Assessment of Licensed Communication Spectrum for Electric Utility Applications

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NOTE

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ABSTRACT

Creating a pervasive communications infrastructure is a common theme for utilities that are planning for current and future enhancements of the electric power grid to improve reliability, resiliency, performance, and efficiency. These and other benefits that derive from the smart grid depend to a large measure on the ability of elements within the grid to communicate with one another—and with central and distributed control systems.

This report focuses on communications networks operating in private licensed spectrum. Several research questions arise when considering licensed spectrum for a utility FAN that can support applications with ubiquitous coverage over a wider area, including the following:

- What are the present and future communications requirements for transmission and distribution applications?
- Which parts of the spectrum bands best meet these requirements?
- What standards and equipment support the identified spectrum bands?
- What is the current use and availability of the identified spectrum bands?

The objective of this project is to answer these questions in conjunction with leveraging EPRI's ongoing research, for example, EPRI's Field Area Network Demonstration (FAN Demo) Project in which field trials are being conducted at several utility host sites to study the advantages and disadvantages of different communications technologies, public vs. private networks, and licensed vs. unlicensed spectrum for utility field operations. The *Field Area Network Guidebook*, currently scheduled for publication by EPRI in 2016, is expected to summarize the findings of the FAN Demo Project and will be extended to include the findings of this project.

Keywords
Communications networks
Field area networks (FANs)
Private licensed spectrum
Spectrum bands

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1 INTRODUCTION

Creating a pervasive communications infrastructure is a common theme for utilities that are planning for current and future enhancements of the electric power grid to improve reliability, resiliency, performance, and efficiency. These and other benefits that derive from the smart grid depend to a large measure on the ability of elements within the grid to communicate with one another—and with central and distributed control systems. Each utility will create its own unique communications infrastructure to best meet its specific needs. This infrastructure could include a variety of communications technologies, including fiber, power line carrier (PLC), and wireless. Wireless options may use both public and private networks, and/or operate on both licensed and unlicensed spectrum. A utility's choice of the technology or technologies that make up its communications infrastructure will be shaped by many factors, including type of utility, location, geography, and population density.

There is no single solution that will optimally meet all of the communications needs for every utility. Many operational, economic, and technical factors influence the architecture and design of utility communication networks. Fiber provides excellent bandwidth and reliability, and those who deploy it typically do so to selected locations because the cost of deployment to every field device is prohibitive. New technologies such as Fiber to the Home (FTTH) and the related business models are changing the cost factor for fiber in some geographic areas. Still, many utilities are finding that wireless field area networks (FANs) offer them the best solution to provide ubiquitous connectivity to field devices outside the substation. Because of this, EPRI is conducting extensive research designed to understand the following:

- The relative advantages and disadvantages of public vs. private networks
- The relative strengths and weaknesses of different communications technologies, including WiMAX and long-term evolution (LTE)
- The relative advantages and disadvantages of using licensed and unlicensed spectrum
- The impact that emerging communications technologies may have on utility operations

EPRI research activities in the area of communications include field demonstrations, laboratory evaluations, literature searches, and cost-benefit analyses. It is envisioned that the findings of this research may help utilities determine the communications technologies that best meet their specific needs.

This project specifically focuses on communications networks operating in private licensed spectrum. Figure 1-1 represents a simplified selection process for a communications network. The complex set of business, technical, and economic factors behind each of the decisions represented by yellow diamonds are not covered in this report. This report does not consider the advantages and disadvantages of the other options or make any judgment on their relative merits. The starting point for this assessment is at the lower right of the figure, where a decision for private licensed spectrum has already been made.

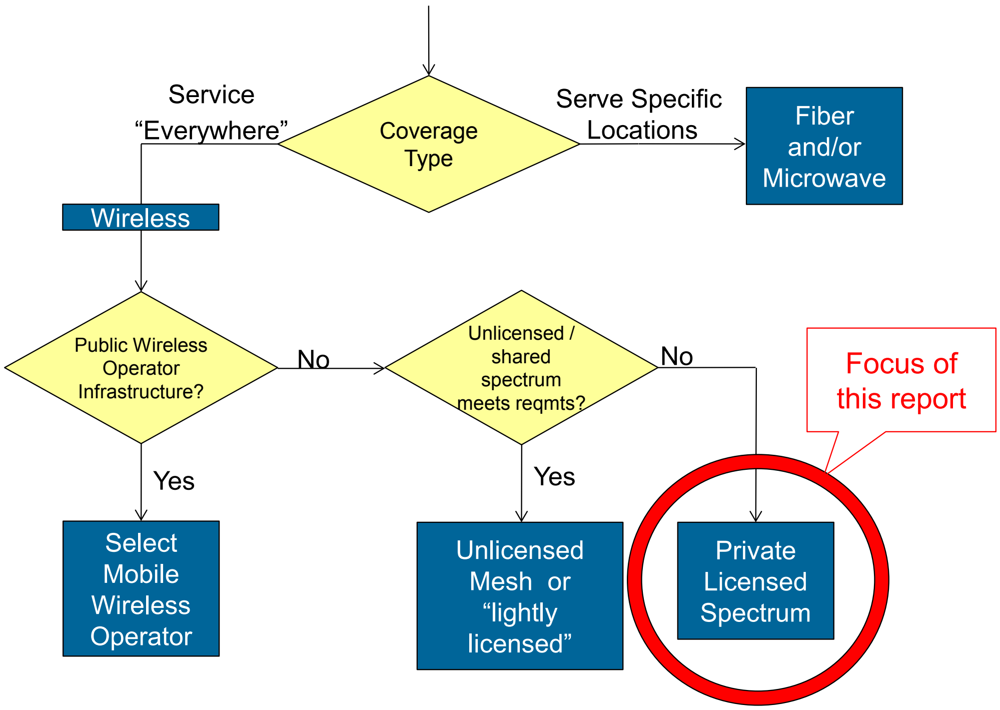

Figure 1-1
Simplified Selection Process for a Communications Network

Utilities have long used licensed communications spectrum for both operational and non-operational applications on electric transmission and distribution systems, but most of these licensed operations consist of narrowband communications and point-to-point microwave communications for backhaul. Several research questions arise when considering licensed spectrum for a utility FAN that can support applications with ubiquitous coverage over a wider area, including the following:

- What are the present and future communications requirements for transmission and distribution applications?
- Which parts of the spectrum bands best meet these requirements?
- What standards and equipment support the identified spectrum bands?
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The objective of this project is to answer these questions in conjunction with leveraging EPRI's ongoing research, for example, EPRI's Field Area Network Demonstration (FAN Demo) Project in which field trials are being conducted at several utility host sites to study the advantages and disadvantages of different communications technologies, public vs. private networks, and licensed vs. unlicensed spectrum for utility field operations. The *Field Area Network Guidebook*, currently scheduled for publication by EPRI in 2016, is expected to summarize the findings of the FAN Demo Project and will be extended to include the findings of this project.

History of Critical Infrastructure Communications

Communications systems—both wireless and wireline—have played a vital role in the operation and maintenance of systems that provide power, water, and gas to millions of residences and businesses. Initially, the public telephone system allowed these critical infrastructure industries to communicate with personnel at distant offices and field locations. The introduction of wireless communications increased the ability for instant communications between office and field workers, improving the reliability and stability of systems on which our society has come to rely.

A major leap in quality of service occurred in the mid-twentieth century when wireless and wireline control and monitoring were applied to utility systems. Adding communications to electric substations, water pumps, and gas pipelines created methodologies that permitted utilities to gain previously unheard-of data—ensuring that the lights stayed on, water was fresh and potable, and often dangerous gas and oil distribution remained safe. As the century passed, greater efficiencies were achieved as both the systems that delivered these resources and the communications that monitored and controlled them improved.

Voice communications remain an important part of utility operations. However, systems that transmit data are the key to the dramatic improvement in critical infrastructure system stability. Sensors and controllers that transmit and receive data allow for nearly instantaneous recovery from power line faults and dangers in water and gas distributions. To an extent, utilities have come to rely on data systems as much as, if not more than, voice communications.

The Need for Modernization

Unfortunately, much of the technology that controls water, gas, and electric systems still dates back to the 1970s and earlier. Since then, communications technologies—especially wireless systems—have improved at an exponential rate. The computing capability that once filled an entire room now sits in the palm of one's hand. Internet protocol (IP) communications facilitate the reliable transmission of large amounts of data. Even voice communications are being converted to IP technology.

IP communications (whether carried on the public Internet or a private IP network) improve the reliability of data infrastructures by dividing messages into relatively small "packets" that can be automatically and individually retransmitted if not correctly received. Forward error correction and data encryption can also be applied to data packets, further enhancing communications reliability and preventing interception, for example, by those seeking to damage utility infrastructures.

Drivers Forcing Critical Action

A number of factors are forcing utilities to plan and implement infrastructure modernization sooner than they anticipated. Advancing communications technologies are only one consideration. While the analog telephone circuits implemented in the mid-twentieth century continue to serve their desired functions in supporting grid operations, wireline carriers are being pressured to discontinue analog lines in favor of broadband fiber-optic services. In many cases, analog, DS0, and DS1 circuits can no longer be maintained at their current pricing. Utilities are being notified that these circuits will be terminated and are offered either wireless solutions or other options at dramatically higher rates. Some utilities have thousands of DS0 and DS1 circuits. A cost-effective, reliable solution is needed.

Residential and commercial utility customer demands for reliability and near-real-time consumption information are also placing demands on communications infrastructure. Reliability in the electric grid requires connectivity with an ever-increasing number of monitoring and control devices. Circuit breakers and reclosers aid in recovering from faults in power lines and speed recovery or even prevent power outages. Phase measurement units provide visibility to grid parameters that ensure that power quality is at its highest possible level. The limited capacity, coverage, and security of legacy grid communications systems cannot support the thousands of new devices being added.

Regulatory mandates for renewable energy integration create additional pressure on utility infrastructure. Residential use of solar panels adds two-way communication requirements that may or may not be able to leverage smart meters and the associated communications infrastructure. Extensive advanced metering infrastructure (AMI) deployments generate massive amounts of data that need to flow between the meters and billing and network operations centers. New construction of utility-grade solar farms, wind turbine operations, and other renewable sources must be supported by a communications network where none exists currently.

Even if the legacy communications systems could support some of these functions, those systems were designed in a different era—the biggest threat to the electric grid was an errant tree limb that caused a fault in the lines. Today we live in an age in which dangers are also man-made, with cyber attacks on utility networks seeking to gain valuable financial and operational information. Legacy communications, often supported by dial-up modems, often have minimal or ineffective security and could leave infrastructure vulnerable to attack. Security integration adds a level of complexity along with traffic overhead that dictates more robust networks.

Utility Field Area Networks

Utility communications systems have historically been deployed in a number of ways. For example, each location where communications are required could be provisioned with a connection to a wire- or fiber-optic data network. The obvious drawback to this approach is that each connection would need to be individually engineered and, where no cable or fiber exists, establishment of right of way and physical cable installation would be required.

A second alternative for utility communications would be the use of point-to-point and/or point-to-multipoint radio (that is, microwave) links. While such links are generally faster and easier to deploy than cables, they are costly and still by and large must be engineered on a case-by-case basis.

The explosive growth of commercial broadband wireless networks providing data communications to mobile user devices points to a third alternative for utility communications: the use of ubiquitous coverage broadband FANs. FANs offer a number of advantages that could benefit current smart grid operations and have an even more significant impact on smart grid evolution.

A fundamental feature of FANs is that they allow broadband data communications to be provided to any arbitrary location (within the FAN's coverage) without the need for individual engineering or link provisioning. Indeed, with FAN connectivity, provision of communications to a smart grid device is almost inherent with the installation of the device itself.

By using an air interface technology based on commercial open standards, such as long-term evolution, a FAN can leverage the fact that compatible devices are manufactured in huge numbers by multiple vendors—bringing equipment costs down sharply. Further, because commercial standards generally embrace the concept of *forward and backward compatibility*, FANs using such technologies should be able to evolve gracefully to adapt to new requirements and implement network enhancements.

With connectivity provided by a ubiquitous coverage FAN using an open standards commercial air interface technology, cost and engineering difficulty of communications facilities are essentially removed as constraints on smart grid operations and enhancements. Monitoring, metering, and control devices can then be placed where and when needed throughout the smart grid to optimize its efficiency and reliability.

FANs with sufficient data handling capacity to meet the current and future needs of the smart grid will require radio spectrum on which to operate. Unfortunately, radio spectrum within the frequency range that can be practically used for ubiquitous coverage wireless data networks is currently at a premium in the United States and will likely become even scarcer in the future. Therefore, a significant problem for utilities is identifying spectrum for smart grid FANs that can be acquired and used within a reasonable time and at acceptable cost.

Purpose of the Study

This study is intended to assist electric power utilities in the United States in formulating their processes for deployment of smart grid FANs. For the purposes of this study, a *field area network* is a broadband wireless packet data network that provides essentially ubiquitous service coverage over a defined geographic region. FANs are assumed to be cellular in architecture; that is, their geographic coverage is provided by a plurality of cells, each served by a base station that is an element of the network. Base stations provide connectivity over the "air interface" between remote devices (comparable to mobile user devices in commercial networks) and one or more packet data networks. In commercial networks, connectivity is most commonly to the global Internet. In the case of smart grid FANs, it is more likely that connectivity will be to a private packet data network dedicated to smart grid operations. Connections between FAN base stations and this broader packet data network may use a number of different types of fixed facilities, including copper wires, fiber-optic cables, and point-to-point microwave. In addition, and depending on the technology employed for the FAN, the base stations may connect to an intermediate "packet core" that is part of the network and provides for such features as mobility management. Characteristics and requirements for the fixed connections to (and potentially between) base stations—and any requirement for provisioning of a "packet core" portion of the FAN—are beyond the scope of this study.

Like commercial broadband data networks, each smart grid FAN covering a particular geographic region will need to operate on a defined portion of radio spectrum. This requirement gives rise to two broad areas of inquiry that need to be addressed in order for utilities to make realistic decisions about FAN deployments. These areas of inquiry, each of which is considered in some detail within this study, are summarized next.

