Analyzing LTE and LMR Coverage

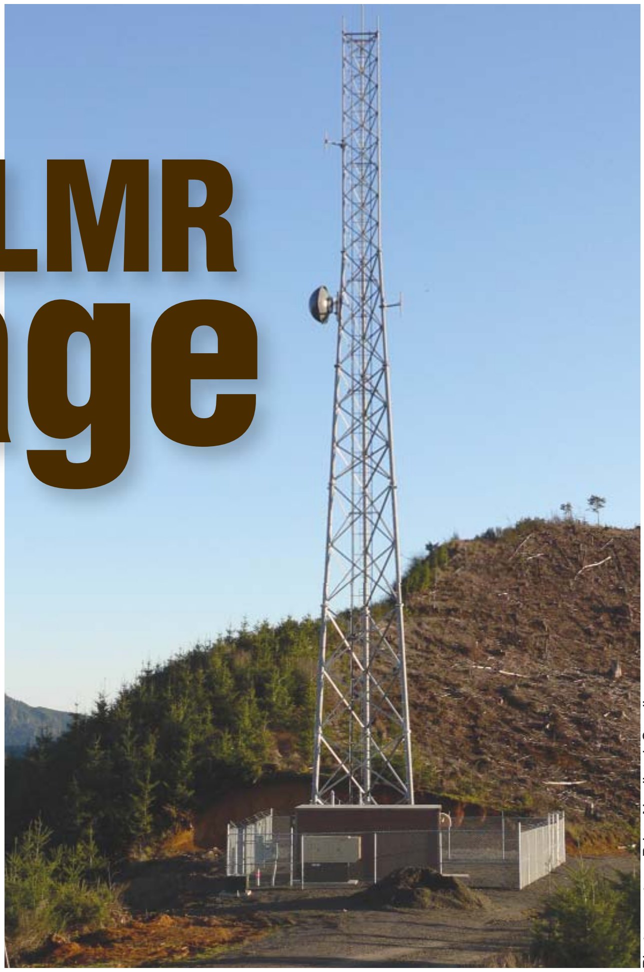


Photo courtesy Brian Nordlund, Sparling

Big differences between two-way radio and LTE coverage mean solid planning is essential as broadband networks are built.

By Afeite Dadja and Joe Ross

Long Term Evolution (LTE) is the globally accepted standard of 4G wireless communications. With an air interface optimized to provide high spectral efficiency and low latencies, LTE has been adopted by major wireless commercial carriers worldwide and was selected as the broadband standard in the 700 MHz public-safety band. Much has been said about LTE's lack of key features, such as direct communications between units, and other challenges that the nationwide network will face. But a fundamental challenge is securing the required coverage for the nationwide LTE network.

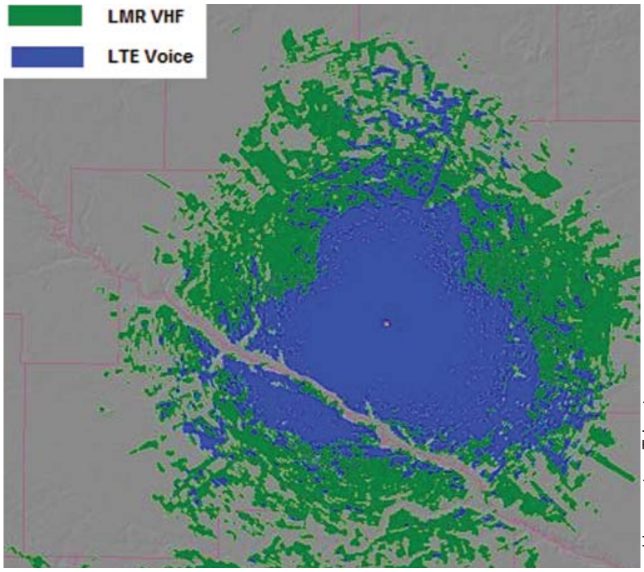
Presumably, public safety will require the nationwide LTE systems to provide equivalent or better coverage than existing LMR coverage. This will be imperative should LTE's coverage provide a replacement for mission-critical voice, but it's likely that where public safety currently has LMR voice coverage, it will also need broadband coverage. If additional LTE sites are required for coverage, it will impact the capital and operating costs for the nationwide network. Therefore, it's important to understand the factors affecting LTE coverage and how LTE compares to LMR in supporting the needs of public safety.

