fiber or point-to-point microwave due to their inherent reliability, which will be discussed in more detail in later sections.

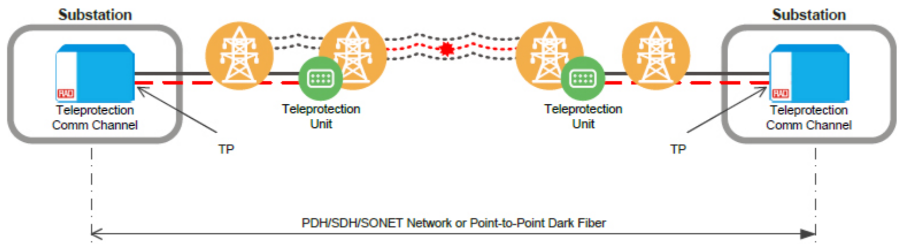


Figure 1. Teleprotection Connectivity with Ultra-Low End-to-End Delay

Smart Grid

With Smart Grid deployment, much of the new DA technology is being extended deeper into the field, providing significantly more information to control-center operators. This includes the introduction of automatic distribution sectionalizers or reclosers that have adequate intelligence to make realignment decisions based on communications independent of external manual controls. In other words, if a fault occurs on a distribution feeder, multiple sectionalizers/reclosers can sense it and communicate to other sectionalizers to open or close in an attempt to route power around the fault, thus minimizing the impact to as few customers as possible. The addition of more reliable intelligence that can be communicated in the field reduces overall customer downtime. Should the communication between reclosers be interrupted, the recloser scheme would fail to operate properly, likely resulting in a larger outage footprint requiring local manual intervention and extended restoration time.

Beyond greater control and automation, advances in utility telecom and the Smart Grid are creating a new transformational class of service referred to as "Distributed Energy Resources" (DER) or "Distributed Generation." Microgrids can be included in this category as well, which are campuses and communities that can be isolated from and operate independently of the larger power grid. DER and microgrids refer generally to home rooftop solar panels, community solar, solar farms, wind turbines, and, eventually, energy storage located throughout the distribution system. These advancements further increase the need for reliable communications and higher throughput enhancing control and visibility to the grid, improving overall grid stability.

There are numerous other applications for utility communications that are not directly tied to grid operations, but are important nonetheless. These include video surveillance/security, AMI deployment, and Land-Mobile Radio (LMR) needed for storm response and service restoration. These topics are critical to utility operations generally but in isolation do not directly impact grid reliability.

Importantly, the convergence of multiple applications on a common transport will further amplify the criticality of the network as well as bandwidth burden, and will also reduce the number of individual network systems required to be supported by the utility.

Public Carrier vs. Private Telecom Services

Utilities have created a telecom ecosystem with many similarities to a commercial telecommunications carrier, which begs the question, why not just use commercial carrier services? The answer is simple: the telecommunications carrier's business model is not congruent with that of a utility's business model. For one, the commercial carriers primarily provide services with what could be termed "best-effort delivery" and will be repaired in accordance with the carrier's schedule. At least for wireless services, there are no "service-level agreements" (SLAs) that commit to an acceptable level of performance meeting a utility's requirements, specifically in technologies such as cellular services. Furthermore, cellular services are designed for mobility, while most utility assets are fixed and require a persistent end-to-end connection, as opposed to the type of random interval mobile connections experienced with a smartphone, for instance.

Still, the biggest concern amongst utilities regarding the commercial networks is availability—or lack thereof--when needed the most, such as following a natural event like a hurricane or storm with damaging winds. The carrier's network may become congested with consumer traffic or unavailable due to storm-related damage. In this time of need, when the grid is in a transient state, with power lines down, the utility must perform switching within the Distribution Automation (DA) system and re-align reclosers to restore as many affected customers as possible. This is arguably the most critical time for utility telecommunications to be available, and is also the most likely time when carrier services would not be available.

Additionally, history has shown that carriers have not been up to the challenge of maintaining their infrastructure available during these critical times. Numerous examples can be cited to underscore that statement including Hurricane Katrina, Super Storm Sandy, and most recently hurricanes Florence and Michael, where carrier service was interrupted. Yet critical utility communications infrastructure remained operational in support of restoration efforts. This is why utilities prefer to build and operate their own private telecoms.

