Comparison of Licensed and Unlicensed Spectrum for Utility-Owned Distribution Area Communication Networks

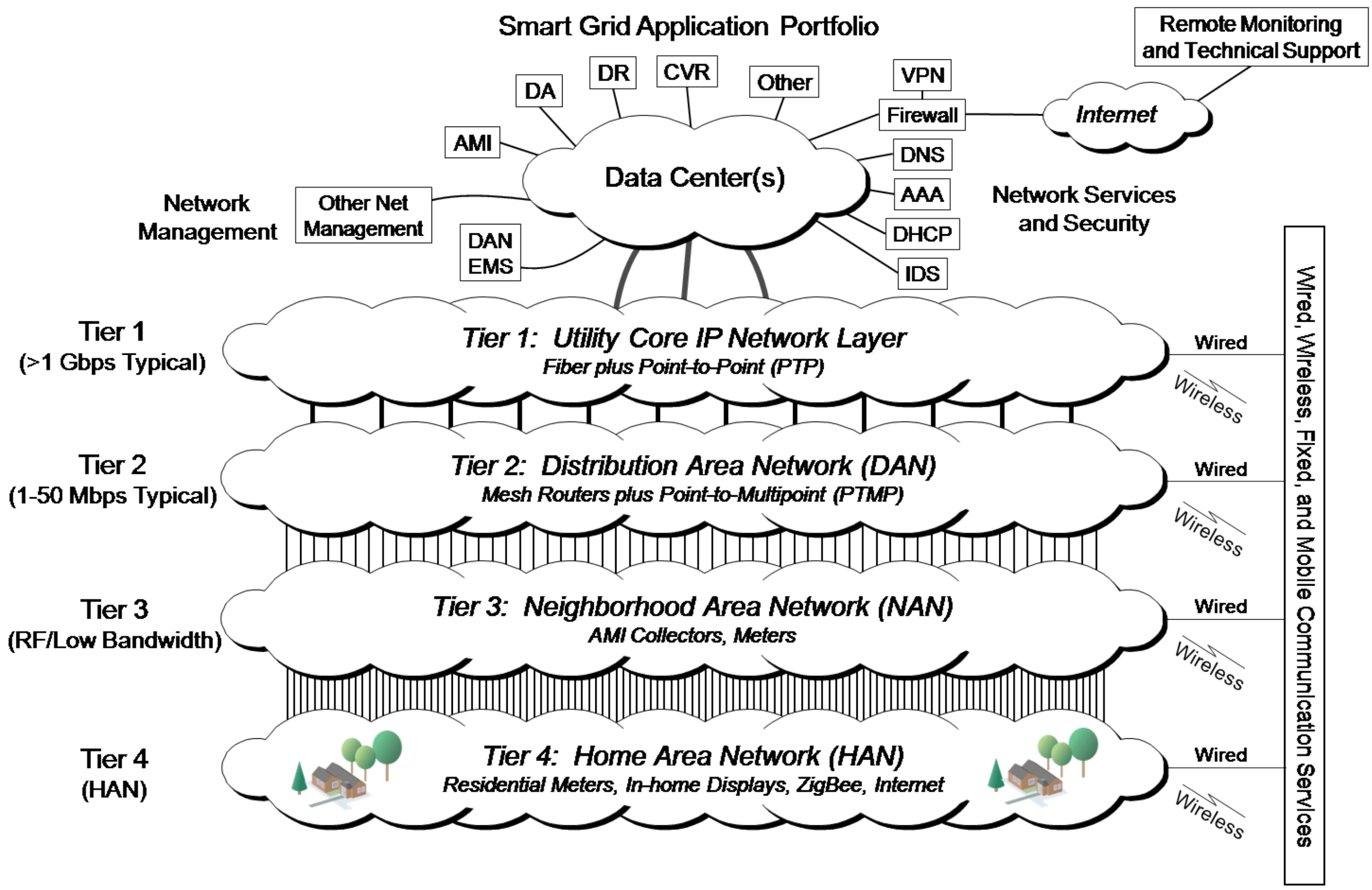
Utilities are weighing multiple wireless communications options using licensed spectrum and a number of unlicensed frequency bands. This tech brief explores the tradeoffs between licensed and unlicensed approaches for distribution area communication networks, examining cost, availability, reliability, security, and application fit.

