MAKING THE RIGHT CHOICE:

SELECTING A PRIVATE MOBILE RADIO TECHNOLOGY TO SOLVE CRITICAL MACHINE-TO-MACHINE COMMUNICATIONS NEEDS

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ABOUT UTC
Created in 1948, the Utilities Telecom Council (UTC) is an international trade association for the telecom and IT interests of electric, gas and water utilities and other critical infrastructure industries (CI), such as oil and gas pipeline companies.

UTC's members include large investor-owned utilities that serve millions of customers, as well as smaller municipal and cooperatively organized utilities that serve only a few thousand customers. In addition to its members in the United States, UTC has members in Canada (UTC Canada), Europe (European UTC), South America (UTC America Latina) and Africa. UTC's members own, manage or operate extensive wireless and wireline communications networks used to support the safe, reliable and effective delivery of essential energy and water services to the public at large.

UTC advocates before federal, state and local government executive, legislative and judicial bodies to support the advancement and security of the telecom and IT networks of utilities and other CI. It provides education and information services through conferences, publications and electronic media. It also provides networking and technical services, including frequency coordination, to its utility and CI members and their associated technology partners, such as equipment manufacturers, engineering firms, and consultants.

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EXECUTIVE SUMMARY

THE EVER GROWING IMPORTANCE OF M2M

Utilities and other critical infrastructure (CI) industries around the globe are being challenged to improve service delivery while at the same time deal with security threats that aim to take down their operations. Compounding these challenges are the pressures from investors and regulatory agencies to streamline operations and reduce costs all while dealing with the complexities of a retiring workforce. To conquer these formidible challenges, critical infrastructure industries require greater visibility into their operations and are looking to leverage Machine to Machine (M2M) communications technology & communications to provide the means to increase the automation of their operations.

In its simplest form, M2M describes the ability to add communications to existing infrastructure equipment for monitoring and control purposes via relatively low-cost communication modules. These low cost communication modules can easily enable connectivity components and deliver new levels of near real-time visibility into operations. M2M easily enables connectivity to applications like demand response, distribution automation, load balancing, smart meters and other smart grid applications. With the new levels of visibility, proactive decisions can be made about grid configurations, outages, maintenance schedules, consumption, theft of service and many others. The addition of M2M communication devices facilitates the creation of a highly reliable, highly available Industrial Internet of Things (IIoT) network capable of delivering visibility into operations during the most critical times. In short, M2M is a game changer.

Despite all of its benefits, utilities and other CI industries have been reluctant to implement M2M communication modules since they have typically only been available on public cellular networks - which aren't designed for the mission, life and safety needs that critical infrastructure industries require. Utilities have been unable to get private licensed broadband spectrum assigned to their market from the federal government to support their increased data communications requirements. In lieu of obtaining private licensed broadband spectrum, these CI industries are virtually handcuffed to using non-mission critical public networks or even shared unlicensed spectrum to achieve their data needs. This creates vulnerabilities to thier critical applications because public communications networks are susceptible to outages and congestion, and shared unlicensed spectrum is subject to interference. Utilities prefer to own their own private communication networks, which are designed to their specific coverage, capacity, reliability and availability needs. The men and women who support the nation's critical infrastructure require mission critical radio networks that are always available to support their operations and protect their safety.

Due to advancements in technology and economies of scale, the cost of communication devices has been reduced to price points, which enable their use across more infrastructure and applications.

In the face of these challenges, the market has responded and there is good news to be reported. Utilities have traditionally relied on narrowband spectrum for mission critical Land Mobile Radio (LMR) voice systems to provide communications to their field employees. As these systems have transitioned from analog to digital, the ability to support M2M and other IIoT applications becomes viable. Advancements in digital technology can double or quadruple the existing channel capacity on these narrowband LMR systems. Greater channel capacity enables the support of advanced data services — like M2M applications — without impacting voice operations on these LMR systems. By leveraging the new digital mission critical LMR systems, CI industries can now support both voice and data services including M2M applications on a highly reliable network that provides coverage across their entire service territory. It's a win-win!