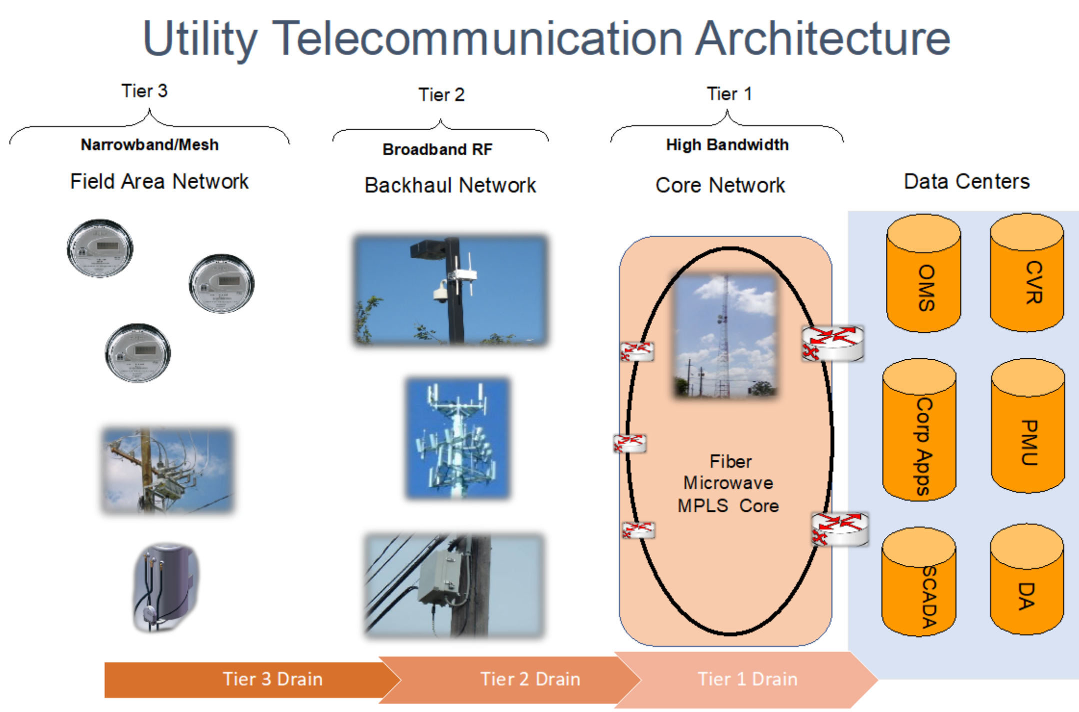
In the situations where utilities have leased commercial carrier circuits, they have also suffered many of the same challenges as outlined above. As services continue to converge and the telecom pathway expands, leased services become less desireable to meet the critical needs of utilities.

Finally, regarding lifecycle management. carriers tend to upgrade and sunset technologies at a rapid pace. When a technology is sunset by a carrier, the utility must replace infrastructure associated with migrating to a new technology, perhaps prematurely. For the utility, the legacy technology may be performing just fine, but because the carrier no longer wants to support it, an expensive and unnecessary migration to the new technology must occur. This has most recently been seen in the sunset of carrier TDM technology including POTs lines. Utilities have thousands of legacy terrestrial circuits on legacy TDM, and carriers want to move away from TDM. Many have issued letters of intent to stop supporting TDM technology in the coming years requiring utilities to migrate and invest in alternative technologies.

All of this is not to say that carrier-based commercial telecom services do not have a role in the utility telecom toolbox; however, the use cases need to be strategically analyzed on economic and technical considerations. It should be noted that utilities use a significant amount of carrier backbone services for enterprise traffic, including their externally facing Website, emails, and customer-service phone lines.

Utility Telecommunications Architecture

With a fundamental understanding of the utility structure and associated application portfolio required to manage the grid along with the customer interface through the above discussion, the telecommunications architecture required to provide the connectivity will make better sense. In this context, the utility telecommunications architectural ecosystem can be divided into three distinct tiers as viewed in the diagram below.