Determine Spectrum Requirements for Broadband FANs

Based partly on the findings of earlier analyses, this study will endeavor to determine the requirements of spectrum that could be used for FAN operation—in particular, the amount of such spectrum that would be needed within the range of practical frequencies. In performing these analyses, the study will consider radio propagation characteristics and traffic density in several different "morphologies" for the FAN, including dense urban, urban, suburban, and rural environments.

Identify Potential Spectrum Bands for FAN Use

Having determined spectrum requirements for FANs, the study will then focus on identifying specific blocks of spectrum that might be available to utilities within the United States for FAN deployment. In assessing different frequency blocks, criteria to be considered include the following:

- Current established use for the spectrum and potential for changing that use to FAN operation
- Potential for FAN operation to share the spectrum with incumbent users
- Cost for utilities to acquire licenses for use of the spectrum
- Proximity of the spectrum to established commercial bands so that currently available infrastructure and remote device equipment can be used with little or no modification

Licensed vs. Unlicensed Spectrum

Considering the scarcity of licensed spectrum suitable for FAN use, some utilities may consider the idea of deploying a FAN within the bands designated for unlicensed use (for example, the 902–928 MHz industrial, scientific, and medical [ISM] band). The disadvantages of this strategy have been documented in other studies.[1] Primary among them are the severe restraint on transmit power, making it impractical to deploy a network with ubiquitous coverage over a geographic region, and the inability to control the level or location of external interference, making it difficult if not impossible to achieve any defined level of service reliability. In any event, any consideration of the use of unlicensed spectrum for smart grid FAN use is beyond the scope of this study, which is limited to spectrum that could be licensed by utilities.

[1] See, for example, EPRI report 1022421, *Wireless Field Area Network Spectrum Assessment: Technical Update*. December 2010.

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SPECTRUM REQUIREMENTS FOR THE FAN

The primary purpose of this study is to assess spectrum bands that could potentially be used for smart grid FANs. However, before that can be undertaken, it is necessary to first determine the required characteristics for candidate spectrum and spectrum bands to allow cost-effective operation of a FAN with sufficient capacity, performance, and reliability to meet the needs of the smart grid. Chief among these characteristics is the range of frequencies to be considered and the bandwidth required for FAN operation.

The utility industry has been collecting and refining application requirement information and makes this information available for analysis. EPRI's Smart Grid Resource Center has long been a source of use case data.[2] The National Institute for Standards and Technology (NIST) created the Smart Grid Interoperability Panel (SGIP) to accelerate the implementation of grid modernization through the use of open standards. Although the SGIP is now an independent nonprofit entity, NIST continues to be involved in the process and maintains a knowledge base that is available at no charge.[3] The Smart Grid Clearinghouse is a joint venture among Virginia Tech, the Institute of Electrical and Electronics Engineering (IEEE) Power and Energy Society, and EnerNex Corporation. Their web site[4] provides use case information for download. These resources provide a rich source of requirement information that has been used to develop spectrum requirement models.

Defining a Benchmark Technology for Smart Grid FAN Requirements Analysis

Open Standards vs. Proprietary Solutions

Over the years, a number of vendors have offered power utilities various proprietary systems for handling wireless data communications associated with grid operations and metering. Such proprietary systems have a seemingly significant advantage in that all elements are provided by a single source, making problems of incompatibility much less likely. This is an obvious benefit in cases in which operational and control communications are critical to grid functionality. On the other hand, there are many factors that weigh strongly against relying on proprietary systems for smart grid FANs. Among the most significant are the following:

- Reliance on a single vendor for products and technical support
- Long-term risks associated with vendor financial stability
- Higher costs, particularly for expansion, due to lack of competition
- Uncertainty regarding scalability, future technical evolution, and backward compatibility

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[2] http://www.smartgrid.epri.com/repository/repository.aspx.

[3] http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/IKBUseCases.

[4] http://www.sgiclearinghouse.org/.

The alternative to proprietary systems for smart grid FANs is the implementation of a network based on open technical standards promulgated and supported by a recognized industry organization or standards-making body. The use of open standards effectively eliminates (or at least greatly curtails) the one main benefit associated with proprietary solutions: lowered risk of incompatibility between communicating devices. Several decades of experience with cellular radio systems have demonstrated that devices and equipment from multiple vendors can reliably interoperate—even through complex air interface protocols—on the basis of strict adherence to published, open standards.

The analyses of spectrum requirements and assessments of spectrum bands undertaken in this study assume the use of open standards network technology for smart grid FANs. It is recognized, however, that some utilities may prefer to use proprietary systems for their smart grid data communications despite the limitations described previously. This study does not provide analysis of spectrum requirements for FANs using any such proprietary systems and therefore presents no conclusions as to whether the identified candidate spectrum bands for FAN use would be of sufficient bandwidth—or would otherwise present required characteristics—necessary to support the use of any proprietary solution.

In assessing individual spectrum bands for possible FAN use, those with bandwidths smaller than the minimum deemed necessary are rejected on that basis alone and without regard to their potential availability, cost, or any other factors. Because analysis of required bandwidth is predicated on the use of open standards technology, the suitability of thus rejected bands for use with any proprietary system is not considered in this study.

Selection of an Open Standards Technology

Given the demonstrated efficacy of standards-based cellular networks and the many advantages they provide compared to proprietary systems, this study will assume that smart grid FANs will be based on open technical standards. Currently, the state of the art for commercial wireless data networks is so-called *Fourth-Generation*, or *4G*, technology employing broadband orthogonal frequency division multiple access (OFDMA). Globally, the commercial wireless industry has effectively settled on a particular 4G OFDMA standard: Long-Term Evolution (LTE). Technical standards for LTE are developed and maintained by a collaboration of global industry groups called *3rd Generation Partnership Project*, or *3GPP*.

A second 4G, OFDMA-based standard for wireless broadband data network is Worldwide Interoperability for Microwave Access (WiMAX). Standards for basic channel organization and medium access protocols are defined in IEEE Standard 802.16. Detailed interoperability and networking standards for WiMAX are developed and maintained by the industry group WiMAX Forum.

As previously noted, LTE has effectively become the single global standard for commercial 4G wireless networks. (Several major carriers, having originally launched service using WiMAX technology, have subsequently switched to LTE.) As a result, LTE-compatible infrastructure equipment and user devices are currently being manufactured in high volumes by many companies, and competition has driven prices down significantly. LTE networks have been in large-scale commercial operation for several years, so new networks can be deployed with minimal technical risk.

Technical evolution and refinement of LTE standards is ongoing and is anticipated to continue for at least the next 10 years. It is reasonable to assume that robust product support for LTE infrastructure equipment will continue beyond that for at least an additional 10 years. Beyond that point, the worldwide body of expertise in LTE technology should enable legacy LTE networks (including smart grid FANs employing LTE technology) to remain in service considerably longer. Because of its much smaller "ecosystem," it is not clear whether WiMAX networks will enjoy this level of longevity. That said, were the utility industry to embrace WiMAX as the "standard" for smart grid FANs (either formally or informally), its LTE and support by multiple vendors would likely be ensured on that basis alone.

Several wireless industry groups—most notably 3GPP—have begun preliminary research on fifth-generation (5G) standards for wireless networks. Based on the progression of standards making in previous generations, it is reasonable to expect that 5G standards will not become operational before the early to mid-2020s. For purposes of this study, 5G technology (which is so far mostly undefined) is therefore not considered a viable option for smart grid FANs.

Conceivably, smart grid FANs could be deployed using older, 3G technologies in which the basic channel structure uses Code Division Multiple Access (CDMA). 3G networks are still in widespread operation globally, and compatible infrastructure equipment and remote devices are available from a number of vendors. However, few if any new 3G networks are being deployed, and many are being (or will eventually be) deactivated to free up spectrum for LTE networks. Therefore, life cycle considerations for 3G technology are unfavorable for smart grid FAN use.

In addition to broadband packet data networks, open standards also exist for ubiquitous coverage wireless systems that employ narrowband channels (up to 200 KHz) or spread spectrum channels of modest bandwidth (around 1.25 MHz). These include first- and second-generation cellular systems, which are effectively obsolete for data communications and therefore not considered in this study (although many 2G systems remain in active use worldwide). Other open standards narrowband systems—notably Digital Mobile Radio (DMR) and Terrestrial Trunked Radio (TETRA)—might be employed for smart grid FANs. Unlike 3G and 4G cellular networks, however, such feasibility has not been demonstrated by widespread commercial data communications services. In any event, because they do not support high-speed packet data communications, the analysis of spectrum requirements for narrowband systems would be very different from the broadband case assumed for this study.

Taking into consideration all of these factors and for purposes of defining spectrum requirements, this study will assume that smart grid FANs will employ LTE technology as defined by 3GPP standards. It should be noted that these standards might need to be modified in order to define LTE operation in spectrum bands in which LTE networks are not currently operational anywhere in the world. Such modification is commonly done in periodic 3GPP standards revision releases whenever new LTE bands are defined.

Although this study will assume the use of LTE, there is in fact no practical reason that any given utility could not choose to deploy a smart grid FAN using, for example, WiMAX technology, since there will be no requirement for interoperability between different FAN deployments. That is, because smart grid remote wireless communication devices are typically deployed in fixed locations, they will have no need to "roam" to other FANs. Because the basic physical channel structure of WiMAX is roughly similar to that of LTE, bands that are deemed suitable for smart grid FANs using LTE will likely also be adequate should a utility choose to use WiMAX technology instead. However, in cases in which "candidate" bands identified in this study are of marginally adequate bandwidth, it would be prudent for utilities to undertake more detailed analysis—taking into account their specific current and projected needs—before making any commitments to spectrum acquisition or FAN deployment. Such individualized analysis would be appropriate whether the utility planned on using WiMAX, LTE, or any other network technology.

Limitations on Practical Spectrum

Taking into account all applications, radio communications operate on spectrum ranging from about 10 KHz to around 300 GHz. Unfortunately, only a small portion of this vast spectrum is suitable for ubiquitous coverage, high-capacity broadband wireless networks such as FANs. Following is a discussion of practical considerations that define the spectrum range to be considered within this study.

Two factors make spectrum below around 400 MHz problematic for use in broadband wireless networks. First, the physical size of antennas of reasonable efficiency grows, for lower frequencies, to a point at which their deployment in some environments (for example, on the top of a building in a dense urban setting) might be difficult. Antenna size becomes even more of a factor when directional antennas are needed to define the geometry of multiple cells being served by a single base station. Of course, antenna size (in particular, dipole length) is a major consideration for handheld user devices—but this will probably not be that important for FAN remote devices.

An even bigger problem with the use of lower frequencies is that they tend to penetrate obstructions, particularly man-made structures, with minimal attenuation. This might at first seem like a good thing because it enhances coverage reliability. However, lack of propagation restriction makes it much more difficult to intensely reuse spectrum in dense urban areas where such reuse might be needed to achieve required network capacity.

The highest frequencies in general use for commercial wireless networks are around 2.7 GHz. The main constraint to operation on higher frequencies is that they are severely attenuated by common urban structure. This makes it difficult and costly to provide reliable in-building service. Fortunately, as discussed next, the model for FAN coverage generally does not include a requirement for in-building service—suggesting that FANs could effectively use frequencies above what are practical for commercial wireless networks. To a certain extent, this might be true. However, other propagation limitations of higher frequencies must also be considered.

For many (if not most) utilities, FAN coverage will be required over fairly large rural areas with low usage density. For reasons of economy, it is desirable to serve such areas with as few deployed base stations as possible. Unfortunately, free space[5] attenuation of radio signals increases as the square of the frequency. For example, free space path loss at a given transmitter-to-receiver distance will be 6 decibels (dB) greater at 3 GHz than at 1500 MHz and 12 dB greater than at 750 MHz. All else being equal (in particular, transmit power), a single base station will provide useful coverage over about half the radius, and a quarter of the area, using 3 GHz

[5] http://www.radio-electronics.com/info/propagation/path-loss/free-space-formula-equation.php.

compared to using 1500 MHz. To make matters worse, higher frequencies generally suffer greater attenuation from natural obstructions such as foliage. These factors make the use of higher frequencies much less economical in rural, low usage density areas.

A mitigating factor for the use of higher frequencies for FANs is that remote devices are for the most part deployed in fixed locations. This most likely will make it practical to provision remote devices with directional antennas of relatively high gain. For example, use of a relatively simple 6 dB gain directional antenna on a device operating at 2.8 GHz would effectively negate the 6 dB higher free space path loss compared to the use of a more traditional 0 dBi[6] dipole at 1400 MHz.

A final consideration in using higher frequencies is that they provide less reliable refractive and multipath "fill-in" in urban areas. That is, for frequencies above approximately 3 GHz, coverage tends to become largely limited to "line of sight." Even taking into account that FANs will probably not need to provide in-building coverage, this is a huge limitation for urban networks (and is largely the reason that frequencies above 3 GHz are not being considered for commercial wireless services other than in small-cell applications). Despite the drawbacks of the frequency, the 3.65 GHz "lightly licensed" band is widely used for utility FANs. The range and penetration challenges of the high frequency along with the other users that may be in the band are offset by the availability of the spectrum at low cost.

Taking these limitations into account, this study will limit consideration of FAN operating frequencies to the range of 400 MHz to 2700 MHz. As noted, the unique limitations of FAN operations (that is, remote devices in fixed locations and somewhat insensitive to antenna size, and no requirement for in-building coverage) allow for mitigation of the disadvantages generally associated with operation at the extremes of this range. Accordingly, in considering candidate frequency bands, this study will ascribe no particular preference to one frequency over another. However, individual utilities may find that their specific circumstances favor the use of relatively higher or lower frequencies. For example, even taking into account the possible use of high gain antennas on remote devices, a FAN that dominantly covers large rural areas will probably be more economically deployed and operated if lower frequencies are used, all else being equal.

Factors Defining the Amount of Spectrum Required

For obvious reasons, a crucial factor in identifying candidate frequency bands for smart grid FAN operation is the amount of spectrum required. In turn, the spectrum requirements depend on several factors.