For decades, CI industries have been using a variety of communication technologies in some form or another for supervisory control and data acquisition (SCADA), distribution automation (DA), demand side management (DSM) and other grid-based applications, but they were never placed in a blanket category such as M2M nor were they connected together to create an IIoT. Coupled with the lack of private licensed broadband spectrum options, communication to these applications has been limited and typically only deployed at key locations on a cost-effective basis. Due to advancements in technology and economies of scale, the cost of communication devices has been reduced to price points, which enable their use across more infrastructure and applications.

The energy and utility sectors have been increasingly focused on M2M. It has been estimated that, by 2021, the utility sector will account for 61% of overall M2M device connections, growing at a CAGR of 50%.[1] Through M2M communication, utility companies can remotely monitor and control assets like electricity substations, capacitor banks, line switches, reclosers and many other key critical infrastructure applications. In addition, utilities can leverage M2M communications for applications like demand response, which provides tremendous cost savings to both the utility and its customers. Enabled by M2M communications, the potential benefits for the energy and utility sectors are far-reaching, including improved energy efficiency, reduced equipment failures, enhanced safety and security, as well as faster and better decision-making.

M2M enables utilities to be proactive in their operations rather than be reactive. Utilities can greatly reduce maintenance and administration costs by automating remote monitoring and cutting down on the number of site visits to check equipment. Scheduling regular site visits to perform routine checks on equipment is time-consuming and expensive, especially for assets in remote locations. With M2M solutions, equipment can be remotely monitored and controlled continuously without human intervention. This allows utilities to check for gradual changes in the status and performance of assets and to schedule equipment maintenance during times that will minimize disruption and inconvenience to customers.

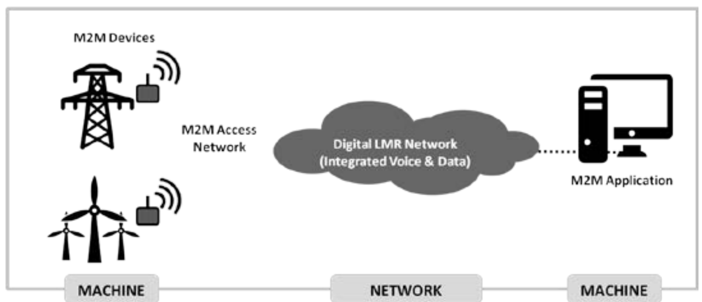

Fig 1: M2M Communications Architecture

The secure and reliable exchange of information is of paramount importance to utility operations and customer service. As one of the 16 critical infrastructure industries, electric utilities rely on their communication networks to protect lives and ensure the safety of their employees during critical service restoration periods, as well as during normal daily operations, keeping power flowing. M2M communication is a key differentiator in generating the intelligence that utilities need to make informed real-time decisions.

KEY FEATURES OF MISSION CRITICAL M2M COMMUNICATIONS

The characteristics of an M2M communication system are:[2]

- **Low Mobility:** M2M devices do not move, move infrequently, or move only within a certain region.
- **Application Independent:** M2M devices enable communications to key applications that don't have any communication today and are completely transparent to the application. The application is unaware that the communication service is provided by a wired or wireless connection.
- **IP-based**: As LMR communication networks migrate from analog to digital, these new digital networks support IP bearer services and have the ability to transport both IP and serial-based protocols over the IP-based network.

[1] M2M device connections, revenue and ARPU: worldwide forecast 2011–2021, Analysis Mason, May 2012

[2] Government of India, Telecommunications Engineering Centre, White Paper Machine to Machine Communication, 2011.