Tier 1 represents the utility network core or backbone, a high-bandwidth network providing application aggregation and is woven throughout the utility territory. It consists predominantly of fiber optic and point-to-point microwave transport technology typically constructed in a ring topology for redundancy, with the majority of utilities using the 6 GHz spectrum band for the wireless segments. Fiber is the preferred transport medium; however, it is also the most

expensive, ranging between $50,000 to $150,000 per mile for deployment. It offers nearly unlimited amounts of bandwidth constrained only by the optical driver equipment lighting the fiber. Point-to-point microwave operating in the 6 GHz spectrum band is also broadly deployed as well, capable of multi-Gbps throughput at a comparable path cost of less than $100,000 per path on existing towers. A microwave path, defined by two to four radios attached to large towers in a line-of-sight configuration, has the advantage of covering long distances at a more economical cost than that of fiber and operates at similar, if not better, levels of availability assuming stable signal strength.

The ratio of fiber miles to microwave paths will vary from utility to utility. Survey results from the UTC[2] provide insights to microwave and fiber deployments and suggest that utilities have anywhere from 20 to as many as 200 or more microwave paths within a given territory, with each path being on average 20 miles. This represents roughly 20% to 75% of the backbone infrastructure utilizing point-to-point microwave. Many of these paths are located in urban centers as well as suburban and rural areas.

Again, the transport backbone requires the highest level of reliability and availability as it aggregates all of the critical application services discussed above including the most critical, teleprotection (relay protection), and backhauls data to the respective data centers for application processing. Availability for Tier 1 telecom is required to be 99.999%, or Five-9's, at a minimum, which translates roughly into five minutes of downtime per year.

From a physical design perspective, Tier 1 end-point nodes will typically pass through utility substations and service centers in a ring topology. The endpoint equipment, routers, and multiplexers drop traffic to connect to RTUs, relays, security cameras, etc. located in the substation. The routers and multiplexers also regenerate the light signal to the next hop around the ring. Fiber has a limited propagation point-to-point distance of about 50 miles, which lends itself well to substation handoffs located in reasonable proximity to one another. Similarly, many substations have microwave towers in place with radios that have a path limit up to approximately 50 miles, depending on the line of sight characteristics, antenna height, and terrain. Typical path distances, however, are in the 20-30 mile range. The ring path may be a combination of fiber and microwave paths that are engineered based upon cost and infrastructure assets available.

Looking at the logical design, Tier 1 may be a combination of packet-based IP technologies such as Multiprotocol Label Switching (MPLS) or Carrier Ethernet. Time Division Multiplexing (TDM) such as Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) is also in broad use. However, SONET/SDH is now considered legacy and is being sunset in favor of packet technologies. Regardless, they can function together within the Tier 1 ecosystem. In light of the ring design discussed above, all of these technologies have the ability to perform "protected path switching," which is the concept of detecting a fault in the active

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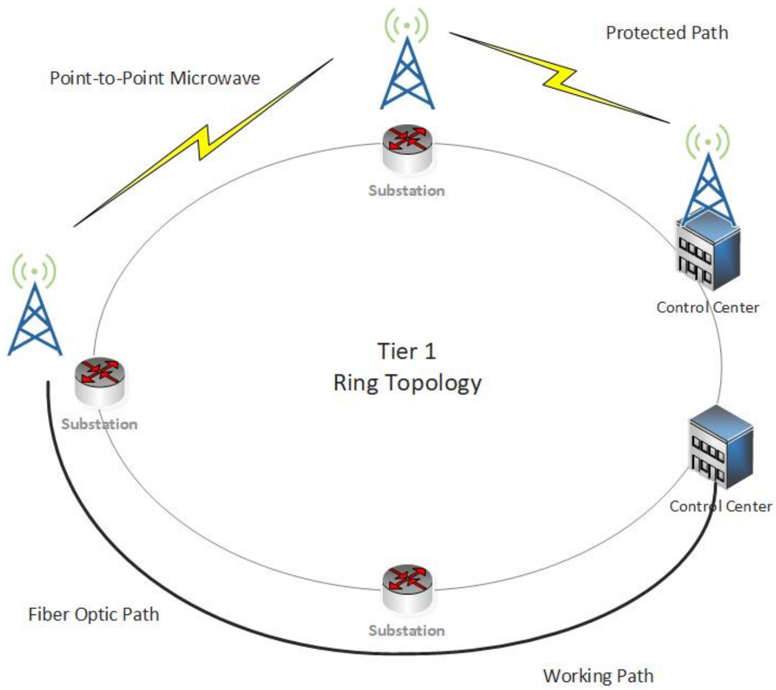
[2] UTC Utility Network Baseline, © 2017

working path and quickly changing direction of the traffic around the other side of the ring to get to the same destination or "protected path." It should be noted that a fault occurring in Tier 1 has a very large fault domain and will have a significant impact on the overall network and associated applications.