For purposes of this study, it will be assumed that cost of FAN deployment is of primary concern. Dominating this cost will likely be the acquisition of spectrum and the cost of purchasing and deploying FAN infrastructure equipment, primarily base stations. Cost of remote device purchase and deployment will also be significant but will be largely if not completely insensitive to the amount of spectrum occupied by the FAN.

All else being equal, spectrum acquisition costs will depend heavily on the amount of spectrum involved. This is not to suggest a linear relationship; the first MHz may cost much more—or much less—than the second MHz. However, it is reasonable to assume that the goal of overall

[6] http://whatis.techtarget.com/definition/decibels-relative-to-isotropic-radiator-dBi.

cost minimization is best served by needing to acquire as little spectrum as possible. An additional benefit is that the smaller the required "chunk" of spectrum, the more potential candidate bands there are to consider.

Balanced against the preference for minimum required spectrum is the need to deliver required capacity density. (*Capacity density* may be defined as the data throughput capacity of a cell divided by that cell's geographic area. In this study, capacity density will generally be stated in units of kilobits per second per square kilometer [kbps per sq. km].) Generally speaking, capacity density in a wireless network with a given spectrum bandwidth is increased by making cells smaller—that is, by putting base stations closer together and thus increasing the density of frequency reuse. This approach has many limitations, but for purposes of this study we will focus mainly on cost implications.

Deployment of base stations in a wireless network is always a costly proposition. Besides the cost of the infrastructure equipment itself, there is the cost of purchase or lease of the physical premises, provisioning of *backhaul* (the data links connecting the base station with the rest of the network), engineering, and maintenance. Traditionally, base station costs make up a large majority of capital and operational expenses for a wireless network operator. This will most likely be particularly true for smart grid FANs because utilities will likely require that they provide a significantly higher level of reliability and "disaster-hardening" than commercial wireless networks. This reliability enhancement will most significantly impact the cost of base station deployment and maintenance, for example, in provisioning extended-term backup power systems and redundant path backhaul links.

The high cost of base station deployments in smart grid FANs argues for engineering FANs with as few base stations as possible, which is the minimum number required to provide coverage of acceptable reliability over the defined service area. In most cases, this so-called *coverage-limited* scenario will be assumed in this study for purposes of determining the amount of spectrum required for smart grid FANs. The exception will be for consideration of the lowest frequency (400–600 MHz) spectrum bands, where coverage-limited networks in dense urban areas would require unreasonable amounts of spectrum. In those cases, the study will assume a realistic amount of spectrum in keeping with what is available in candidate frequency bands.

Another factor that has obvious implications for determining the required capacity density of a FAN—and therefore the amount of spectrum required—is the types of traffic that will need to be supported. At a minimum, one can assume that the FAN will provide connectivity for operational devices, which could include supervisory control and data acquisition (SCADA) terminals, dynamic line rating devices, synchrophasors, distributed generation controls and monitors, distributed storage controls and monitors, and other intelligent electronic devices associated with monitoring and operating the grid itself. Some utilities may elect to expand the role of their FANs to include AMI communications (either providing backhaul for neighborhood collection points or, more efficiently, connecting directly to meters), mobile workforce voice and data communications, security monitoring (possibly including streaming video), and/or other enterprise communications not directly related to grid operations. For the requirements analysis in this study, however, it is assumed that FANs will be used exclusively for machine-to-machine grid operational data communications.

FAN Morphologies

In the field of wireless network planning and engineering, a fundamental consideration is what is commonly termed *morphology*. Generally speaking, *network morphology* is the collection of localized factors—such as natural terrain, man-made structure height and density, population density and distribution, and per-population wireless usage—that need to be considered in order to effectively design or optimize a wireless network serving that area. This study is not intended to provide any guidance on the design or engineering of smart grid FANs. However, as noted previously, to determine spectrum requirements it is necessary to first identify required FAN capacity density, which obviously will vary significantly in different network morphologies.

Assuming that a smart grid FAN will be dedicated to smart grid–related data communications, its required capacity density in any area within its region of service is equal to the maximum current and/or anticipated usage density of all smart grid remote devices deployed within that area. *Usage density* in a given area is defined as the collective throughput requirement of all remote devices in the area divided by the area's size. As with capacity density, usage density will be stated in kbps per sq. km.

As a model for smart grid usage density, this report will rely on the findings of a 2014 study conducted jointly by the Utilities Telecom Council and Edison Electric Institute titled *Estimating Smart Grid Communication Network Traffic* (the UTC study).[7] The UTC study identified four models for smart grid FAN morphology, differentiated by population density as shown in Table 2-1.

Table 2-1
Smart Grid FAN Morphology Models Differentiated by Population Density

Morphology	Dense Urban	Urban	Suburban	Rural
Population density (per sq. km)	25,000	4,500	250	100

For each of these morphologies, the UTC study establishes densities of various smart grid operational device deployments and their associated data throughput requirements. The findings indicate that smart grid FAN throughput will be highly asymmetrical, with far more traffic in the uplink direction (that is, remote device transmit, base station receive) than in the downlink. It is interesting to note that this is exactly the opposite of the usual situation for commercial wireless broadband data networks in which downlink traffic dominates.

From the findings of the UTC study, we can derive the following smart grid operational communications uplink usage densities for the different defined morphologies (see Table 2-2).

Table 2-2
Smart Grid Operational Communications Uplink Usage Densities

Morphology	Dense Urban	Urban	Suburban	Rural
Uplink usage density (kbps per sq. km)	1713	293.6	4.24	1.85

[7] Kenneth C. Budka et al., *Estimating Smart Grid Communication Network Traffic*. UTC and EEI, March 17, 2014.

Determination of Spectrum Requirements

Having determined capacity density requirements for smart grid FANs in several model morphologies, we can proceed with considering the amount of spectrum required.

In addition to required capacity density, there are several additional factors that will be involved in this determination. One (as mentioned previously) is that traffic on the FAN is expected to be highly asymmetrical with uplink dominance. This is important because, for various technical reasons, the uplink channel of wireless data networks—including LTE networks—is generally less spectrally efficient than the downlink.

Another factor that will inform spectrum requirements is whether the FAN will operate using frequency division duplex (FDD) or time division duplex (TDD). In FDD networks, the uplink and downlink channels occupy different frequency channels and therefore require the use of "paired" spectrum blocks. In TDD networks, the uplink and downlink channels occupy the same frequency channel, which is partitioned between uplink and downlink use in the time domain. LTE standards define both FDD and TDD operation, and either should work effectively for smart grid FANs.

In addition to not requiring paired spectrum bands, TDD operation has another advantage that may be of particular importance. The time partition between uplink and downlink use of the radio channel does not need to be symmetrical, but rather can—within limits—be adjusted to accommodate asymmetry between uplink and downlink traffic levels. Accordingly, because traffic on smart grid FANs will be dominantly in the uplink, the total amount of spectrum required for the FAN should be lower with TDD operation than with FDD operation.

This study will consider smart grid FAN spectrum requirements for three representative frequencies within the search range between 400 and 2700 MHz. These frequencies (450, 700, and 1800 MHz) correspond to bands commonly used for wireless networks.

700 and 1800 MHz Cases

As discussed previously, for the 700 and 1800 MHz cases, the following analysis is intended to determine the amount of spectrum required for a smart grid FAN, using FDD or TDD, so that required capacity density is provided in each of the model morphologies with a coverage-limited network design. This analysis requires the application of two additional factors for each of these frequencies. First, we need the maximum amount of coverage (in sq. km) that can be provided by each base station in each morphology, taking into account required coverage reliability. Second, for each morphology, we need to know the uplink throughput spectrum efficiency (that is, bits per second per Hertz of total available spectrum) that can be provided by each base station (which will not be particularly sensitive to frequency in networks that are coverage-limited). Values used for these factors, based mainly on analyses provided by a 2010 EPRI report, *Wireless Field Area Network Spectrum Assessment* (the 2010 EPRI study),[8] are listed in Table 2-3.

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[8] EPRI report 1022421, *Wireless Field Area Network Spectrum Assessment: Technical Update*. December 2010.

Table 2-3
Factor Values Used for 700 MHz and 1800 MHz FAN Spectrum Requirements Calculations

Morphology	Dense Urban	Urban	Suburban	Rural
Per-base station coverage, 700 MHz (sq. km)	2.5	15	95	2600
Per-base station coverage, 1800 MHz (sq. km)	1.8	8.2	50	1500
Per-base station uplink throughput (bps/Hz)*	1.75	1.75	2.00	2.25

*Assumes that each base station provides three LTE cells (that is, three-sectored base station configuration). Values are for FDD networks. For TDD, prorate according to fractional uplink channel use.

The analyses of required spectrum for smart grid FANs operating at 700 MHz and 1800 MHz now devolves to straightforward mathematics, as presented in Tables 2-4 and 2-5, respectively.

Table 2-4
Calculation of Required Spectrum for Smart Grid FANs Operating at 700 MHz

	Morphology			
	Dense Urban	**Urban**	**Suburban**	**Rural**
Uplink usage density (kbps per sq. km)	1,713	293.6	4.24	1.85
Coverage per base station (sq. km)	2.5	15	95	2600
Required uplink throughput per base station (kbps)	4283.5	4403.7	402.8	4810.0
Per-base station uplink throughput, FDD (bps/Hz)*	1.75	1.75	2.00	2.25
Per-base station uplink throughput, TDD (bps/Hz)* ♦	1.05	1.05	1.20	1.35
Spectrum requirement FDD (MHz)†	4.9	5.0	0.4	4.3
Spectrum requirement TDD (MHz)	4.1	4.2	0.3	3.6

* Assumes that each base station provides three LTE cells (that is, three-sectored base station configuration).

♦ Assumes maximum allowed use of uplink slots per TDD LTE frame.

† Total of two paired (uplink and downlink) spectrum blocks of equal size

Table 2-5
Calculation of Required Spectrum for Smart Grid FANs Operating at 1800 MHz

	Morphology			
	Dense Urban	Urban	Suburban	Rural
Uplink usage density (kbps per sq. km)	1,713	293.6	4.24	1.85
Coverage per base station (sq. km)	1.8	8.2	50	1500
Required uplink throughput per base station (kbps)	3084.1	2407.4	212.0	2775.0
Per-base station uplink throughput, FDD (bps/Hz)*	1.75	1.75	2.00	2.25
Per-base station uplink throughput, TDD (bps/Hz)* ♦	1.05	1.05	1.20	1.35
Spectrum requirement FDD (MHz)†	3.5	2.8	0.2	2.5
Spectrum requirement TDD (MHz)	2.9	2.3	0.2	2.1

* Assumes that each base station provides three LTE cells (that is, three-sectored base station configuration).

♦ Assumes maximum allowed use of uplink slots per TDD LTE frame.

† Total of two paired (uplink and downlink) spectrum blocks of equal size.

These analyses indicate that LTE smart grid FANs operating in FDD mode at frequencies around 700 MHz would need a minimum total bandwidth of 5 MHz (that is, paired 2.5 MHz channels) to allow the use of strictly coverage-limited configuration. For TDD mode operation, a single block of 4.2 MHz would be required for strictly coverage-limited configuration. LTE standards define channel bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz (although it is possible to configure an LTE network for different, nonstandard bandwidths). It is therefore reasonable to assume that, in searching for potential FAN spectrum at frequencies around 700 MHz (a plausible range would be 600–1200 MHz), single blocks of at least 5 MHz should be considered for TDD operation. For FDD operation, paired blocks of 3 MHz each should be considered.

For FAN operation at frequencies around 1800 MHz, these analyses indicate that FANs operating in FDD mode would need a minimum total bandwidth of 3.5 MHz (that is, paired 1.75 MHz channels) to allow the use of strictly coverage-limited configuration. For TDD mode operation, a single block of 2.9 MHz would be required. Therefore, considering standard LTE channel bandwidths, in searching for potential FAN spectrum in the range of 1200–2700 MHz, single blocks of at least 3 MHz (and more conservatively at least 5 MHz) might be considered for TDD operation. For FDD operation, paired blocks of 3 MHz each should be considered.

450 MHz Case

As discussed previously, a smart grid FAN operating at the lower end of the frequency range under consideration probably cannot be deployed in strictly coverage-limited configuration. This is because, particularly in dense urban environments, the maximum per-base station coverage would be so large as to require an impractical amount of spectrum to achieve required capacity density. Accordingly, for the 450 MHz case, the analysis of required spectrum will postulate a practical amount of spectrum for FDD and TDD networks and will then determine if it is practical to provide the required capacity density, using that amount of spectrum, in each morphology. In other words, the operative question is this: Can a FAN be economically engineered with sufficient density of base station deployments to achieve required capacity density, given the postulated amount of spectrum?

Taking into account the limited amount of spectrum that might be made available for smart grid FANs in frequency bands below 600 MHz, it is prudent to postulate modest bandwidths for FANs operating there. For the following analysis, we will therefore assume that in the 450 MHz case, an FDD FAN would occupy paired spectrum with a total of 6 MHz, and a TDD FAN would occupy 5 MHz of spectrum. These both correspond to LTE standard channel bandwidths.

As with the higher frequency cases, our analysis for 450 MHz requires establishment of uplink throughput spectrum efficiency for each morphology. However, because the network will no longer be strictly coverage limited—at least in dense urban and urban morphologies—throughput spectrum efficiency (in bits per second per Hertz) will be somewhat degraded because of elevated intercell interference. Based mainly on analyses provided by the 2010 EPRI study, assumed values for this factor are as shown in Table 2-6.

Table 2-6
Uplink throughput values used for 450 MHz FAN spectrum requirements calculations

Morphology	Dense Urban	Urban	Suburban	Rural
Per-base station uplink throughput (bps/Hz)*	1.20	1.50	2.00	2.25

*Assumes that each base station provides three LTE cells (that is, three-sectored base station configuration). Values are for FDD networks. For TDD, prorate according to fractional uplink channel use.

The analyses of the 450 MHz case for smart grid FANs now follows, as presented in Tables 2-7 and 2-8, respectively.