- Small Data Transmissions: M2M devices frequently send or receive small amounts of data, leveraging the extra capacity enabled by migrating to a new time division multiple access (TDMA)-based digital LMR network.
- High Reliability: High reliability means that whenever and wherever M2M communication is required or triggered, the connection and reliable transmission between the M2M device and the M2M server shall be available, regardless of the operating environment. High reliability is required in M2M applications that involve either the prospect of an emergency or highly sensitive data. Utility LMR systems have long been designed for high reliability for their voice needs, and the benefit of this is extended directly to the M2M applications that leverage the same network. Mission critical networks are designed for high reliability and redundancy where failure is not an option while business enterprise operations networks are not designed to meet the same redundancy and reliability specifications.
- Network Priority: Network priority means that there is a method for providing a hierarchical prioritization of users or applications within the solution when applications, voice or data, are competing for network access. The P25, TETRA and DMR standards and the systems provided by the manufacturers have provisions in their protocols to accommodate a prioritization scheme, whether it is simple or sophisticated. This is important as utilities have long considered their voice communications to be mission critical because they rely on them for both safety and security, such that prioritization cannot be disrupted. Many fixed data applications, which weren't previously considered mission critical, are now being considered as such since the information about the grid's performance has a direct impact on a utility's operation and performance.
- Security: Security functions include the protection and confidentiality of M2M data, authentication of users prior to access to M2M devices, and encryption of the data transferred across M2M networks. Knowing that utilities desire private LMR networks for their higher levels of security provides a strong platform that can be leveraged when using the same security for M2M applications.
- Latency Tolerant: Latency is a time interval between the stimulation and response. When leveraging a LMR network for M2M the target applications should be those that aren't latency sensitive. The general one-way latency of an LMR network is approximately 1 second. Those polled applications or reports by exception-based applications that don't require immediate responses measured in milliseconds but rather in seconds are target applications for M2M over LMR.

As they are one of the most crucial of the critical infrastructure markets, utilities require systems that -- just like their electrical grid -- are highly reliable and always on. Public cellular and unlicensed wireless technologies are not designed to the demanding levels of reliability and availability that utilities require. However, the wireless communication networks utilities have been using for decades were designed for these high performance levels have been their LMR systems, which provide the mission/life/safety critical link to field crews during both outages and daily operations. These radio systems are relied upon heavily for restoration activities and during times when failure is not an option because lives are at stake.

As LMR networks are transitioning from analog to digital, they now have the ability to support data communications and M2M devices in addition to the existing voice communications services – all over a highly reliable and available network that they have relied upon and trusted for years. Choosing the right digital LMR standard to which to migrate is incredibly important because now both lives and key grid operations are at stake. There are three global IP-based digital LMR standards that are available to utilities and understanding their differences is imperative.

The three global standards are P25, TETRA and DMR and each vary considerably on their applicability for mission critical or business critical use, their maturity level, architecture, security, adoption in the market, and performance characteristics. Despite the fact that the standards have similar sounding feature sets in their marketing materials, their implementation and resulting performance vary greatly, so thorough investigation of the technical details is required. Many factors go into deciding to either purchase a new digital LMR technology platform or to leverage an existing digital LMR platform for M2M communications needs. Digital LMR networks based on global standards like APCO Project 25, Terrestrial Trunked Radio and Digital Mobile Radio (P25, TETRA and DMR respectively) offer a large ecosystem of vendors that provide solutions and products to meet a variety of coverage, capacity, security and interoperability needs.

This paper presents some basic system considerations, technical considerations as well as some financial considerations when evaluating which digital LMR standard to consider for voice and M2M needs.

MACHINE TO MACHINE OVER LAND MOBILE RADIO

Owing to their lack of access to private broadband spectrum, utilities and other critical infrastructure (CI) industries are resorting to using non-mission critical public networks or even shared unlicensed spectrum. This exposes vulnerabilities to utility operations from interference to mission critical control applications.

At the same time, these industries continue to rely heavily on private, narrowband land mobile radio (LMR) systems for mission critical voice communications that utilities and CI industries use to support their daily operations, maintenance and critical restoration activities. As utilities reinvest in their mission critical narrowband LMR networks by moving to a new digital platform, the good news is that advancements in digital technology can double or quadruple the existing channel capacity of these LMR networks.