Utilities generally subscribe to a *"no single point of failure"* philosophy for critical transport systems and *at a minimum will design to N+1 redundancy*, and, in some cases, design to N+2. This means the functional integrity of the system will be maintained with one or even two failures, assuming a protected ring topology is implemented and is required to deliver Five-9's of availability. This generally requires that end-point equipment have redundant elements, such as power supplies, line cards, etc. installed in routers and multiplexers. In many cases, utilities will opt to install a complete redundant device (router/multiplexer) in a given substation to further enhance redundancy. Power is a critical focus area and utilities will have local battery backup as well as generator capability to power their communications for extended outages. In the event a failure does occur, such as a fiber break or microwave path fade, traffic will re-route from the working path to the protected path, placing the system in single contingency, meaning an additional failure will render the system unavailable. In certain cases, this may require the utility to take compensating action such as removing a transmission line from service, which may then compromise the overall integrity of the grid.

Tier 1 (see image page 12) is designed to be the most robust and managed with most attention within the utility telecom ecosystem. It is important to note that the underlying design basis for Five-9's in an N+1 system, i.e., ring topology with two possible paths, is that each path has an individual availability of approximately 99.7% for their combined availability to be Five-9's.To maintain Five-9's, any individual link in the system must have a high "mean time between failures," routine interruptions caused by microwave loss of signal fade caused by interference cannot be tolerated.



Tier 2 can be characterized as the middle mile or bridging network between Tier 1 and Tier 3 (Field Area Network). Tier 2 is typically a point-to-multipoint RF technology similar to cellular technology. It is used to provide SCADA telemetry and Distribution Automation backhaul to base stations located in substations that have a point of presence to the Tier 1 backbone. It is a broadband type of technology, and the capacity will vary by what RF spectrum is available to the utility. Presently there are very few spectrum options to provide adequate capacity in this tier. Utilities have also been challenged to compete with the large commercial carriers and other entities in spectrum auctions, particularly in Major Economic Areas (MEAs). Consequently utilities do not have as many options or the ability to compete with the large global communications carriers.

Furthermore, utilities, while considered critical infrastructure, are thus far not able to share Public Safety spectrum in a non-preemptive manner. Thus the only option for utilities has been to compete with other commercial entities in a variety of spectrum bands, including the 6 GHz and other bands, or to purchase small blocks of spectrum offered by brokers. The Citizens Broadband Radio Service (CBRS) in the 3.5 GHz spectrum band works well in some markets but is plagued with interference by other operating entities, which has resulted in sporadic and limited availability. Consequently, it has not been widely adopted within the utility community. It should also be noted there are pending FCC rule changes in the CBRS spectrum as well that could negatively impact the viability of that band for utilities.