Contributing Factors

A variety of factors determine the coverage of an LMR system. Factors include tower height, output power, receiver sensitivities, frequency, antenna gain, cable loss, noise levels and obstructions. These same factors determine the coverage of an LTE system. However, several key differences between the technologies make LTE coverage more difficult to predict. First, LTE systems typically reuse the same frequency on every cell in the network. This means that the primary source of interference of an LTE network is the network itself, not a co-channel licensee 50 miles away. As the user travels away from the LTE cell site, its serving cell signal degrades while the interfering signal levels increase. Second, the LTE bandwidth is shared with many other applications that could be highly asymmetric. For example, the base-to-mobile traffic levels could dwarf those of the mobile-to-base traffic. The link budget defines the worst case propagation loss for a successful communications link with the worst case path, typically from the mobile to the base station. LTE link budgets are typically stated to deliver specific downlink and uplink throughput levels, while LMR link budgets reflect a single audio channel, such as analog or Project 25 (P25).

To compare narrowband and broadband systems for this article, we made the following assumptions:

- Both LMR and LTE are uplink limited. This assumes a coverage, not capacity limited LTE uplink. We assume that both are using portable handheld devices and that both devices are subjected to the same body loss.
- Comparing voice over LTE to LMR, we assume the LTE system uses the Third Generation Partnership Project (3GPP) Adaptive Multi-Rate (AMR) codec with minimal



Graphics courtesy Televate

This map depicts a sample site's predicted coverage area for VHF LMR and 700 MHz LTE voice coverage in the rural area.

overhead for push to talk (PTT) over LTE. This results in 8 kilobits per second (kbps) of load on the LTE network per channel. In recent Public Safety Communications Research (PSCR) testing, this codec produced higher voice quality scores than the P25 codecs.

■ The LTE system is carrying voice and data. Because we expect full use of the spectrum for data, we limit voice to 10 percent of the full 20 megahertz. This is generous given recent projections of the demand for public-safety broadband services, especially during an incident.

■ Comparing broadband data coverage to LMR coverage, we assume the FCC-defined throughput requirements at the cell edge. This requires 768 kbps downlink and 256 kbps uplink. We also assume 70 percent interference load throughout the entire network. Finally, we assume that in delivering these throughput levels, no more than 10 percent of the resources on the sector can be used.

■ We recognize and account for the differences between rural and metro area system design. In rural areas, the LTE system supports eight voice channels on a single sector, with a typical antenna height of 300 feet. Eight channels result in 64 kbps net uplink throughput for a sector for the voice channels. We assume that the typical rural LMR system uses VHF frequencies.

The metro scenario assumes the existing LMR network is a 700 MHz trunked network and the target capacity of the LTE system at cell edge is 30 voice channels on a single sector. Thirty voice channels result in 240 kbps net uplink throughput for a sector for the voice channels. We use a typical LMR tower height of 180 feet.

■ The LTE system is using evolved Multimedia Broadcast Multicast Service (eMBMS) to support voice traffic. This allows one audio stream to tens or hundreds of public-safety users instead of multiple individual streams to each user, which would be highly inefficient. Otherwise, the downlink path for the LTE system would be the more limiting path.

The VHF site has more than two times the coverage footprint of the 700 MHz LTE site for voice communications.

■ LMR systems use high-gain omnidirectional antennas while LTE systems use higher-gain directional antennas, as is typical in both systems.

■ We assume a 3-watt portable output power for LMR systems and a 200 milliwatt (mW) for LTE user equipment.

■ The transmission line loss depends on cable length and frequency.

■ The modeling was performed for a general site example in a hilly, not rough, terrain area.

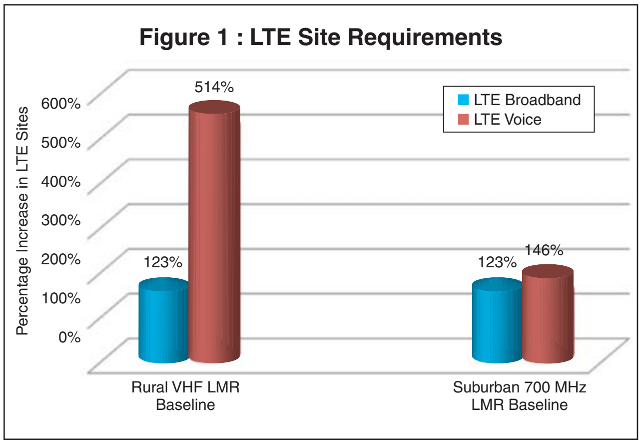
Model Comparison

The link budget is then the combination of output power, gains, losses and receiver sensitivity. Each of these parameters is impacted by other assumptions. Essentially, to establish a reliable link at the required quality, the total signal loss cannot exceed the maximum value. Using this maximum loss, we can determine the associated site radius and coverage area.