Greater channel capacity enables the support of advanced data services — like M2M applications — without impacting voice usage. The mission critical LMR network has already been designed to provide coverage across their entire service territory. Now, the movement to digital adds data services like M2M across the same service territory. It's a win-win.

Choosing the best radio standard for the company's M2M needs can be a daunting task. Voice services are mission critical for operational safety, and should serve as the starting point for deciding which standard is ideal for M2M. That way, the maximum return on investment (ROI) can be obtained from the new digital radio platform.

This paper will provide the reader with an understanding of three open global LMR radio standards radio standards; APCO Project 25, Terrestrial Trunked Radio and Digital Mobile Radio (P25, TETRA and DMR respectively) offer insights into the capabilities of each standard for supporting M2M applications; and describe a model decision process to help select an LMR standard for M2M data applications. Though their features will look comparable, both P25 and TETRA are considered mission critical radio systems where the protection of life or safety during normal operations or a disaster response is a priority, while DMR is considered business or operations critical, where communications for performing general business operations is a primary driver for the radio system.[3]

ADVANTAGES OF PRIVATE RADIO NETWORKS FOR M2M COMMUNICATIONS

THE 5 C'S OF LAND MOBILE RADIO

In light of the most important features of an M2M communication system, there are several benefits to deploying M2M solutions over an existing private LMR network. Owning the mission critical communications network, gives the utility the ability to design the system for optimum performance and support the level of call volumes during a crisis and to design a system, which meets specific needs.

For the past 20 years, the 5 C's of radio communications have been the defining differentiators on the value of a private radio network:

- **Coverage:** Designed to meet specific requirements, whether it is a single-site facility or a multi-site operation.
- **Capacity:** Engineered to address peak usage, using dedicated, licensed spectrum; and right-sized to each organization's specific needs so information always gets through.

[3] Other non-global proprietary solutions do exist in the market, but due to industry's movement to open standards based solutions, these proprietary solutions are not addressed in this paper.

- **Cost:** Predictable costs with no additional airtime fees like those associated with cellular providers.
- **Control:** High degree of control over system requirements, design, priorities, features, and operation – allowing a system to be configured for a specific use case.
- **Capabilities:** Providing devices built to specific needs with additional data functionality to augment voice communications and a reliable system that provides always-available communications.

Each utility's territory needs are different, and private radio systems provide the ability to tailor the system to specific voice and data needs.

PRIVATE RADIO NETWORKS OFFER SUPERIOR COVERAGE

Safety ranks among the highest priorities within a utility. Field crews rely on mission critical radio networks to be their lifeline to safety regardless of their location in the service territory. Ensuring utilities have coverage where it's needed is fundamental to a mission critical network design. Therefore, the coverage provided by private radio networks must be designed to meet the specific geographic, coverage and performance needs of the utility. As these systems migrate from analog to digital, the capabilities offered within the areas of coverage have increased to support both voice and M2M data. Thus, no additional infrastructure should be required to enable key applications with communications.

RELIABILITY AND RESILIENCE ARE DEPENDABLE WHEN USING PRIVATE LMR NETWORKS

Mission critical LMR networks must be reliable and resilient to support the critical voice communications that keep utility employees safe and the grid operational. Enhancing the reliability of individual components, or put another way, minimizing the chance a component will fail, is a key requirement in ensuring system availability. To ensure maximum availability, a system must also be resilient. A fully resilient network can withstand multiple single-point failures in its core before functionality is affected and will continue to offer service, even in the presence of faults. Redundancy is driven by minimizing the single points of failures by the use of duplicated modules, subsystems, devices or the entire core of the radio network - all working to ensure that a component failure won't become a system failure. By their nature, mission critical systems must provide the necessary levels of redundancy to ensure these systems are always available for a user's push of the emergency button or a voltage regulator reporting that its values are at a critical level. Because utilities require mission critical communications for their analog voice networks, as these networks migrate to digital, the same reliability and resiliency requirements are automatically included for M2M.