While utilities typically do not hold licenses for large blocks of spectrum, they do, in some instances, use licensed spectrum for smart grid applications. The amount of available licensed spectrum and its propagation characteristics help determine where in a network it is best applied. In cases where licensed spectrum is available, overall system performance may be optimized by reserving it for use outside of the distribution area communication network. Further, while licensed spectrum is traditionally viewed as a more reliable resource, recent advances in mesh networking technology have enabled the aggregation of multiple unlicensed frequency bands with frequency and path diversity that allow unlicensed spectrum to exceed the reliability requirements of mission-critical utility applications.

Utility Communication Networks: A Multi-Tier Architecture

A utility-owned network is typically designed with multiple tiers. Each tier serves a different purpose and has its own requirements.

At the highest level is the utility's core IP network, typically constructed using fiber optic cable with wireless point-to-point (PTP) links employed where required. The core IP network generally extends into the service territory, terminating at substations and other points of presence in the field. This tier requires very high capacity, bandwidth and reliability.



Next is the distribution area network (DAN). It is a high capacity, multi-purpose network that provides connectivity between the core IP network and AMI collectors, distribution automation equipment, sensors and mobile workers.

The third level is the neighborhood-area network (NAN), which enables two-way communication between meters and a collector. It does not have the same capacity requirements as the DAN but must penetrate foliage and buildings very reliably to reach meters.

Finally, within the home, is the home area network (HAN). It connects in-home displays and, in the future, smart appliances.

Each of these tiers has different operational requirements and challenges which dictate technology and network architecture selection to meet overall end-to-end performance goals.

These four tiers need to coexist across the same geography, so spectrum must be chosen not only to meet the requirements of the individual tier, but also to be coordinated across tiers. Further, if licensed spectrum is available, it should be allocated in a manner that optimizes the end-to-end performance and reliability of the overall network.

Core IP Network

The core IP network connects lower tiers of the network as well as substations, generation facilities, offices and data centers. Since a core network failure can affect all lower tiers of the network over a large area, reliability is critical. Fiber is best suited for the backbone, but PTP wireless links can be used as a backup, an extension to the fiber network or as the main backbone where fiber is unavailable. If licensed spectrum above 1 GHz is available, it may be best used for PTP links in the core IP network. However, if links are built with highly directional antennas, vulnerability to interference is mitigated and lightly licensed (3.65 GHz) or high-frequency unlicensed (5.4 GHz or 5.8 GHz) spectrum may be considered.

Capacity and latency requirements depend on the applications in use and the headroom reserved for future expansion. If phase or measurement units are to be used in substations, core IP network latency must typically be in the sub-10 millisecond range. Video surveillance for substation security may require capacities of 10-100 Mbps per substation. Support for mobile workers through the DAN can similarly require a high-capacity core network, as can future requirements for advanced sensors throughout the distribution system. Latency, total capacity, and individual link speeds must all be considered when scoping the requirements for the core IP network. While the latency capabilities of licensed and unlicensed systems are not systematically different, network capacity is typically higher in unlicensed bands due to wider swaths of available spectrum, especially in the 5 GHz frequency bands.

Distribution Area Network (DAN)

The distribution area network (DAN) has demanding requirements for reliability, coverage and capacity. It must be able to deliver connectivity extending from substations out to pole-top distribution automation equipment, sensors, meter collectors, and mobile workers. As the “last mile” connection for outage management equipment, it must work reliably in all conditions, using battery backup to function without mains power and reorganizing automatically to recover from failures. Unlike the backbone, which only needs to connect a fixed set of endpoints, the DAN provides general coverage over tens to hundreds of square miles extending out from each substation, accommodating equipment and mobile workers anywhere within the utility service area. Capacity requirements can also be quite high, in the range of 1-10 Mbps, depending on the applications in use, and advanced sensors within the distribution network are expected to push the capacity requirements further.