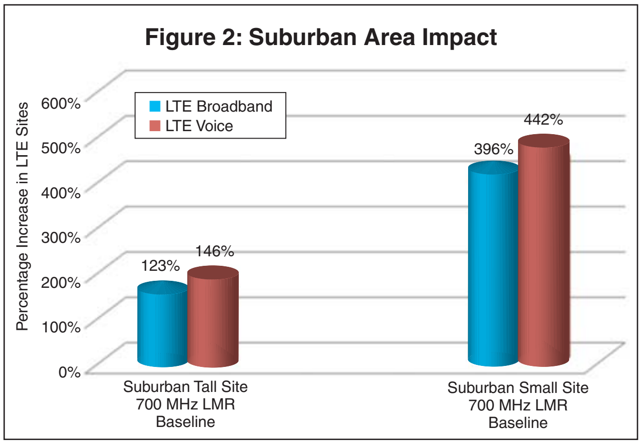
The map depicts a sample site's predicted coverage area for VHF-based LMR and 700 MHz LTE voice coverage in the rural area. Using the assumptions and parameters described, the map depicts the estimated coverage area of each technology and frequency combination. The models use the same transmitter height for each scenario. The map shows the clear coverage benefits of the VHF system because of lower path loss at that frequency. The VHF site has more than two times the coverage footprint of the 700 MHz LTE site for voice communications.

Higher gain directional antennas help to mitigate the difference in mobile output power; however, it's still not enough. Note that terrain impacts both LTE and LMR at 700 MHz equally southwest of the site. As a result, in a real-world design, the actual difference in coverage depends on the specific site and site geometry. For example, in a mountainous area, the VHF signal may also be obstructed, resulting in little difference in coverage. Normalizing coverage without the terrain effect, we can use the COST 231 Hata propagation model and assume flat earth to calculate the site radius and coverage area of various scenarios.

Figure 1 on Page 28 shows that more than 100 percent more sites are needed compared with the LMR baseline coverage. However, if trying to provide broadband LTE speeds using VHF LMR infrastructure, more than six times the sites are needed, a 514 percent increase. When the requirements are relaxed to support only the eight voice channels at cell edge, 123 percent more sites are needed compared with a VHF system. LTE coverage is more comparable to that of 700 MHz LMR systems. The difference



The figure shows the percentage increase of LTE sites compared with LMR sites.



The figure shows that restricting LTE sites to 70 feet has a dramatic impact on the service area per site.

in the suburban case is less severe because of the 30-channel voice support. However, both cases require more than double the sites. An LTE system designed to voice coverage requires 123 percent more sites than a 700 MHz LMR system, while an LTE system designed at the FCC-specified broadband rates requires 146 percent more sites.

However, Figure 1 reflects differences only of throughput, frequency and technology, and assuming consistent tower heights could be unwise. LMR systems in metropolitan areas often have tower heights of 180 feet. The average height of existing LMR sites in the National Capital Region is about 180 feet. This figure assumes that the LTE system also would use 180-foot towers. But the chart clearly shows that more than double the sites are needed to provide matching coverage. Such tall towers throughout metro areas are rare. Existing commercial towers are generally far lower than 180 feet in an urban area because of carrier need and zoning ordinances.

Whatever additional sites required beyond public safety's existing assets are unlikely to approach 180 feet. Shorter sites will then result in a reduced footprint per site, exacerbating the difference in coverage.

Figure 2 presents the suburban area impact of limiting LTE sites to 70 feet while existing LMR sites can remain

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at 180 feet. The figure shows that restricting LTE sites to 70 feet has a dramatic impact on the service area per site. When an LTE system is restricted to 70 feet, it requires five times the number of sites an LMR system does at 180 feet. But if 180-foot sites are allowed throughout the LTE service area, only 123 percent and 146 percent more sites are needed for LTE voice and LTE broadband systems.