PRIORITIZATION IS AVAILABLE ON PRIVATE LMR NETWORKS

By their very nature, private systems are built by a single entity for its own use, so the single entity always has priority on its network. Having access to the network when it's needed the most is another reason why mission critical private LMR networks are a good choice for supporting M2M applications. Ownership of the network and the associated spectrum eliminates other access to the network. Private LMR networks are designed for specific coverage and capacity needs. If utilities relied on unlicensed or commercial networks for their mission critical

COMMERCIAL AVAILABILITY DURING AN EMERGENCY

EVENT	FAILURE	CAUSE	IMPACT
SUPERSTORM SANDY OCTOBER 2012	CELL PHONE SERVICE DISRUPTED	COMMERCIAL CARRIER CELL SITES KNOCKED OUT OF SERVICE BY EXTREME WEATHER CONDITIONS	25% OF THE REGION'S COMMERCIAL CELL SITES WERE KNOCKED OUT OF SERVICE
MID-ATLANTIC EARTHQUAKE AUGUST 2011	CALL PHONE CALLS BLOCKED	CELL PHONE NETWORKS OVERWHELMED WITH VOICE CALLS TO AND FROM AFFECTED AREAS	SERVICE WAS NOT RESTORED UNTIL HOURS LATER WHEN CALL VOLUME SUBSIDED
NORTHEAST BLACKOUT AUGUST 2003	BLACKOUT WITH OUTAGE THROUGHOUT THE EAST COAST	WIDESPREAD DISTRESS IN THE ELECTRICAL GRID CAUSED BY A SOFTWARE BUG	CELLULAR SERVICE WAS INTERRUPTED AS MOBILE NETWORKS WERE OVERLOADED WITH THE INCREASE IN CALLS

Fig 2: M2M Commercial Availability During an Emergency

applications, they would be just another customer not distinguished in importance from any other customer and would risk lack of availability at potentially critical times.

Networks that operate in unlicensed spectrum bands are always in contention with every other user in the neighboring area that shares the same spectrum. Similarly, the cellular networks fail to provide sufficient levels of priority access and are subject to congestion at busy times. Examples of this could be seen during the 9/11 terrorist attacks, hurricane Katrina and Superstorm Sandy. The cellular networks were so congested with calls that nobody could get through the mobile phone lines.[4] This "system overload" can crash an entire network. Moreover, if one relies on M2M to keep operations up and running, it could be jeopardized.[5]

However, utilities and other CI entities could ensure priority access for their communications over their private radio networks, underscoring the value of private networks designed for mission critical operations on licensed spectrum. As digital networks, these private networks would offer the same prioritization to M2M users as they would to voice users.

UTILITIES BENEFIT FROM CONTROLLING PRIVATE RADIO NETWORKS

The benefits of utilities controlling their own communications system are tough to ignore[6]. Above all else, private, mission critical LMR communications deliver control over who can access the system and who can't, what changes need to be made and when, and provide the status of all users. Private LMR networks also provide other key elements of control, such as call prioritization. Built-in authentication identifies users, their location and denies connectivity to unauthorized devices. Private LMR systems are designed to meet specific coverage and capacity needs. Unlike a commercial carrier, ownership of a mission critical network, gives the ability to design it for optimum performance during a crisis. Control of the private radio network also allows for design the system to meet specific voice and M2M needs for the 5 C's of radio system design: Coverage, Capacity, Cost, Control and Capabilities.

PRIVATE NETWORKS ARE MORE SECURE

The Federal Energy Regulatory Commission (FERC) is considering new safety regulations proposed by an industry-dominated electric power organization. After a series of articles appeared in *The Wall Street Journal* detailing how susceptible the electric system is to attack, FERC, which regulates the nation's high-voltage transmission system, told the industry that it must act to fortify the grid.[7]

By their very definition, private mobile radio networks are 'private' and should be less open to security threats than public networks. Added to this, the latest digital radio standards include high levels of protocol encryption for the ultimate levels of security demanded by public safety services, critical infrastructure providers and government agencies.