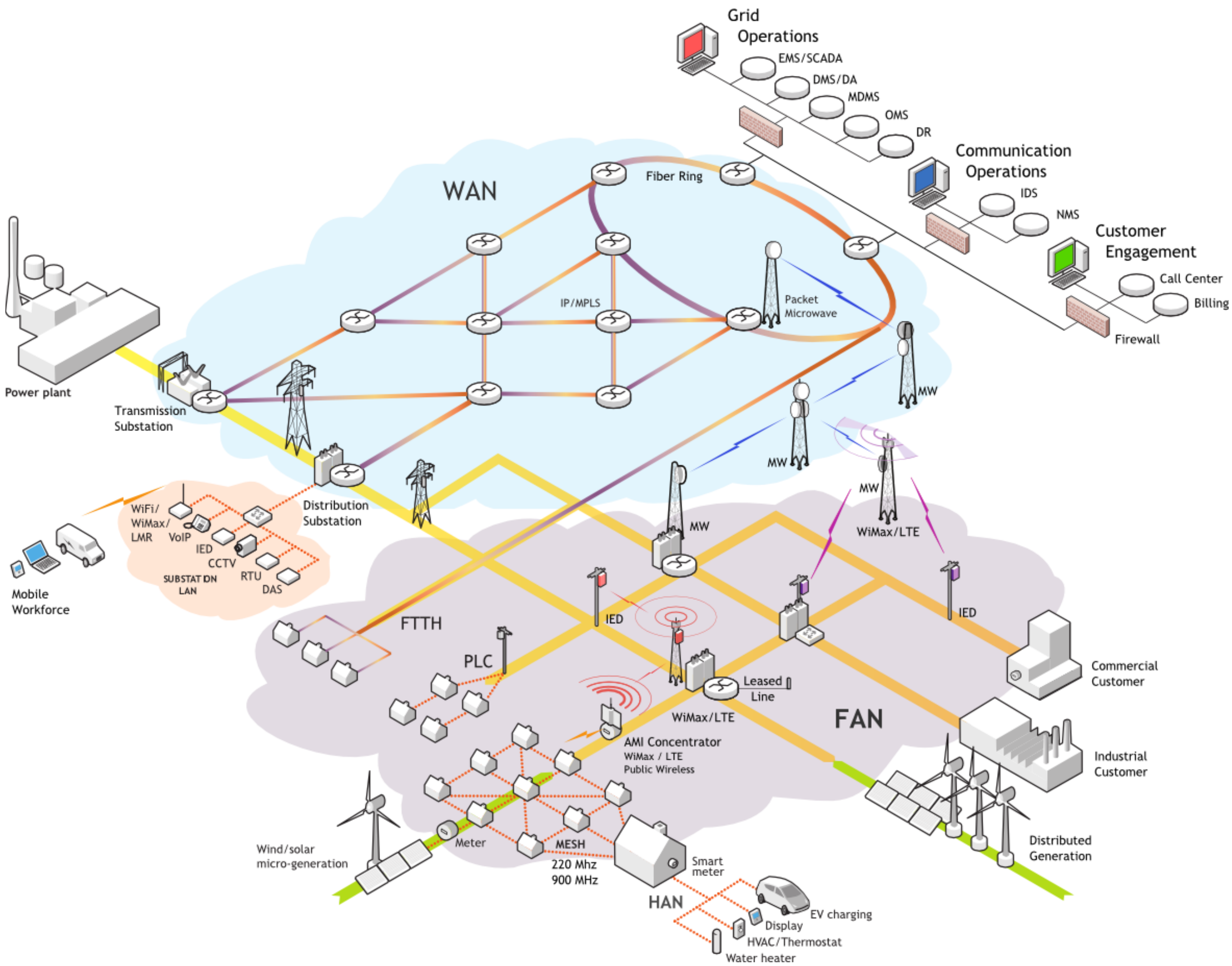
To create an acceptable level of functionality in the Tier 2 network, there would have to be a minimum of a 5x5 MHz spectrum allocation and arguably a 10x10 MHz allocation to adequately address all the utility broadband use cases, including SCADA, mobile workforce, LMR, security video, and forward-looking applications addressed earlier in this paper. Today, there is essentially no allocation of adequate workable broadband spectrum available to utilities in the United States.

Tier 3, commonly referred to as the Field Area Network (FAN), is a relatively low bandwidth network that is either a mesh architecture operating in unlicensed ISM 900 MHz space using a frequency hopping modulation technology or a licensed narrowband point-to-multipoint technology typically with 12.5 kHz or 25 kHz channels, with obvious limitations on bandwidth capacity.

Most but not all AMI solutions are mesh, as millions of meters in relatively close proximity to one another lend themselves well to hopping from meter to meter to carry their payload (meter reads). Operating in the unlicensed ISM band has a limitation on radiated power, but that is overcome with the density of meters deployed coupled with a large number of access points (network drain). The drain or access point out of the mesh may use a carrier-based LTE backhaul or a private Tier 2 RF technology. There are also AMI solutions that employ a point-to-multipoint architecture on narrowband licensed spectrum. Due to the higher power permitted with licensed spectrum, it is possible to obtain adequate coverage across the utility territory with fewer base stations as compared to the number of access points required in a mesh topology, obviously reducing the number of FAN drain points. The result is fewer base stations to maintain and an opportunity to leverage Tier 2 backhaul points of presence. However, the nature of the narrowband channels limits the capacity of this architecture.

In the grid management application portfolio, DA operates on a similar segregated network from AMI. Again, maintaining application groups segregated (i.e. DA from AMI) is a security best practice and, arguably an operational best practice. DA functions best in a point-to-multipoint architecture due in part to latency sensitivity, and deterministic traffic flows, i.e., controlling how the traffic routes.