The coverage requirements of the DAN favor lower frequencies (below 3 GHz) that can penetrate foliage and buildings to operate in near-line-of-sight or non-line-of-sight conditions. While there is often flexibility in locating AMI collectors in order to engineer direct line-of-sight to base stations on towers, there is less flexibility with regard to distribution automation devices such as reclosers and sectionalizers, and line-of-sight may or may not be available at any particular location. Coupled with requirements for capacity and interoperability, this often favors an unlicensed or combination licensed/unlicensed solution. One challenge is to guarantee reliability in the presence of interference from other unlicensed devices. Fortunately, advances in mesh technology have resulted in demonstrated five nines reliability using unlicensed spectrum, rivaling or exceeding that of licensed point-to-multipoint systems. Software that manages radio resources, switching channels to avoid noise, rerouting around failures, and adaptively reconfiguring according to the radio environment is responsible for this step up in reliability. The mesh can provide redundant coverage with no single point of failure, unlike a point-to-multipoint system that is engineered with little ability to self-heal. A mesh of multi-radio nodes can combine different technologies for a “best of both worlds” solution; for example licensed for reliability and unlicensed for capacity and interoperability, or sub-3 GHz for coverage and high frequency for capacity.

Bands used in lower and higher tiers of the networks may need to be avoided to allow colocation of antennas and to avoid generating self-interference. Of the remaining options, 2.4 GHz and 5 GHz are viable unlicensed options for this tier, as are licensed spectrum options at 3.65 GHz and, possibly in the future for the United States, 4.9 GHz. IEEE 802.11g/n Wi-Fi operating in the 2.4 GHz band is an excellent option for maximum compatibility with the widest variety of devices. Multi-radio nodes with additional radios at 3.65 GHz, 5.4 GHz, 5.8 GHz or higher licensed frequencies can augment the capacity of the DAN.

Neighborhood Area Network (NAN)

The radio technology used for the neighborhood area network (NAN) will depend strongly on the selection of meters and meter collectors. Both licensed and unlicensed options are available, typically operating at 900 MHz or below for the best coverage. Since meters are mounted close to ground level and use inexpensive, low-powered transmitters, higher frequencies are impractical. Meters and meter collectors are nearly always chosen together, so interoperability is not a major concern. Frequencies used include the low-power 260-470 MHz unlicensed band as well as licensed and unlicensed 900 MHz frequencies. NAN equipment using the 2.4 GHz band is available but the number of meter collectors required to guarantee coverage makes it less practical than systems using lower frequencies. In general, the unlicensed 900 MHz band is a good fit for the range and capacity requirements of the NAN and a mesh architecture provides adequate reliability and failover protection.

Home Area Network (HAN)

Within the home area network (HAN), the ZigBee protocol operating at 2.4 GHz is quickly becoming a de-facto standard. As the master "coordinator" radio is typically built into the utility meter, the frequency band is not an independent choice for this tier. Interoperability and standardization is critical in this tier, however, since displays, repeaters, and smart appliances will all come from different manufacturers. Alternatives to ZigBee such as Z-Wave also use the 2.4 GHz or 900 MHz unlicensed bands.

Sample Smart Grid Spectrum Allocations

Core IP Network	DAN	NAN	HAN
Licensed	5.8/2/4 GHz	900 MHz	2.4 GHz
3.65 GHz	4.9/2.4 GHz	900 MHz	2.4 GHz
Fiber	3.65/2.4 GHz	900 MHz	2.4 GHz

Security

Few generalizations can be made about the relative security of licensed and unlicensed frequency bands. Licensed equipment may be slightly more difficult for hackers to obtain, but obscurity cannot compensate for real security flaws. Radio jammers, used to mount denial-of-service attacks, can be tuned to operate in any frequency band. An agile mesh system is more resilient than a centralized point-to-multipoint system, and can route around a localized jammer or quickly change channels. A multi-radio mesh can continue to operate in one band even if the other is completely unusable. Rather than looking at unlicensed or licensed technology for security, equipment should be chosen based a flexible architecture and independent security certification for compliance with standards such as FIPS 140-2, NERC CIP, and the upcoming NIST Smart Grid Cyber Security standards.

Conclusion

Licensed and unlicensed frequencies both have their places in a smart grid communications network. When available, licensed frequencies should be reserved for the tiers that can use them to the greatest advantage, and unlicensed spectrum should be used for greater interoperability and capacity. The best use of licensed frequencies is in the core IP network and as a complement to unlicensed frequencies in a multi-radio mesh DAN. Unlicensed bands provide excellent capacity and coverage, and a mesh architecture with intelligent radio resource management can rival licensed systems for reliability and availability.

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