By their very definition, private mobile radio networks are 'private' and, therefore, less open to security threats than public networks.[8] Moreover, the latest digital radio standards include high levels of protocol encryption for the ultimate levels of security demanded by CI organizations that include utilities, public safety and government agencies. LMR networks can be tailored with various information assurance options to manage and mitigate security-related risks, which include the ability to encrypt all voice and data communications with AES encryption. Commercial networks don't offer the same security options or levels of protection.

[4] Mission Critical Communications Designed to a Tougher Standard by Motorola Solutions, 2013.
[5] "Public-safety Communications Fare Better than Commercial Networks after Superstorm Sandy," Urgent Communications, November 6, 2012 "Public-safety Communications Fare Better than Commercial Networks after Superstorm Sandy,"
[6] M2M and the Role of Radio, By Stephen Jenkins and Andy Grimmett, Simoco Group, page 7, February 5, 2014, available online at http://www.radiocomms.com.au/articles/64949-Radio-39-s-role-in-M2M
[7] Grid Terror Attacks: U.S. Government Is Urged to Take Steps for Protection, Groups Say Industry Response to Potential Threats Is Insufficient by Rebecca Smith, Wall Street Journal, July 6, 2014.
[8] M2M and the Role of Radio, By Stephen Jenkins and Andy Grimmett, Simoco Group, page 7, February 5, 2014, available online at http://www.radiocomms.com.au/articles/64949-Radio-39-s-role-in-M2M

DATA COSTS ARE LOWER ON PRIVATE LMR NETWORKS

In the world of M2M communications, it's the small data that matters.[9] LMR systems are usually purchased as a capital expense, which meets most utilities' financial needs models. However, as important as voice communication is to any utility's operation, leveraging the same network for additional applications like M2M can easily improve the overall ROI. Some applications such as capacitor bank controllers, voltage regulators, reclosers, fault circuit indicators, line switches, SCADA and other distribution automation applications may be excellent candidates for M2M enablement over the digital LMR network. As a further benefit, there are no monthly operational expenditures resulting from data transmission costs involved across private radio systems. And, existing capacity can be leveraged to carry the M2M data. Similarly, there are no data overage charges on private radio networks. Where data transfer forms the crux of day-to-day operations, LMR may offer significant savings over a cellular data plan.

MULTIPLE CHANNEL ACCESS ENABLES PRIVATE LMR RADIO FOR M2M

The Federal Communications Commission's (FCC) narrowbanding mandate forces licensees to make technology decisions and has helped accelerate the movement to digital-based communications. One of the many benefits that came from the movement to digital was the additional capacity resulting from the multiple channel access methods used in digital communications[10] [11]. Channels that traditionally carried a single call at a time in the analog domain are now being divided so they can carry multiple calls simultaneously in the digital domain. The two channel access technologies that exist are frequency division multiple access (FDMA) and time division multiple access (TDMA). Though FDMA is used in some radio communication systems, it's the movement to TDMA that exemplifies the capacity benefits of digital communications. TDMA separates users by time, allowing each user to share a portion of the radio channel by assigning them different time slots. P25 Phase 2, TETRA and DMR Tier II & Tier III all use TDMA technology. In 12.5 KHz narrowband channels (VHF, UHF, some 800 MHz and 900 MHz) both P25 Phase 2 and DMR systems offer 2:1 TDMA which essentially doubles the amount of channel capacity, allowing data services to be added to the system without impacting the voice. In 25 KHz narrowband channels (some UHF and the business and industrial channels at 800 MHz), TETRA offers 4:1 TDMA while P25 and DMR offer 2:1 TDMA. However, it should be noted that in the 800 MHz business and industrial channels it is possible to achieve 4:1 TDMA efficiencies with DMR and P25, thus, putting them on a similar playing field as TETRA. It is through the efficiencies and capacity gains resulting from the TDMA channel access methods found in digital communication systems that M2M data services can be supported by the private, mission critical LMR networks without affecting the performance or capacity of the voice communications.