The primary limitation with DA using a point-to-multipoint architecture operating on narrowband spectrum is capacity. Using 25 kHz channels is limited on the bandwidth that can be managed for thousands of DA devices. This will continue to be an ongoing limitation until such time that the broadband access conundrum is resolved. In a situation where a utility has broadband access, it would permit the convergence of both Tier 2 and Tier 3 into a unified FAN architecture. Access to broadband spectrum is one of the biggest political challenges preventing this convergence.



Multi-Tier Utility Telecommunications Architecture

Reliability & Performance Requirements

This paper has outlined the utility telecommunications landscape with an examination of grid management applications along with the telecom transport infrastructure required to enable those applications. This section further explores the availability of critical applications and discuss fault mechanisms along with their business impact.

Beginning with Tier 1, the backbone is clearly the most critical transport ecosystem managed by the utility. It aggregates all of the application and service groups, aggregating Tier 3 and Tier 2 services. An unrecovered or undetected fault in Tier 1 will have a major impact on utility operations, including loss of visibility and control of the grid, and therefore is considered a large fault domain. This is the why Tier 1 is designed with a minimum of 99.999 (Five-9's) availability requirement. Every link in the transport medium, be it fiber or microwave, must be robust. This can be well managed in fiber optics, given it is self-encased and preferably installed on transmission structures far above the ground out of harm's way. Distribution poles, while reliable, are subject to downed trees and automobile accidents. Microwave communications are a resilient technology as well. Assuming a well-designed, line-of-sight path and proper tuning of the system, i.e., adequate fade margin (~40 dBm) and signal strength, it has historically proven to be quite capable of maintaining Five- to Six-9's availability. To reiterate, Five-9's is accomplished through the use of redundant ring pathways and requires approximately 99.7% availability per path to achieve a combined Five-9's availability per path for the whole telecom system. With the prospect of potential interference in the 6 GHz band due to a proposal pending before the Federal Communications Commission, that may no longer be the case. Periodic signal fade caused by interference will have a marked impact on the overall system reliability.

Microwave Path Design Considerations

It must be noted that designing a microwave path is a complex undertaking. This is further complicated when external unforeseen or accounted for forces are present. Microwave radios in the 6 GHz range are relatively low power, typically 1 watt due to their highly directional antennas and being digital, have a signal threshold defining the operable and non-operable state, unlike a legacy analog microwave where signal fade is more tolerable. Consequently, once the signal drops below the operational threshold, it stops passing traffic altogether; even if there still is a level of signal between the radios, it is not adequate to maintain data communication. This is analogous to the legacy analog televisions with a poor signal, where the viewer would experience a fuzzy or snowy picture contrasted to digital televisions, where you see pixilation followed by a blank screen, it is an all or nothing effect. As a rule of thumb, a microwave path is designed with 40 dBm of fade margin, assuming proper alignment of the primary lobe across the endpoints of the path. After all the attenuation and gain factors are taken into account, on a blue-sky day, it is desired to have the 40 dBm margin to loss of signal. This margin is intended to account for further reductions in attenuation such as rain, snow or other clutter changes. With the introduction of unlicensed devices given access to 6 GHz spectrum transmitting in proximity to the path, a squelching to the available fade margin could occur, resulting in loss of signal and, likely, communications across the link. Given the mobile nature of these devices, it will be nearly impossible to track down the offending device(s) resulting in unacceptable periodic drops in link availability.

Additionally it will be incumbent on the 6 GHz licensee to identify and report the offending device(s). To date, point-to-point microwave systems have functioned well as the spectrum has been clean with a predictable and reasonably static noise floor, unencumbered by interference and meeting expected availability requirements set forth above. If devices operate in proximity to an active path and emit energy into the primary lobe, it would increase background noise likely beyond the design base fade margin resulting in loss of signal, and the link will drop. This would require the routing electronics to take action to find an alternate path and will immediately degrade the overall system availability.