Cost Challenges

These factors will make construction of the nationwide public-safety network using only public safety's LMR assets a major challenge. The model is simplistic and provides a rough estimate of the number of sites. Terrain, site availability, usage requirements and other factors will determine the ultimate quantity of sites. But this analysis underscores the importance of establishing requirements for coverage and throughput with capital and operational cost in mind. For example, rural coverage will be a major challenge if the system is designed to provide broadband speeds. And the analysis compares usage scenarios that are the same. For example, if the LTE network must be designed for in-building coverage, but the LMR system, because of the availability of talkaround, is only designed for outdoor coverage, substantially more sites will be needed.

If the nationwide public-safety network requires additional sites beyond public safety's site assets, commercial towers are needed. This could, in turn, increase the operational cost of the network and jeopardize the sustainability of the network. This also underscores the importance of private partnerships for access to towers. As the public-safety community works to migrate data applications to LTE technology, replacing the mobile radio systems will be extremely costly because of the number of additional sites required.

To reduce capital and operational costs, the First Responder Network Authority (FirstNet) will need to leverage existing private and commercial wireless infrastructure as much as possible. This may be easier to do in metropolitan areas where existing government structures are often readily available and commercial towers are plentiful. But given the potential cost of commercial sites, public-safety assets will be critical and can include:

- Existing government-owned towers and

Shorter sites will result in a reduced footprint per site, exacerbating the difference in coverage.

moderate-height buildings (universities, jails, government office buildings, etc.);

- Other utility facilities such as water towers and high-voltage transmission towers; and
- Other potential partner facilities such as hospitals.

Ultimately, FirstNet and its partners will establish the height of structures, but there will likely be some incentive to conform to tower heights available commercially — often in the 50- to 70-foot range in urban areas. Furthermore, the sites will need to be evenly spaced to provide consistent coverage. Nearby sites will not provide even coverage and will interfere with each other. The substantial data backhaul requirements for LTE will also be a challenge. As a result, facilities with existing fiber or microwave should be the first priority. These factors underscore the need for a comprehensive assessment of public-safety site assets and their feasibility for use with FirstNet. However, more than likely, public safety must rely heavily on commercial assets.

Rural Deployments

In rural areas, especially those operating at VHF, public safety will likely lack sufficient site assets for comprehensive LTE coverage. And because many of these areas have limited commercial appeal, there may be limited commercial options as well. Given the funding constraints for the nationwide buildout, it's unlikely that public safety could afford a major tower construction effort. Public safety could employ multiple strategies to resolve this problem. Two potential solutions are satellite communications and higher-powered LTE mobile devices.

Satellite communications offers a nationwide footprint. Unfortunately, there is limited capacity over satellite and the cost for service is generally far greater than terrestrial cellular. In addition, it has two fundamental challenges. First, geostationary satellite services have a high latency because of the 44,000-mile round trip between Earth and the satellite. Such a round trip can take more than 500 milliseconds, more than the latency limitation in the "Public Safety 700 MHz Broadband Statement of Requirements" put together by the National Public Safety Telecommunications Council (NPSTC) in 2007. The latency issue can be resolved with low or medium earth orbit satellites but they are more expensive to maintain than geostationary satellites because of the increased quantity of satellites and other factors. Geostationary services also suffer from shadowing from natural and manmade obstructions in the southern direction, particularly in northern latitudes. Additionally, satellite systems have limited capabilities to provide indoor service.

Another alternative for rural areas is the use of high-power user equipment. One of the biggest impediments to LTE is the transmit power of the user equipment, 15 times less than that of a portable radio. This power is capped by 3GPP with the objective to minimize interference between adjacent systems. To ease the concerns of adjacent commercial carriers, a high-power device could be limited to high power only in the middle of the public-safety band. This will extend the LTE range to that of VHF voice levels. With power control, LTE portables will transmit at full power only when they are far away from their serving base stations; therefore, devices would only use the full power when absolutely necessary. Other solutions for rural areas such as high-gain "smart" antennas may be feasible, but these come with other drawbacks, such as increased loads on towers and increased maintenance costs.

Public safety will face huge financial and operational challenges as it attempts to meet its LTE coverage needs. Such challenges are substantially higher if LTE must match LMR voice coverage. For the foreseeable future, both systems will have to co-exist. In the meantime public safety should work with industry to explore the feasibility of high-power devices and to provide other coverage-enhancing techniques to minimize the number of sites required to meet public safety's coverage needs. ■

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