Table 2-7
Calculation of Required Base Station Densities for FANs Operating at 450 MHz

	Morphology			
	Dense Urban	**Urban**	**Suburban**	**Rural**
Uplink usage density (kbps per sq. km)	1,713	293.6	4.24	1.85
Assumed uplink bandwidth, FDD (MHz)	3.00	3.00	3.00	3.00
Assumed uplink bandwidth, TDD (MHz)	5.00	5.00	5.00	5.00
Per FDD base station uplink throughput (bps/Hz)*	1.20	1.50	2.00	2.25
Per TDD base station uplink throughput (bps/Hz)* ♦	0.70	0.90	1.20	1.35
Maximum uplink traffic per FDD base station (Mbps)	3.60	4.50	6.00	6.75
Maximum uplink traffic per TDD base station (Mbps)	3.50	4.50	6.00	6.75
Maximum coverage per FDD base station (sq. km)	2.10	15.3	1,415	3,648
Maximum coverage per TDD base station (sq. km)	2.04	15.3	1,415	3,648

* Assumes that each base station provides three LTE cells (that is, three-sectored base station configuration).

♦ Assumes maximum allowed use of uplink slots per TDD LTE frame.

Based on the network engineering experience of the authors of this study, it is reasonable to expect that an LTE network operating at 450 MHz could be economically engineered with base station densities as high as 5 per 10 square km area (that is, 2 sq. km coverage each) but that it might be difficult to achieve higher densities without significant reductions in per-base station throughput (largely negating any capacity increase) or sustaining substantially higher costs. Accordingly, it appears reasonable to assume that, in considering frequencies in the range of 400–600 MHz, at least 5 MHz would be needed for a TDD FAN, and paired spectrum of at least 3 MHz each (a total of 6 MHz) would be needed for an FDD FAN.

Other FAN Requirements

Certain FAN characteristics and requirements—not specifically identified in the preceding analyses—nonetheless may bear on spectrum requirements. Two such factors are discussed next.

Coverage Reliability

In the analyses presented above, one of the "input" factors (for the 700 MHz and 1800 MHz cases) is maximum per-base station coverage in the various model morphologies. The values used, which are based largely on the findings of the 2010 EPRI study, derive from certain assumptions on required coverage reliability. For example, in suburban areas it is assumed that service is available in 99.9% of outdoor locations with a remote device antenna height of 1.5 meters above ground level and in 99.99% of outdoor locations with an antenna height of 8 meters. In essence, this suggests that FAN service must be available absolutely everywhere within suburban portions of the FANs service area, at least outdoors. However, it is recognized that it is acceptable—in small numbers of the most problematic areas—to obtain service through the use of elevated remote device antennas. In considering requirements for a smart grid FAN, utilities should of course take into account their specific needs for coverage reliability. For example, if a utility's distribution facilities are largely underground, it might be difficult to place remote device antennas much above the height of a pad mount enclosure.

Requirement for Disaster-Hardening

As discussed previously, smart grid FANs will ideally be configured for strictly coverage-limited operation, primarily because of the high cost of deploying and maintaining "disaster-hardened" base stations. It should also be noted that the required capacity density of the FAN may change during disaster recovery efforts. For example, a utility might depend on commercial wireless networks for routine mobile workforce voice and data communications, but commercial services might not be available following a natural or man-made disaster. In addition, smart grid operational communications requirements might be significantly different in support of post-disaster grid restoration compared to normal operations. In determining their own specific needs for smart grid FAN capacity—and correspondingly the amount of spectrum the FAN requires—utilities should take into consideration the potential impacts on FAN operation following a worst-case disaster.

3

ASSESSMENT OF POTENTIAL SPECTRUM FOR SMART GRID FANS

Criteria for Identifying Potential Spectrum Bands for FAN Use

Having determined a range of frequencies that are practical for smart grid FAN operation and minimum amounts of spectrum for FANs that will allow them to economically meet required capacity densities, this study will now focus on the assessment of specific bands within the search range to identify those that might be candidates for FAN use. Following is a discussion of the criteria used to make such identifications.

Required Bandwidth

Based on the analyses presented in the previous section, the following minimum spectrum bandwidths are used in the identification process:

- For TDD operation, a single band of 5 MHz is required; however, in the range of 1200–1800 MHz, a band as small as 3 MHz might be considered.
- For FDD operation, paired bands of at least 3 MHz each are required.

Availability

A band that otherwise meets criteria for consideration will be deemed a candidate if—based on current and anticipated designation by the FCC, current and anticipated use, or declared or anticipated intention regarding disposition by current licenser holders—it appears likely that utilities might be able to secure the right to deploy and operate smart grid FANs on the band.

Cost

A detailed analysis of the price a utility might have to pay for spectrum to operate a smart grid FAN is beyond the scope of this study. However, it is assumed that utilities would have difficulty justifying the expense if they had to pay amounts comparable to "the going price" for spectrum suitable for commercial wireless networks, as demonstrated by recent FCC spectrum auctions. Accordingly, with certain exceptions, bands that are currently used for commercial broadband networks will not be considered as candidates. However, as discussed in greater detail next, it is certainly possible that a utility might negotiate the purchase or lease of spectrum within such commercial bands.

Practicality of LTE Network Operation

A spectrum band will not be considered as a candidate if FCC regulatory requirements or other factors would preclude or significantly inhibit the operation of LTE-compatible networks and remote devices within that band, unless it appears that removing the inhibitions would be a practical undertaking.

LTE Standard Operating Bands

As previously noted, LTE-compatible infrastructure and remote terminal devices are currently being manufactured in huge quantities by numerous vendors; these volumes and competition have led to low prices for network operators and consumers (particularly in light of the high levels of complexity and technical sophistication involved in LTE devices). As discussed next, utilities will be most likely to be able to leverage these economies of scale if their smart grid FANs operate in or near bands that are defined in 3GPP standards as “standard” LTE bands.

Table 3-1, which is reproduced from 3GPP Standard Document TS 36.101, Version 12.6, shows the currently defined “standard” LTE operating bands. The various bands are, in general, those in which commercial LTE networks operate—or are anticipated to operate—at least in some locations throughout the world. This is of particular importance in the identification for potential spectrum bands for smart grid FAN operation because, in most cases, LTE infrastructure and remote device radio equipment for these bands is either currently being manufactured or is in development; therefore, compatible hardware (primarily the specialized and frequency-specific chip sets that support LTE “physical layer” operation) will likely be available at a reasonable cost.

The list of standard LTE operating bands is generally expanded as required in periodic revisions of LTE standards when new bands become available for possible LTE network deployments (for example, when the FCC auctions new broadband spectrum in the United States). Note that the latest polished list, shown in Table 3-1, does not yet capture the recently auctioned Advanced Wireless Services–Band 3 (AWS-3) band.

Although there are clear advantages to operating an LTE smart grid FAN in one of the LTE standard bands, this should not be considered an absolute requirement for placing an otherwise attractive band in consideration as a candidate. For one thing, hardware designs can often be “pulled” by between 5% and 10% of center frequency with little or no difficulty; therefore, operating in a band that is outside but close to a standard band may be quite practical. Furthermore, even if the required hardware configuration is not currently being manufactured for a selected smart grid FAN band, if a reasonable number of utilities acquire spectrum in that band, the collective market for infrastructure and remote device radio equipment will likely be sufficient so that the required specialized equipment would be obtainable at acceptable cost. Finally, it should be noted that the most significant complexities associated with LTE standards generally relate to the so-called “protocol stack,” which implements required base station–remote device interoperability and which is generally independent of operating frequency.

As noted previously, LTE standards define operations with channel bandwidths of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. However, not all of these bandwidths are applicable to all of the defined standard bands. Table 3-2, which is also reproduced from 3GPP Standard Document TS 36.101, Version 12.6, shows currently defined mapping between defined channel bandwidths and standard operating bands for LTE.

Table 3-1
LTE Standard Operating Bands[9]

LTE Operating Band	Uplink (UL) Operating Band BS Receive UE Transmit F_{UL_low}–F_{UL_high}			Downlink (DL) Operating Band BS Transmit UE Receive F_{DL_low}–F_{DL_high}			Duplex Mode
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894 MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD

[9] 3rd Generation Partnership Project, Technical Standard TS 36.101, Version 12.6.0, Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception. December 2014.

Table 3-1 (continued)
LTE Standard Operating Bands

LTE Operating Band	Uplink (UL) Operating Band BS Receive UE Transmit			Downlink (DL) Operating Band BS Transmit UE Receive			Duplex Mode
	F_{UL_low}–F_{UL_high}			F_{DL_low}–F_{DL_high}			
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
29		N/A		717 MHz	–	728 MHz	FDD[2]
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
32		N/A		1452 MHz	–	1496 MHz	FDD[2]
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD

Note 1: Band 6 is not applicable.

Note 2: Restricted to E-UTRA operation when carrier aggregation is configured. The downlink operating band is paired with the uplink operating band (external) of the carrier aggregation configuration that is supporting the configured Pcell.

Table 3-2
Defined LTE Channel Bandwidths by Operating Band[10]

LTE Band/Channel Bandwidth						
LTE Band	**1.4 MHz**	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
1			Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]
3	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]
4	Yes	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes[1]		
6			Yes	Yes[1]		
7			Yes	Yes	Yes[3]	Yes[1, 3]
8	Yes	Yes	Yes	Yes[1]		
9			Yes	Yes	Yes[1]	Yes[1]
10			Yes	Yes	Yes	Yes
11			Yes	Yes[1]		
12	Yes	Yes	Yes[1]	Yes[1]		
13			Yes[1]	Yes[1]		
14			Yes[1]	Yes[1]		
...						
17			Yes[1]	Yes[1]		
18			Yes	Yes[1]	Yes[1]	
19			Yes	Yes[1]	Yes[1]	
20			Yes	Yes[1]	Yes[1]	Yes[1]
21			Yes	Yes[1]	Yes[1]	
22			Yes	Yes	Yes[1]	Yes[1]
23	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]
24			Yes	Yes		
25	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]
26	Yes	Yes	Yes	Yes[1]	Yes[1]	
27	Yes	Yes	Yes	Yes[1]		
28		Yes	Yes	Yes[1]	Yes[1]	Yes[1, 2]
30			Yes	Yes[1]		
31	Yes	Yes[1]	Yes[1]			
...						

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[10] Ibid.

Table 3-2 (continued)
Defined LTE Channel Bandwidths by Operating Band

LTE Band/Channel Bandwidth						
LTE Band	**1.4 MHz**	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
33			Yes	Yes	Yes	Yes
34			Yes	Yes	Yes	
35	Yes	Yes	Yes	Yes	Yes	Yes
36	Yes	Yes	Yes	Yes	Yes	Yes
37			Yes	Yes	Yes	Yes
38			Yes	Yes	Yes[3]	Yes[3]
39			Yes	Yes	Yes[3]	Yes[3]
40			Yes	Yes	Yes	Yes
41			Yes	Yes	Yes	Yes
42			Yes	Yes	Yes	Yes
43			Yes	Yes	Yes	Yes
44		Yes	Yes	Yes	Yes	Yes

Note 1: Refers to the bandwidth for which a relaxation of the specified UE receiver sensitivity requirement (subclause 7.3) is allowed.

Note 2: For the 20 MHz bandwidth, the minimum requirements are specified for E-UTRA UL carrier frequencies confined to either 713–723 MHz or 728–738 MHz.

Note 3: Refers to the bandwidth for which the uplink transmission bandwidth can be restricted by the network for some channel assignments in FDD/TDD co-existence scenarios in order to meet unwanted emissions requirements (Clause 6.6.3.2).

Existing Commercial Wireless Bands: General Discussion

Within the search range of 400–2700 MHz established for this study, roughly 635 MHz lies within bands that are commonly used for commercial wireless networks or that will likely be so used in the foreseeable future. The latter category includes the AWS-3 spectrum blocks recently auctioned by the FCC. Some of that spectrum, in some locations, is still being used for legacy voice telephone networks, but the majority is used for broadband packet data networks (a mix of 4G LTE and older 3G networks). Virtually all newly exploited commercial wireless spectrum in the United States is being used to launch new LTE networks or to expand existing ones.

With winning bids totaling roughly $45 billion for 65 MHz of spectrum nationwide (an average of $692 million per MHz), the results of the FCC's recent AWS-3 auction provide ample evidence of the high value attributed to spectrum that can be used for broadband wireless networks in the United States. Assuming an average valuation of $692 million per MHz of nationwide spectrum in recognized commercial wireless bands, one could anticipate that a single 5 MHz channel would cost around $3.46 billion on a nationwide basis.

Of course, the overwhelming majority of this cost would be for spectrum in major urban areas in which congestion on wireless networks is the greatest. In rural areas, spectrum valuation is much lower. This suggests that utilities that operate exclusively in rural areas might be able to purchase or lease access to spectrum in commercial wireless bands at tolerable prices from existing license holders. In most cases, however, the high value of spectrum in bands suitable for commercial broadband networks will probably preclude its use for smart grid FANs. There is at least one important exception to this generalization, which is discussed in detail next.

It should be noted that not all spectrum in commercial wireless bands is suitable for broadband network use. For example, in the upper 700 MHz band (comprising the range of 746–806 MHz), the “A” and “B” blocks each consist of paired 1 MHz portions (see Figure A-5). Because the minimum bandwidth for LTE-compliant systems is 1.4 MHz, these blocks are not by themselves suitable for LTE network operation. As a result, their valuation—even in urban areas—is much lower on a per-MHz basis than bands of greater bandwidth. Currently, upper 700 MHz “A” block licenses are being marketed in several regions. Unfortunately, the very characteristic that depresses their valuation—insufficient bandwidth to support an LTE network—prevents them from meeting the prerequisites identified previously in this study. However, that does not disqualify them from consideration. If the shortcomings (that is, inability to use LTE and therefore standards-based equipment; reduced capacity) can be managed, these bands may be useful for at least some grid data communications. For example, a narrowband 700 MHz network of limited capacity could be combined with another network operating in a different band, possibly using a different technology.