Furthermore, depending on how the interference is manifested, it could result in the path going into a "flapping state" where it is transient, up and down with a rapid period, too fast for the routing electronics to stabilize and thus could place the network in an indeterministic state resulting in a complete network failure. The network is designed to react to a hard fault, enabling the system to reroute and stabilize traffic on the protected path. In the event of a network failure caused by "flapping," all network traffic stops and control center operators will lose visibility and control of the grid as well as all other application services until communications are restored. Any teleprotection services will be compromised between the two substations where the fault occurs, leaving the utility vulnerable to a transmission system disruption and possibly requiring removing the affected transmission lines from service and dispatching operators to substations to perform local monitoring. Even if the network reroutes or wraps to the protected path, the utility is in single contingency and thus more vulnerable, which itself is compromising, warranting compensatory action be taken. A corresponding second failure in the backup link would result in the loss of visibility to the grid and compromise transmission system integrity. This would also impact the other critical DA services carried on Tier 1 as well. Single-contingency operation in the utility ecosystem should only be relied upon in extreme circumstances that are outside the control of the utility and not to address routine interruptions coming from known sources such as sporadic microwave path interference.

Simply stated, if a Tier 1 point-to-point microwave link is in any way impacted by periodic interference, it will be incapable of maintaining the Five- to Six-9's of availability for the whole system, and it would no longer be a candidate for a Tier 1 transport service. This would likely result in remediating dozens, potentially hundreds, of point-to-point microwave links, removing them from service and replacing them with fiber or some alternative transport medium.

In Tier 2, where the 3.5 GHz CBRS spectrum may be deployed, utilities have observed harmful interference, requiring an alternative path approach either through a second path or coping with the loss of telecom for a period of time. As noted earlier, the expected availability in Tier 2 is Three- to Four-9's; interference is the primary driver for the reduction in availability but is tolerable due to the smaller fault domain (number of devices impacted) for a given Tier 2 path. If it is calculated that interference will result in an even lower availability, it will not be considered an acceptable solution. This is the reason teleprotection and other critical applications are never used in Tier 2 CBRS technology.

Tier 3 FAN is designed to exist with a certain amount of interference, considering its deployment in ISM 900 MHz spectrum. The two application groups that have been discussed in the FAN are AMI and DA. Overall availability for AMI in Tier 3 is expected to be around Three-9's; this is regarded as acceptable due to the multiple paths within the mesh and the non-critical nature of the meter data. For DA, Three-9's is at the low end of acceptability and interference becomes more problematic, which is why a licensed point-to-multipoint architecture, protected from interference is preferred to obtain Four-9's or more availability.

Summary

Utilities are a unique industry in their use of telecommunications infrastructure. They manage a large network transport technology portfolio and rely heavily on its use and always being available. The cliché, "A chain is only as strong as its weakest link," is appropriate in the utility telecom ecosystem as it is clear how one vulnerability can impact a utility's entire grid.

While opening access to licensed 6 GHz bands may appear an attractive approach to improving spectrum availability to unlicensed entrants, there is a considerable risk to critical infrastructure relying on the integrity of the spectrum as it exists today. Additionally, it will place management of interference remediation on the licensee, rather than the source of the interference, which will be difficult if not impossible to track down. Real-world microwave path calculations are complex and made moresowhen introducing the type of transient devices that could even momentarily impact signal integrity.

Although not specifically addressed in this paper, gas and water utilities would be highly affected by this as well. Many of them rely heavily on point-to-point microwave links located in urban centers where there would be a high presence of the unlicensed 6 GHz devices.

As the industry transforms into the "Utility of the Future," the reliance and need for reliable and available telecommunications will be ever increasing. Telecommunications is foundational in control and management of the power grid as well as other utility services and in light of its criticality to society, should have the best in class technology services available. Managing the stability of the grid is challenging enough without the added burden of telecom reliability through microwave interference. Any decisions that have the potential to challenge telecom reliability and availability should be well thought through with an understanding of the potential impact that has been outlined through this paper.

Definitions

Availability – The probability that the network system will be up or operational, a measure of the amount of time the system is operational as a percentage of the amount of time a system should be operational. Assuming it should be operational 100% of the time, any time it is not available will be calculated as a fraction based on the amount of time not available.

- Five 9's is 5.26 minutes of downtime a year (99.999)
- Four 9's is 52 minutes a year (99.99)
- Three 9's is 8.75 hours a year (99.9)
- Parallel Systems Availability

$$A = 1 - (1 - A_x)(1 - A_Y)$$

Where A is system availability, A_x *is availability of primary path and* A_Y *is the availabilty of redundant parallel path*

Reliability – The probability the network will function for a given period of time, often referred to as the "Mean Time Between Failures."

Telemetry – Transmitting parameter data or information from a field device to a control center or data center for processing, i.e., voltage, current, power, etc.