Current and anticipated commercial wireless bands—and the designated channel blocks they comprise—are depicted in Appendix A.

Anticipated FCC Auctions

Primarily as a result of rapidly growing demand for wireless broadband services and consequential congestion in existing commercial broadband networks, the FCC has for several years been aggressively seeking ways in which underused spectrum in suitable bands can be repurposed. It then typically auctions licenses for that spectrum on a regional basis. Most recently, the FCC concluded a successful licensing auction for AWS-3.

Although most of these auctions are intended for competitive bidding by commercial wireless operators, there are generally no rules that would prohibit a utility from bidding on one or more spectrum blocks that it intended to use for a private network such as a smart grid FAN. Of course, given the previously noted high valuation of such spectrum, it is unlikely that the utility would “win” such an auction with bids that it could financially justify.

The next anticipated FCC auction of broadband spectrum is the so-called “incentive auction” of frequencies below 698 MHz, currently scheduled for some time in 2016. This spectrum is currently licensed for ultrahigh frequency (UHF) television broadcasting. The FCC believes that the recent conversion from analog to digital television broadcasting has enabled a reduction in the spectrum required for broadcast television, with many UHF stations being able to move to very high frequency (VHF) channels without excessive interference. However, for various reasons, the FCC has decided not to “force” such moves. Instead, it has developed a novel “incentive” scheme for freeing up what are currently UHF television (TV) channels for use by wireless networks. Under this scheme, the FCC hopes to be able to auction a total of seven channel blocks, each consisting of paired (uplink and downlink) 5 MHz channels (see Figure A-1). However, “holdout” broadcast license holders may create geographical “holes” in some or all of these channel blocks, and there is concern that interference from remaining UHF television broadcasts will significantly degrade wireless network performance. Consequently, bidding for some of the more vulnerable 600 MHz blocks might be depressed. Characteristics of smart grid FANs—mainly that remote devices are generally in fixed locations—may mitigate some of these technical concerns. Taking these factors into consideration, utilities may wish to monitor developments surrounding the 600 MHz incentive auction.

Overview of Current Spectrum Use

Tables 3-3 through 3-10 examine the current FCC regulatory status, current use, and anticipated repurposing (if any) of the various designated frequency bands in the range of 400–2700 MHz. As previously discussed, this represents the search range for possible spectrum that could be effectively used for smart grid FANs. Bands that appear to present or include candidate spectrum for smart grid FAN use are highlighted, with reference to other areas of this report where they are discussed more fully.

Table 3-3
Current Spectrum Band Designations and Uses in the United States: 400–698 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
400	401	1.0	Satellite communications	Inadequate bandwidth; incompatible with current use
401	402	1.0	Earth exploration satellite; space exploration operations; medical device communications	Inadequate bandwidth; incompatible with current use
402	403	1.0	Earth exploration satellite; medical device communications	Inadequate bandwidth; incompatible with current use
403	406	3.0	Medical device communications	Inadequate unpaired bandwidth for TDD; incompatible with current use
406	406.1	0.1	Personal locator beacons	Inadequate bandwidth; incompatible with current use
406.1	420	13.9	Private land mobile	See "406–420 MHz Band" discussion below
420	450	30.0	Private land mobile; amateur	Incompatible with current use
450	460	10.0	Private land mobile and others; divided into narrowband channels	Inadequate bandwidth in individually licensed channels
460	470	10.0	Private land mobile and others; divided into narrowband channels	Inadequate bandwidth in individually licensed channels
470	698	228.0	Broadcast television: a portion of this band is likely to be repurposed to wireless broadband services (see Figure A-1) "White space" devices	See "Anticipated FCC Auctions" discussion above See "Television 'White Spaces'" discussion below

Table 3-4
Current Spectrum Band Designations and Uses in the United States: 698–824 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
698	746	48.0	Commercial wireless lower 700 MHz band (see Figure A-2)	See "Existing Commercial Bands – General Discussion" above
746	758	12.0	Commercial wireless upper 700 MHz band (see Figure A-2)	Includes downlink channel of upper 700 MHz "A" Block; see "Existing Commercial Bands – General Discussion" above
758	775	17.0	700 MHz D-block and public safety (see Figure A-2)	See "700 MHz D-Block/Public Safety Shared Network" discussion below
775	788	13.0	Commercial wireless upper 700 MHz band (see Figure A-2)	Includes uplink channel of upper 700 MHz "A" Block; see "Existing Commercial Bands – General Discussion" above
788	805	17.0	700 MHz D-block and public safety (see Figure A-2)	See "700 MHz D-Block/Public Safety Shared Network" discussion below
805	806	1.0	Commercial wireless upper 700 MHz band (see Figure A-2)	Inadequate paired bandwidth for FDD
806	809	3.0	Public safety; paired with 851–854 MHz; divided into narrowband channels	Inadequate bandwidth in individually licensed channels
809	824	15.0	Public safety and private land mobile; paired with 854–869 MHz; divided into narrowband channels	Inadequate bandwidth in individually licensed channels

Table 3-5
Current Spectrum Band Designations and Uses in the United States: 824–896 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
824	849	25.0	800 MHz cellular mobile networks (see Figure A-3)	See "Existing Commercial Bands – General Discussion" above
849	851	2.0	Commercial air-to-ground; paired with 894–896 MHz	Inadequate paired bandwidth for FDD; incompatible with current use
851	854	3.0	Public safety; paired with 806–809 MHz; divided into narrowband channels	Inadequate bandwidth in individually licensed channels
854	869	15.0	Public safety and private land mobile; paired with 809–824 MHz; divided into narrowband channels	Inadequate bandwidth in individually licensed channels
869	894	25.0	800 MHz cellular mobile networks (see Figure A-3)	See "Existing Commercial Bands – General Discussion" above
894	896	2.0	Commercial air-to-ground; paired with 849–851 MHz	Inadequate paired bandwidth for FDD; incompatible with current use.

Table 3-6
Current Spectrum Band Designations and Uses in the United States: 896–941 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
896	901	5.0	Private land mobile; paired with 935–940 MHz divided into narrowband channels	Previously Nextel/iDEN, this band was acquired by Pacific DataVision, which intends to use it for a nationwide common carrier "push-to-talk" dispatch service with narrow channel technology; FAN use is incompatible
901	902	1.0	Narrowband PCS	Inadequate bandwidth
902	928	26.0	Unlicensed (ISM)	Incompatible with current use; see "Licensed vs. Unlicensed Spectrum" discussion above
928	929	1.0	Multiple address service	Widely used by utilities for narrowband; inadequate bandwidth for FAN
929	930	1.0	Paging	Inadequate bandwidth
930	931	1.0	Narrowband PCS	Inadequate bandwidth
931	932	1.0	Paging	Inadequate bandwidth
932	935	3.0	Fixed microwave	Inadequate bandwidth for unpaired TDD
935	940	5.0	Private land mobile; paired with 896–901 MHz; divided into narrowband channels	Previously Nextel/iDEN, this band was acquired by Pacific DataVision, which intends to use it for a nationwide common carrier "push-to-talk" dispatch service with narrow channel technology; FAN use is incompatible
940	941	1.0	Narrowband PCS	Inadequate bandwidth

Table 3-7
Current Spectrum Band Designations and Uses in the United States: 941–1435 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
941	944	3.0	Various fixed link applications	Inadequate bandwidth for unpaired TDD
944	960	16.0	Various licensed services, primarily fixed link	Incompatible with current use
960	1164	204.0	Aeronautical navigation and radar	Incompatible with current use
1164	1215	51.0	Aeronautical navigation and global positioning system (GPS)	Incompatible with current use
1215	1240	25.0	Federal use for radar	Incompatible with current use
1240	1300	60.0	Federal use for radar, amateur	Incompatible with current use
1300	1350	50.0	Federal use for radar	Incompatible with current use
1350	1390	40.0	Federal use for radar, Department of Defense (DoD) point-to-point tactical communications	Incompatible with current use
1390	1392	2.0	Commercial telemetry	See “TerreStar Telemetry Bands” discussion below
1392	1395	3.0	Commercial telemetry; paired with 1432–1435 MHz	
1395	1400	5.0	Medical telemetry	Incompatible with current use
1400	1427	27.0	Radio astronomy; with few exceptions, no transmission allowed	Incompatible with current use
1427	1429.5	2.5	Industrial telemetry; medical telemetry	See “1427–1432 MHz Telemetry Band” discussion below
1429.5	1432	2.5	Industrial telemetry	
1432	1435	3.0	Commercial telemetry; paired with 1392–1395 MHz	See “TerreStar Telemetry Bands” discussion below

Table 3-8
Current Spectrum Band Designations and Uses in the United States: 1435–1780 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
1435	1525	90.0	DoD, NASA, DoE flight test telemetry	Incompatible with current use
1525	1535	10.0	Commercial mobile satellite	Incompatible with current use
1535	1559	24.0	Commercial mobile satellite	Incompatible with current use
1559	1610	51.0	GNSS (GPS)	Incompatible with current use
1610	1610.6	0.6	Commercial mobile satellite	Inadequate bandwidth; incompatible with current use
1610.6	1613.8	3.2	Commercial mobile satellite	Incompatible with current use
1613.8	1626.5	12.7	Commercial mobile satellite	Incompatible with current use
1626.5	1660	33.5	Commercial mobile satellite	Incompatible with current use
1660	1660.5	0.5	Radio astronomy	Inadequate bandwidth; incompatible with current use
1660.5	1668.4	7.9	Radio astronomy; with few exceptions, no transmission allowed	Incompatible with current use
1668.4	1670	1.6	Federal use for meteorology	Inadequate bandwidth; incompatible with current use
1670	1675	5.0	Commercial mobile satellite (LightSquared); NOAA use for satellite data links and research	See "1670–1675 MHz LightSquared Band" discussion below
1675	1695	20.0	NOAA use for satellite data links and meteorology telemetry	See "1670–1675 MHz LightSquared Band" discussion below
1695	1710	15.0	AWS-3 mobile networks (see Figure A-4)	See "Existing Commercial Bands – General Discussion" above
1710	1755	45.0	AWS mobile networks (see Figure A-5)	See "Existing Commercial Bands – General Discussion" above
1755	1780	25.0	AWS-3 mobile networks (see Figure A-4)	See "Existing Commercial Bands – General Discussion" above

Table 3-9
Current Spectrum Band Designations and Uses in the United States: 1780–2300 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
1780	1850	70.0	Military; anticipated for future broadband mobile use	See "1780–1850 MHz Government Use Band" discussion below
1850	2000	150.0	PCS and AWS-2 mobile networks (see Figures A-6 and A-7)	See "Existing Commercial Bands – General Discussion" above
2000	2020	20.0	Commercial mobile satellite; rulemaking under way to allow terrestrial mobile broadband use; paired with 2180–2200 MHz; held by Dish Networks.	See "2000–2020 and 2180–2200 MHz Dish Networks Holdings" discussion below
2020	2025	5.0	AWS-2 mobile networks (see Figure A-7)	See "Existing Commercial Bands – General Discussion" above
2025	2110	85.0	NASA use for satellite and deep space data links	Incompatible with current use
2120	2180	70.0	AWS, AWS-3 mobile networks (see Figures A-4 and A-5)	See "Existing Commercial Bands – General Discussion" above
2180	2200	20.0	Commercial mobile satellite; rulemaking under way to allow terrestrial mobile broadband use; paired with 2000–2020 MHz; held by Dish Networks	See "2000–2020 and 2180–2200 MHz Dish Networks Holdings" discussion below
2200	2290	90.0	NASA and other use for space communications	Incompatible with current use
2290	2300	10.0	NASA use for space research	Incompatible with current use

Table 3-10
Current Spectrum Band Designations and Uses in the United States: 2300–2700 MHz

Lower Limit (MHz)	Upper Limit (MHz)	Bandwidth (MHz)	Current FCC Designation/Use in the United States	Comments with Respect to Potential Use for FANs
2300	2305	5.0	Amateur	Incompatible with current use
2305	2310	5.0	Amateur; limited military use	Incompatible with current use
2310	2320	10.0	Broadcast satellite	Incompatible with current use
2320	2345	25.0	Broadcast satellite	Incompatible with current use
2345	2360	15.0	Broadcast satellite	Incompatible with current use
2360	2390	30.0	Federal and non-federal flight test telemetry	Incompatible with current use
2390	2395	5.0	Federal and non-federal flight test telemetry; amateur	Incompatible with current use
2395	2400	5.0	Amateur	Incompatible with current use
2400	2417	17.0	Amateur; limited federal use for air-to-ground communications	Incompatible with current use
2417	2450	33.0	ISM: primarily used for unlicensed applications (for example, 802.11)	Incompatible with current use; see “Licensed vs. Unlicensed Spectrum” discussion above
2450	2483.5	33.5	ISM: primarily used for unlicensed applications (for example, 802.11)	Incompatible with current use; see “Licensed vs. Unlicensed Spectrum” discussion above
2483.5	2495	11.5	Commercial mobile satellite	Incompatible with current use
2495	2496	1.0	Commercial mobile satellite and others	Incompatible with current use
2496	2690	194.0	Commercial mobile (licensed and/or leased by Sprint); Educational Broadband Service (EBS) (see Figure A-8)	See “2496–2690 MHz Sprint and EBS Spectrum” discussion below
2690	2700	10.0	Radio astronomy; with few exceptions, no transmission allowed	Incompatible with current use

Possible Spectrum for Smart Grid FANs (Near Term)

This study's analysis of the frequency bands ranging from 400 to 2700 MHz, as depicted in Tables 3-3 through 3-10, has identified the following bands that might be classified as *near-term* candidates—that is, utilities might be able to secure licenses at acceptable cost and make use of the spectrum for LTE-compliant FANs without the need for protracted repurposing policy decisions on the part of the Federal Communications Commission (FCC).

2469–2690 MHz Sprint and EBS Spectrum

Spectrum in this range was originally allocated by the FCC for Educational Broadband Services (EBS) with licenses held by various educational institutions and for point-to-multipoint commercial data services called *broadcast radio services*, or *BRS* (see Figure A-8). Some years ago, Clearwire Corp. began acquiring and consolidating these licenses with the intent of offering a wireless alternative to residential and small business Internet access using the then-under-development WiMAX technology. Although launched in several major cities, this service proved to be economically impractical. Sprint-Nextel, which was a major investor, eventually acquired Clearwire with the intent of using its spectrum holdings around 2.5 GHz for LTE mobile services.

In fact, 2.5 GHz is not a particularly attractive band for mobile broadband networks. In rural areas, it suffers from relatively poor per-base station coverage as a result of relatively high free space path loss and significant signal attenuation in foliage. In urban areas, it often provides poor in-building service because of high attenuation in common building materials. As a result, Sprint has to date made only limited use of its vast 2.5 GHz spectrum resources, although it has plans to more aggressively exploit them—particularly in high-density urban areas—in the near future. To deal with the in-building problem, Sprint is strongly considering extensive use of distributed antenna systems.

Although Sprint has not publicly expressed an interest in selling, leasing, or sub-leasing any of its 2.5 GHz spectrum, there is considerable speculation in the trade press that such a move may be forthcoming. A couple of factors are often cited. First, Sprint clearly needs cash to fund expansion of its LTE networks, including extensive use of costly distributed antenna systems. Second, it could probably afford to give up a relatively small part of this band, with a total of 194 MHz, without seriously diminishing its holdings.

There are several reasons that Sprint might be interested in giving access to some of its spectrum in this band for smart grid FANs. Most importantly, assuming that Sprint would consider any divestiture, it would presumably much prefer to do business with entities—such as utilities—that are not competitors. Smart grid FANs, which would probably require around 5 MHz (for TDD operation), would occupy less than 3% of the spectrum in the band. In addition, besides cash for purchase or lease of spectrum, utilities could offer to Sprint some important benefits in exchange: a large number of base station sites (utility poles and/or transmission towers) and extensive fiber-optic facilities for backhaul.

As noted, this band is less than ideal for mobile broadband networks. However, substantial mitigating factors make it much more reasonable for smart grid FAN use. In rural areas, smart grid remote devices (which are generally in fixed locations) can be provisioned with higher gain directional antennas that would largely negate the free space path loss disadvantages (and to a certain extent mitigate the higher foliage attenuation) compared to lower frequencies. In urban areas, there is assumed to be little if any need for in-building coverage, so this band would be far less problematic for smart grid FANs than for commercial wireless networks.

Although Sprint is certainly not the biggest nationwide carrier in the United States, it is still a major player—and if it plans to aggressively begin to exploit its 2.5 GHz spectrum, compatible LTE radio hardware will almost certainly be available at reasonable prices.

Although Sprint controls much of the spectrum in this band, there remain several EBS license holders who have as yet not sold or leased their holdings. It would certainly be possible for a utility to deal with one or more of these entities rather than, or in addition to, Sprint. However, the geographic region covered by each EBS license is generally quite limited. At least one clearinghouse, EBSspectrum.org (http://www.ebsspectrum.org/), is dedicated to facilitating the leasing of EBS licenses.

2000–2020 and 2180–2200 MHz Dish Networks Holdings

This paired spectrum, also called *AWS-4*, is currently allocated by the FCC for mobile broadband services using *Big LEO* (large-scale, low Earth orbiting) satellites. However, it is generally accepted that the FCC will soon execute a change that will allow its use for purely terrestrial mobile networks.

Dish Networks—best known for its successful broadcast satellite television service—has extensive spectrum holdings in different commercial wireless bands but has never deployed a terrestrial network. It was an active and successful bidder for multiple licenses in the recent AWS-3 auction. Saddled with considerable debt incurred to make spectrum purchases, Dish is facing an impending deadline that requires it to build out networks on its 700 MHz holdings so as to cover 40% of the population within license areas by 2017.

It is generally believed that Dish intends to offer some or all of its commercial wireless spectrum holdings for lease to incumbent carriers in order to expand their network capacities where congestion is a problem. Other observers believe that, in building a spectrum portfolio, Dish is positioning itself for possible merger with an established carrier. In either of these scenarios, the paired 2000–2020 MHz and 2180–2200 MHz spectrum would appear to be less useful than the spectrum Dish holds—for example, in the 700 MHz and AWS-3 bands—and there is considerable conjecture that Dish might be prepared to sell or lease it. If so, the valuation will most likely be very high, but perhaps not quite as high as for spectrum in more established commercial bands.

406–420 MHz Band

This spectrum is actually composed of two separate bands: the 406.1–410 MHz band and the 410–420 MHz band. The 406.1–410 MHz band is allocated exclusively for federal government use. The 410–420 MHz band is allocated for government and nongovernment use. The vast majority of the use of the entire 406–420 MHz band is by federal agencies; the only nonfederal use is for astronomy. The band is currently used for land mobile radio (LMR) purposes—mostly public safety and military—and, interestingly, utility operations (for example, Tennessee Valley Authority). There are some fixed operations in the band, but growth has been flat. Mobile use of the band was at one time reported to be increasing, but it is unclear whether that is actually true.

Since 2001, the band has been identified in several government reports as a candidate band for increased use by nonfederal operations.

First, it was considered as a band for nonfederal public safety users, but ultimately that idea was rejected as a result of resistance from federal users who claimed that increased use of the band could interfere with their existing and planned operations.[11]

Then in 2006, the band became the subject of a spectrum sharing test-bed that was conducted by National Telecommunications Information Administration (NTIA) and the FCC.[12] Interestingly, tests conducted by NTIA in 2007 found that the spectrum band was being used only 3–5% during the busiest times of the day in Washington, D.C. and that other tests around the country showed similar results.[13] The spectrum sharing test-bed is significant because it showed that the spectrum was not heavily used—which is the reason it was selected by NTIA for the sharing test-bed. This supports the conclusion that the band could also be potentially shared with utilities on a TDD basis.

Most recently, the band has been identified as one of several potential candidate bands by NTIA, following an Executive Memorandum directing the federal government to find 500 MHz for commercial broadband.[14] The band did not make the "fast track report" of bands for immediate reallocation, however. Nonetheless, the band was also identified for spectrum sharing as part of a report by the President's Council of Advisors on Science and Technology.[15] Because of its favorable propagation characteristics, the report identified the 406–420 MHz band as one of several "good candidates" to go along with the 3550–3650 MHz band that is currently being allocated by the FCC for broadband small-cell spectrum sharing. This shows that the band is still being considered by the federal government as a long-term opportunity for sharing with nonfederal users for broadband operations.

There are several reasons that this band should be attractive to utilities. First, the frequency range is the same as the frequencies that utilities currently use, which might enable utilities to leverage at least some existing sites and possibly equipment. On a similar note, the frequency range provides favorable propagation to enable broad coverage over a wide area where usage density is low. Second, there does appear to be sufficient capacity to support utility communications needs because there is 13.9 MHz of spectrum available. Third, it is reasonably close to one of the FDD

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[11] "Alternative Frequencies for Use by Public Safety Systems," National Telecommunications Information Administration, NTIA Special Publication 01-48 (December 2001).

[12] "The President's Spectrum Policy Initiative - Spectrum Sharing Innovation Test-Bed," NTIA, Docket No. 060602142-6142-01 (June 8, 2006), visited at http://www.ntia.doc.gov/federal-register-notice/2006/presidents-spectrum-policy-initiative-spectrum-sharing-innovation-test-). See also "Spectrum Sharing Innovation Test Bed Pilot Program" at http://www.ntia.doc.gov/files/ntia/publications/phase_i_test_plan_final_02122009.pdf (identifying the 406–410 MHz band by NTIA for use in the tests).

[13] NTIA Technical Report TR-07-448, *Measurements to Characterize Land Mobile Channel Occupancy for Federal Bands 162–174 MHz and 406–420 MHz in the Washington, D.C., Area*. http://www.its.bldrdoc.gov/publications/07-448.aspx.

[14] "Ten-Year Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband (President's Spectrum Plan Report)" at http://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf.

[15] "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," President's Council of Advisors on Science and Technology (July 2012) at http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

LTE bands, so it would likely support a standardized broadband technology. Fourth, the band is not commercially attractive to the carriers because it is not ideally suited for the high-density frequency reuse that carriers typically need in dense urban environments—which should enable utilities to compete for access to this band. Finally, based on the test-bed studies conducted by NTIA, the band does appear to be suitable for spectrum sharing—rather than reallocation—which should accelerate access and deployment by utilities at lower cost (that is, utilities may not have to buy the spectrum in an auction).

On the downside, the band is less suitable for use in dense urban areas, depending on the way the network is configured and the number of devices that would need to be supported in a given area. As described previously in the analysis of spectrum requirements for the 450 MHz case, engineering a network with tight base station separations can be challenging because of considerations of intercell interference, so that a requirement for high-capacity density may need to be met with greater bandwidth. Ideally, utilities would use this band for wide area coverage in suburban and rural areas; however, based on the analysis presented, it could also successfully be used in urban and dense urban areas, albeit with greater engineering difficulty.

1427–1432 MHz Telemetry Band

The 1427–1432 band is currently authorized for telemetry operations that are licensed on a site-by-site basis. The band is shared with the Wireless Medical Telemetry Service (WMTS), such that WMTS is primary in the lower half of the band (1427–1429.5 MHz) and telemetry is primary in the upper half of the band (1429.5–1432 MHz) except in seven cities.[16] Operations are coordinated so as to avoid interference with one another. In addition to these nonfederal operations, the band is also used by the Department of Defense (DOD) for fixed communication systems supporting voice and data applications at a limited number of test and training ranges within the United States.

The use of the band is light. There are only 141 active licenses in the FCC's Universal Licensing System (ULS) database in this band—many of which are licensed to utilities and commercial, industrial, and institutional (CII) or meter manufacturers. The spectrum can be assigned in channel widths as little as 12.5 kHz or as wide as 50 kHz. Wider channel widths may be authorized upon request to the Commission.

This band is already heavily used by utilities and could be used for broadband or at least wideband operations. This could be accomplished by waiver or by rule. Depending on how many utilities want to use the band, it may be more expedient to obtain a waiver than to seek a rule change to use the band for broadband operations. A rule change would require a period of time of at least a year and half to conduct.

1780–1850 MHz Government Use Band

This band is in essence the "remnant" of a much larger band allocated for use by military and other U.S. government entities for a variety of localized applications. Because the original band was sparsely used, the FCC was able to clear much of it for auctioning, primarily as part of the

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[16] See 47 C.F.R. §90.259. The seven cities where WMTS operations are primary in the 1429.5–1432 MHz band are Pittsburgh, PA; Washington, D.C. metro area; Richmond/Norfolk, VA; Austin, TX; Battle Creek, MI; Detroit, MI; and Spokane, WA.

AWS-3 band. The “clearing” mainly took the form of incumbent users moving as required to the remaining portion of the band.

Because the remaining band is still quite sparsely occupied (and on a localized basis), there is considerable speculation that the FCC will do further “clearing”—that is, further compression of incumbent users into a further reduced band—to free up additional spectrum for commercial wireless broadband. However, in addition to the goal of making more spectrum available for commercial networks, the FCC is also pursuing a policy of encouraging “shared use” of spectrum. It appears likely that sharing spectrum in this band—between existing military and government users and smart grid FANs—would be feasible: in any given region, the number of incumbent users is generally quite limited. Therefore, if rules were appropriately adjusted, it is likely that a utility would be able to coordinate with such users to free up a modest amount of contiguous spectrum (the analysis in this study suggests that 5 MHz would be adequate) for operation of a TDD smart grid FAN. The specific frequencies used would not have to be the same in each region, or even coordinated, because there is no need for remote devices associated with smart grid FANs to be able to “roam” to other FANs.

Because FCC regulations would need to be changed to allow nongovernmental operations in this band, its viability as a near-term candidate for smart grid FAN use is probably marginal.

TerreStar Telemetry Bands

TerreStar Corporation, which is currently in bankruptcy, holds nationwide licenses to paired spectrum bands 1392–1395 MHz and 1432–1435 MHz and an additional unpaired band 1390–1392 MHz. The eventual disposition of these licenses as assets has not yet been determined. The bands are intended for terrestrial wireless telemetry systems, which would appear to comprise the functionality of smart grid FANs.

The paired bands appear to provide just enough spectrum to allow operation of smart grid FANs using FDD configuration. (Uses in adjacent bands do not appear to require additional guard bands.) At the same time, the relatively narrow bandwidths along with spectral isolation from other commercial wireless bands would probably result in the valuation of these holdings being significantly below spectrum within or adjacent to commercial bands.

Because these bands are not in or close to commercial paired wireless bands, no usable LTE-compatible FDD products are currently available. Therefore, viability for smart grid FAN use (at least using LTE technology) would probably hinge on the band’s being embraced by at least a significant number of utilities. Alternatively, there are defined WiMAX *WiGRID* profiles for these bands, but it is not clear whether compatible products are currently being manufactured.

1670–1675 MHz LightSquared Band

Like TerreStar, LightSquared is in bankruptcy. Its spectrum holdings include this band, which it leases from OP Corporation. LightSquared had planned to use it in a scheme to provide terrestrial wireless services in coordination with its mobile satellite system. That scheme failed because another band involved in the plan would present unacceptable interference to the operation of widely used global positioning system (GPS) receivers. However, potential terrestrial use of the 1670–1675 MHz band was not deemed controversial.

The disposition of LightSquared's interest in this band has not yet been resolved in bankruptcy proceedings. If it were to become available for sale, lease, or sub-lease, it could be useful for smart grid FANs operating in TDD mode. The 5 MHz bandwidth would appear to be just sufficient based on the analysis in this study.

As with the TerreStar case described previously, this band is not in or adjacent to any commercial wireless network and is of relatively modest size. Therefore, it would probably have relatively low valuation for commercial network operators. However, economic practicality of use for LTE-compliant FANs would probably depend on its being embraced for that purpose by at least a significant number of utilities.

Possible Longer Term Solutions

Looking beyond the candidate spectrum bands described previously, other possibilities for acquiring smart grid FAN spectrum—despite seeming remote today—may in time present themselves. Two such possibilities are described next.

TV White Spaces

The term *white spaces* in this context refers to broadcast television channels that are unoccupied in a given geographic region. White spaces may exist "naturally" in (typically rural) areas in which the demand for broadcast channels is relatively low, or they may result from the need to avoid mutual interference by provide buffer regions between transmitters using the same channel. By rule, the FCC allows low-powered devices, particularly wireless microphones and similar devices, to operate on a more or less unregulated basis in TV white spaces. It is anticipated that the number of unused TV channels—and therefore the number of white space bands—will be reduced following the FCC's 600 MHz Incentive Auction, particularly in large metropolitan areas. (Although the FCC has indicated that at least one unused channel will remain in every location, it would be effectively shared spectrum and not comparable to a licensed FAN.)

The combination of regulatory transmit power limits and the shrinking number of available white space bands would appear to make this a very low probability for smart grid FAN use; however, two mitigating factors could work in its favor. First, because smart grid FAN remote devices (and obviously their base stations) are generally in fixed locations, the network operator can control the signal (that is, interference) levels they present at defined boundaries. Second, technologies are emerging that will allow broadband networks to coordinate their localized spectrum use with potentially interfering, randomly distributed low-power devices. Therefore, if the FCC were to change rules on white space use to control interference on the basis of maximum boundary line signal level—and to require unregulated low-power devices to coordinate their operation with an overlying broadband network—the use of white spaces for smart grid FANs could become viable. Furthermore, this would pretty much epitomize the "shared use" that is presumably encouraged by FCC policy.

FCC Allocation of Dedicated or Shared Spectrum for Smart Grid FANs

In recent years, the FCC has allocated spectrum for non-governmental use primarily on the basis of competitive auction. Because of the huge demand for spectrum—driven mainly by surging use of broadband data networks—and its relative scarcity, it is difficult to imagine that any spectrum offered for auction will simultaneously be useful for smart grid FAN use and valued at a price that is economically justifiable for that use. However, as has been discussed in several contexts previously, certain characteristics of smart grid FANs would allow their practical operation in frequency bands; under various regulatory restrictions, that would be unattractive for commercial broadband networks. It is therefore possible that one or more future spectrum auctions will present opportunities for utilities to acquire spectrum for FAN use at acceptable cost.

In years past, the FCC often made spectrum allocations on the basis of type of use or user enterprise. For example, in repurposing 700 MHz spectrum, a portion was set aside for the exclusive use of public safety entities. As noted, such practices have long since been abandoned in favor of auctions when it comes to private sector licensees.

Alternatives to FANs on Dedicated Licensed or Shared Use Spectrum

700 MHz D-Block/Public Safety Shared Network

The upper 700 MHz band D-block was originally intended for licensing by a commercial carrier that would collaboratively build and share a broadband data network with public safety entities. Public safety would contribute its own FCC-allocated spectrum (adjacent to the D-block). The scheme fell through when no private carrier bid anything close to the (very modest) reserve bid price for the D-block during the 700 MHz auction. The problem, it seems, is that the needs and priorities of the public safety community are incompatible with those of commercial wireless network operators. For example, the costly disaster-hardening of the network required by public safety could not be supported in a commercial network offering service at competitive prices.

It turns out, however, that the technical requirements of smart grid FANs are **very** compatible with those specified by the public safety community, and the idea of building and sharing a nationwide broadband network on that basis of sharing has been widely proposed. Technically, such a scheme offers a good deal of elegance. Utilities are continuing to discuss the possibility with state agencies and the national FirstNet organization. However, the process is moving slowly, and initial network deployments are estimated to be 5–10 years away. In addition, the questions around the implications of secondary use status for utilities are still unresolved.

A more detailed technical analysis of a shared smart grid/public safety broadband network is provided in the 2010 EPRI study.

Use of Commercial Broadband Networks

Wireless broadband networks have reached a level of deployment in the United States so that coverage extends to the vast majority of areas in which smart grid data communications would be required. And while smart grid data communications would add to what are already high traffic volumes in urban networks, most of that added traffic would be on the uplink—which is typically underused in most commercial networks. These factors may cause some utilities to wonder whether their smart grid data communications needs could be met using commercial wireless networks.

In fact, several factors make such an arrangement less than ideal. For example, what if the commercial network does not quite reach everywhere the smart grid needs it? What about the commercial network's physical vulnerabilities, particularly in natural or man-made disasters? Can the network provide highly secure connectivity directly to the utility's private network (and not just to a **virtual** private network)? Can the utility be assured that, in case of severe network loading, its vital communications will get top priority? All of these issues can probably be resolved with enough money and time, but in the end it is likely that the cost (particularly for disaster-hardening the commercial network) will exceed that of the utility building its own network in the first place.

A more detailed technical analysis of smart grid data communications using commercial broadband networks is provided in the 2010 EPRI study.

4
CONCLUSIONS AND RECOMMENDATIONS

Utilities require a pervasive communications infrastructure that moves data from where they are created to where they can ultimately be used to support grid modernization, new applications, and new devices in the field. Each utility determines its own unique communications infrastructure and architecture that best meet its specific needs. The concept of a broadband network providing multiple services with ubiquitous coverage within a service area is typically referred to as a *field area network* (FAN). In many cases, the FAN operates in licensed spectrum to be able to meet the operational and application requirements.

This study has examined the requirements of licensed spectrum for FANs along with the details of the frequency bands that could potentially meet those requirements, which include capacity densities dominated by traffic in the uplink channel. The requirements analysis identified a search range of 400–2700 MHz. This frequency range has properties that are best suited for FAN implementation. Frequencies outside that range are not necessarily unusable, but they may be more expensive to implement or exhibit other drawbacks. Based on the assessment of a range of applications identified as typical for FANs, the minimum channel width of the desired uplink channel spectrum was identified in the range of 3–5 MHz. At the low end of the frequency search range, where intensive spectrum reuse is difficult to engineer, 5 MHz was found to meet required uplink capacity density even in dense urban areas. At higher frequencies, 3–5 MHz (for the uplink) was sufficient for provision of the required capacity density with the minimum number of required base station deployments needed to achieve full geographic coverage.

The identified resources for potential spectrum fall into two groups; the first is spectrum that is owned by commercial wireless operators or holding companies that may be willing to sell or lease. With some exceptions, such spectrum is likely to be at market prices for commercial networks, which are very high. However, it is the fastest path to acquire spectrum for immediate needs. In addition, some of this spectrum—in bands that are less attractive for commercial networks—may be obtained at somewhat lower cost.

The second group of potential spectrum resources involves spectrum sharing in government bands. This is a longer term solution because of the need for negotiation and possible relocation of existing users. These arrangements would have to be developed on a regional basis. The 406–420 MHz band is particularly attractive. The 14 MHz bandwidth can easily support 4G standards such as LTE, and the proximity to the existing LTE Band 31 near 450 MHz may increase equipment availability. The frequency is relatively low, making it less attractive for commercial wireless operators. Another spectrum sharing opportunity is with FirstNet in the 700 MHz band, but operation in that band is likely a much longer term opportunity.

Finally, in cases in which the requirements for data throughput speed and capacity are substantially lower than those identified in this report as typical of FANs, it may be possible for utilities to use channel bands that are too narrow to support standards such as LTE and WiMAX. These bands are less expensive because they cannot be effectively used by commercial wireless networks.

None of these options is ideal, but they provide multiple options that can be explored by utilities based on how the advantages and disadvantages map to their unique requirements and situation.

A

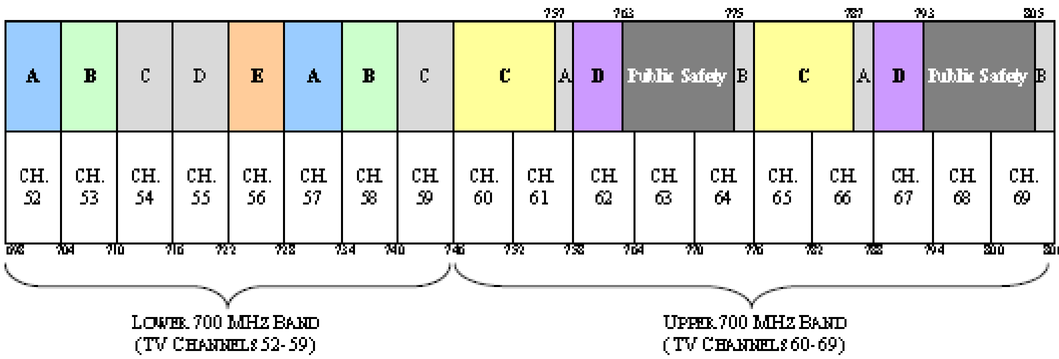
U.S. COMMERCIAL WIRELESS SPECTRUM BAND PLANS

This appendix consists of Figures A-1 through A-8, which show U.S. commercial wireless spectrum band plans.

Figure A-1
600 MHz Band from Incentive Auction (assumes clearing through TV channel 37)

Source: http://www.tvtechnology.com/article/fcc-reveals--mhz-band-plan/274024

Revised 700 MHz Band Plan for Commercial Services



Block	Frequencies (MHz)	Bandwidth	Pairing	Area Type	Licenses
A	698-704, 728-734	12 MHz	2 x 6 MHz	EA	176
B	704-710, 734-740	12 MHz	2 x 6 MHz	CMA	734
C	710-716, 740-746	12 MHz	2 x 6 MHz	CMA	734
D	716-722	6 MHz	unpaired	EAG	6
E	722-728	6 MHz	unpaired	EA	176
C	746-757, 776-787	22 MHz	2 x 11 MHz	REAG	12
A	757-758, 787-788	2 MHz	2 x 1 MHz	MEA	52
D	758-763, 788-793	10 MHz	2 x 5 MHz	Nationwide	1 *
B	775-776, 805-806	2 MHz	2 x 1 MHz	MEA	52

Figure A-2
Lower and Upper 700 MHz Band Plan

Source: http://wireless.fcc.gov/auctions/data/bandplans/700MHzBandPlan.pdf

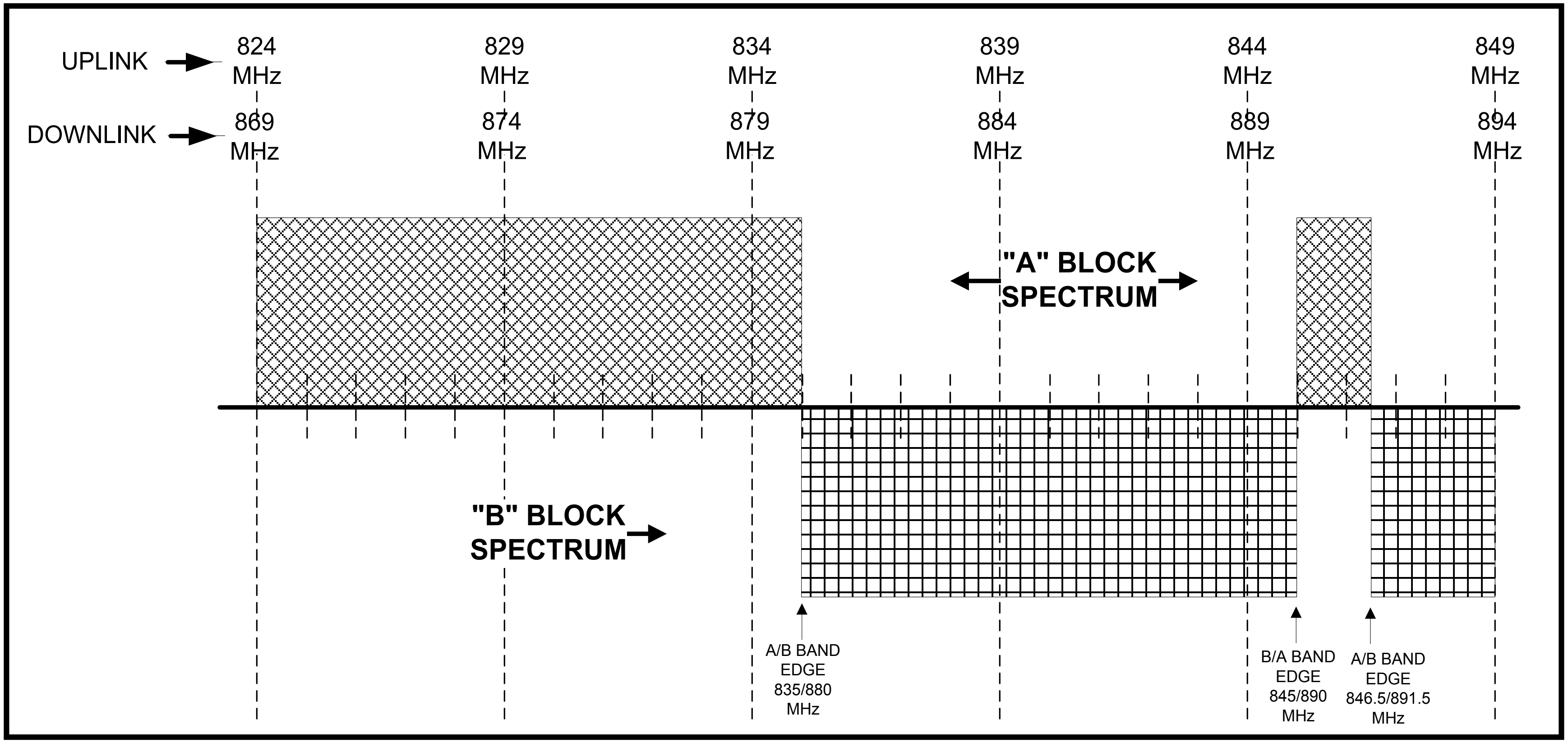
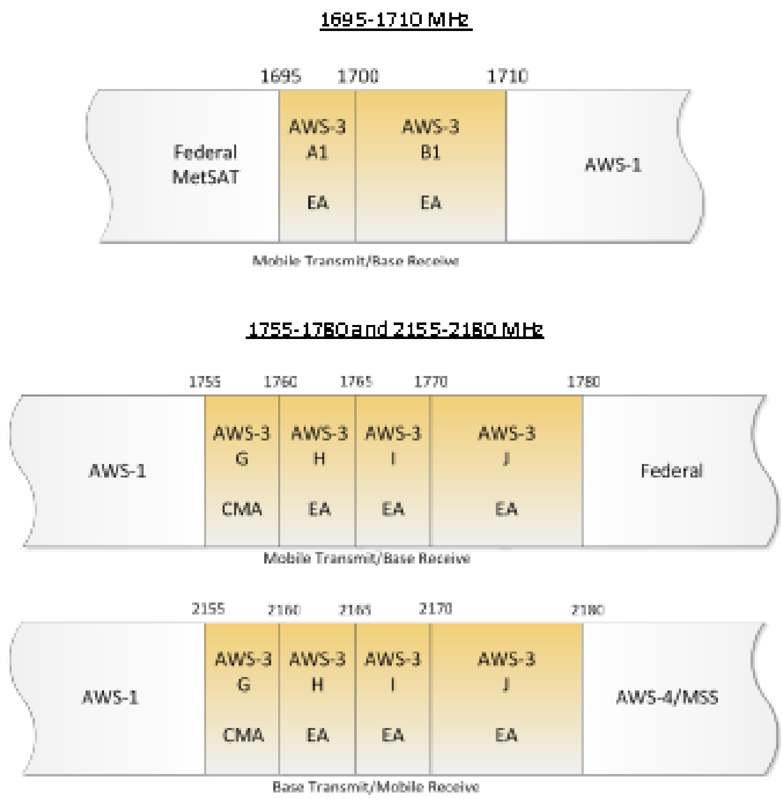


Figure A-3
800 MHz Cellular Band Plan

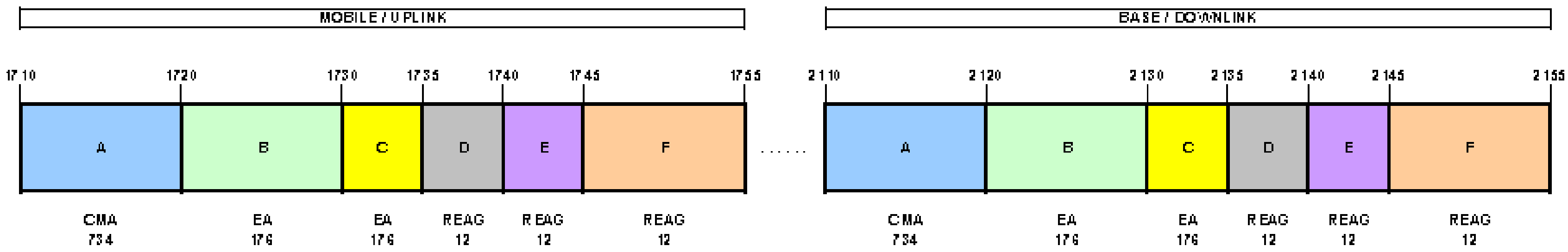


AWS-3 Frequency Block / License Summary

Block	Frequencies	Bandwidth	Pairing	Geographic Area Type	Number of Licenses
A1	1695-1700 MHz	5 MHz	unpaired	EA	176
B1	1700-1710 MHz	10 MHz	unpaired	EA	176
G	1755-1760/2155-2160 MHz	10 MHz	2 x 5 MHz	CMA	734
H	1760-1765/2160-2165 MHz	10 MHz	2 x 5 MHz	EA	176
I	1765-1770/2165-2170 MHz	10 MHz	2 x 5 MHz	EA	176
J	1770-1780/2170-2180 MHz	20 MHz	2 x 10 MHz	EA	176

Figure A-4
AWS-3 Band Plan

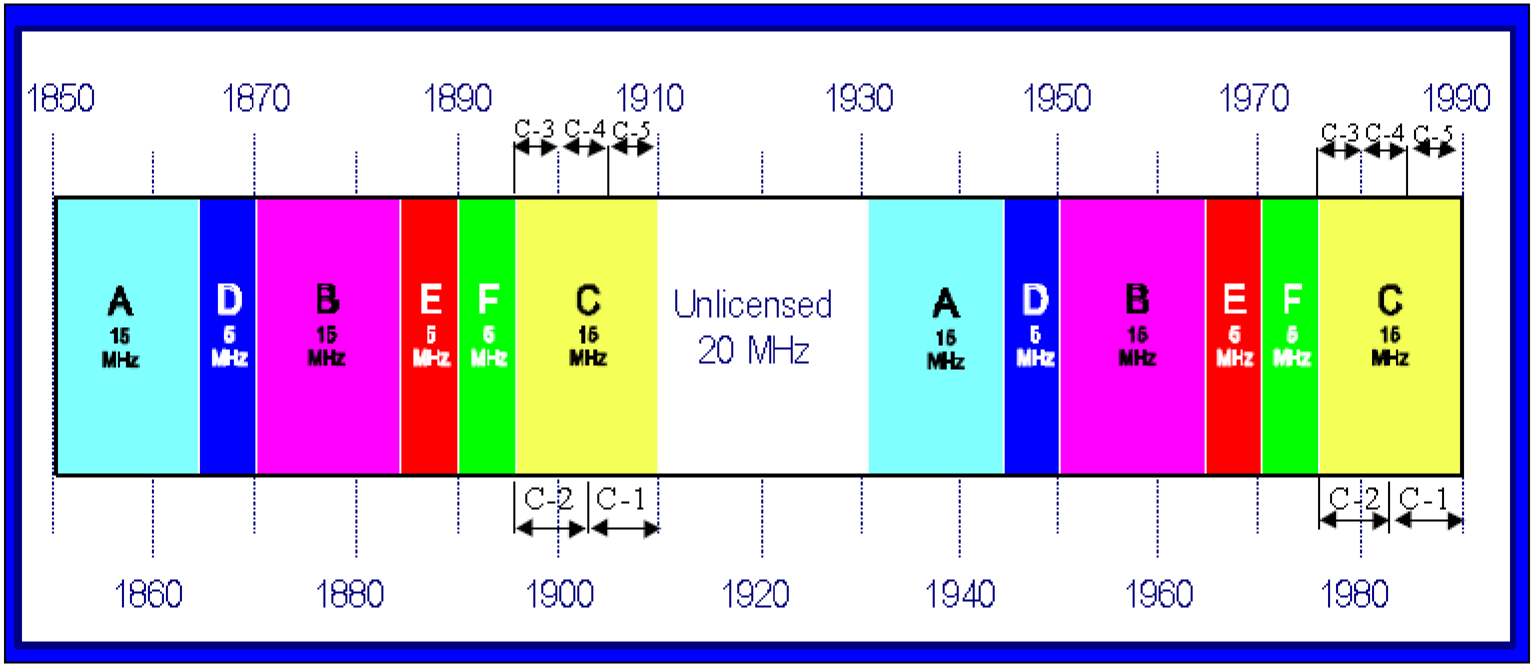
Source: http://wireless.fcc.gov/services/aws/data/AWS3bandplan.pdf



Block	Frequencies	Pairing	Bandwidth	Area	Licenses
A	1710-1720 and 2110-2120 MHz	2 x 10 MHz	20 MHz	CMA	734
B	1720-1730 and 2120-2130 MHz	2 x 10 MHz	20 MHz	EA	176
C	1730-1735 and 2130-2135 MHz	2 x 5 MHz	10 MHz	EA	176
D	1735-1740 and 2135-2140 MHz	2 x 5 MHz	10 MHz	REAG	12
E	1740-1745 and 2140-2145 MHz	2 x 5 MHz	10 MHz	REAG	12
F	1745-1755 and 2145-2155 MHz	2 x 10 MHz	20 MHz	REAG	12

Figure A-5
AWS (AWS-1) Band Plan

Source: http://wireless.fcc.gov/services/aws/data/AWS1bandplan.pdf



Channel Block	Bandwidth (MHz)	Frequencies
C	30	1895-1910, 1975-1990
C 1	15	1902.5-1910, 1982.5-1990
C 2	15	1895-1902.5, 1975-1982.5
C 3	10	1895-1900, 1975-1980
C 4	10	1900-1905, 1980-1985
C 5	10	1905-1910, 1985-1990

Note: Some of the original C Block licenses (Originally 30 MHz each) were split into multiple licenses (C-1 and C-2, 15 MHz; C-3, C-4, and C-5 10 MHz).

Figure A-6
PCS Band Plan

Source: http://wireless.fcc.gov/auctions/data/bandplans/pcsband.pdf

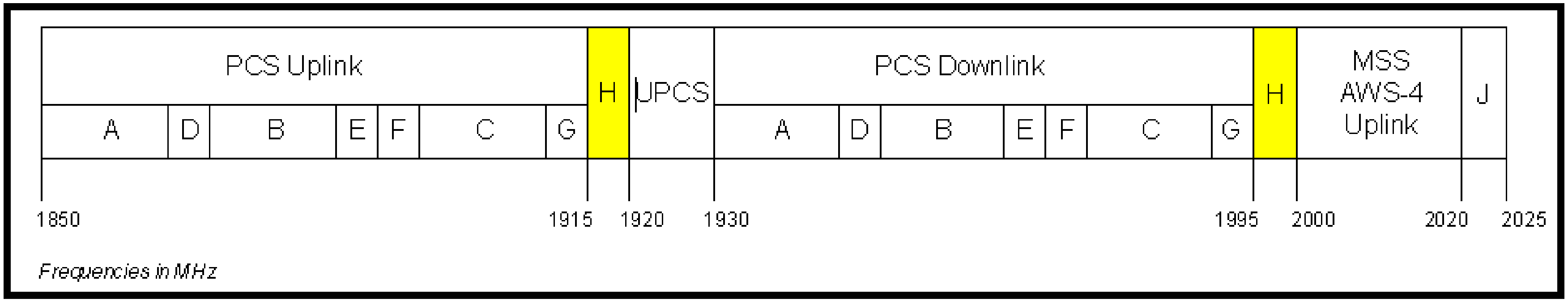


Figure A-7
AWS-2 (PCS H-block) Band Plan

Source: http://wireless.fcc.gov/auctions/data/bandplans/HBlockBandPlan.pdf

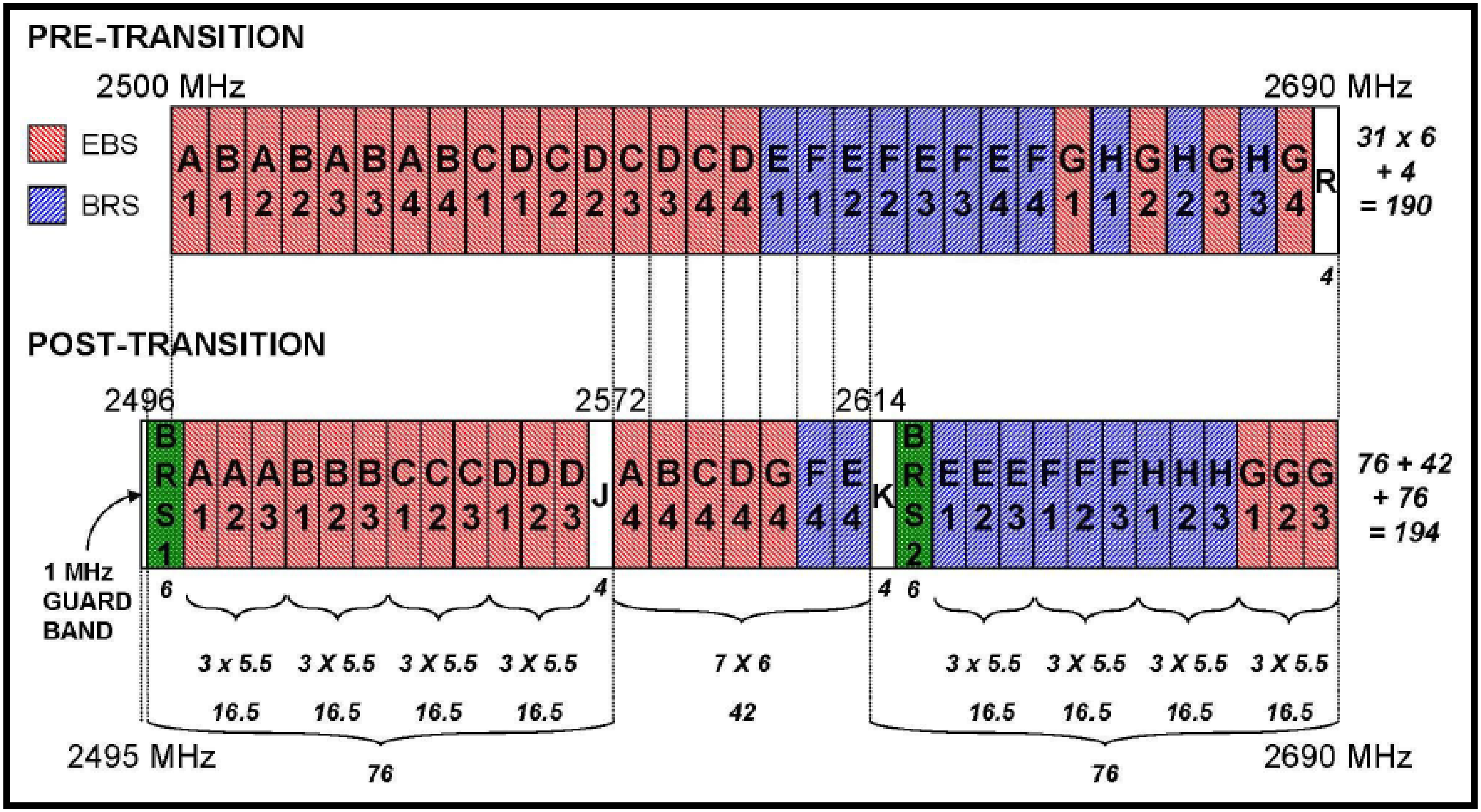


Figure A-8
2496–2690 MHz EBS/BRS Band Plan

Source: http://wireless.fcc.gov/services/brsebs/data/BRS-EBS-BandPlans.pdf

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