There are many benefits that come from digital systems which employ a TDMA channel access method over systems that employ FDMA or other channel access methods, including but not limited to:

- Increased Spectral Efficiency[12]
- Lower Equipment Costs[13]
- Lower Licensing Costs
- Longer Battery Life[14]
- Increased channel capacity for data transmission

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[9] Q. D. Vo, J. P. Choi, H. M. Chang, and W. C. Lee, "Green perspective cognitive radio-based m2m communications for smart meters," in Information and Communication Technology Convergence (ICTC), 2010 International Conference on. IEEE, 2010, pp. 382–383.
[10] How to Choose Between FDMA and TDMA: A Fine Line by Jay M. Jacobsmeyer, Urgent Communications, available online at http://urgentcomm.com/networks-amp-systems-mag/fine-line
[11] TDMA Technology: Bringing Increased Capacity and Functionality to Professional Digital Two-way Radio by Motorola Solutions, page 7, available online at http://www.motorolasolutions.com/web/Business/_Documents/static%20files/Why%20Digital%20White%20Paper%205%2008.pdf
[12] *Id.* At page 3.
[13] Id. At page 9.
[14] *Id. At page 10.*

TDMA divides each channel into multiple time slots and increases the overall capacity that can be supported by each channel. Since TDMA technology separates users according to time, it ensures that there will be no interference from simultaneous transmissions.

LAND MOBILE RADIO FOR M2M

In addition to considering the benefits of TDMA over other channel access methods, a variety of other factors must be considered as part of the decision process in selecting an LMR technology to support voice and M2M needs. Over the years, private LMR networks have clearly demonstrated their benefits for providing mission critical reliability, coverage and security in a cost-effective solution that supports an organization's voice needs. Those same benefits and advantages are extended directly to M2M purposes.

WHY STANDARDS MATTER

OPEN STANDARDS ARE PREFERRED FOR MISSION CRITICAL APPLICATIONS

There are many digital radio technologies in the marketplace. Some are based on proprietary standards, while others are open standards-based. There are key advantages to choosing an open standards technology, including a large harmonized market supported by multiple vendors, increased competition, lower prices, a greater choice of products and applications, as well as many other advantages for the end user. There are three leading, global standards bodies within this open standards arena that are discussed in this paper: APCO P25, TETRA and DMR. When selecting a radio system for critical operations, it is important to note that not all radio systems are created equal. Their outward features may make them appear to be the same but, underneath, they are very different. Both P25 and TETRA standards have been designed to be mission critical where the protection of life, safety and property are an important requirement for the intended users of the network, while DMR was designed for business critical operations use cases where life, safety and property aren't a concern. This is a very important distinction to understand when selecting a radio system, as voice communications is still the driving factor behind the deployment of LMR systems today. The LMR radio's use relative to the environment in which it's being used and the risk of the radio system's failure during times of extreme use or in harsh environments to the employee's safety and the potential for the loss of their life must be considered as one of the most important factors when selecting an LMR platform.

There are key advantages to choosing an open standards technology, including a large harmonized market supported by multiple vendors, increased competition, lower prices, a greater choice of products and applications, as well as many other advantages for the end user.

STANDARDS-BASED LMR OPTIMIZES ROI

Every day, utilities are being driven harder to improve their operating earnings, become more efficient, provide better service and communication with their customers, and achieve better ROI. In any organization, real-time communication and information are the keys to achieving operational improvements. Capital expenditures by utilities require a strong business case that withstands the internal competition for capital resources and the scrutiny of the public utility commissions.

If a utility company already has an existing digital private radio infrastructure, there is no need to replace the system or to develop additional networks to facilitate M2M. TDMA allows the utility to free-up more capacity for data applications, such as M2M. The simple addition of an M2M gateway and some M2M modems can turn an existing radio infrastructure into an M2M bearer network. Organizations drive efficiencies and achieve optimal ROI by leveraging existing LMR networks for multiple purposes and by gaining the maximum benefit from their investments.

THE THREE MAJOR STANDARDS

APCO PROJECT 25 (P25)

P25 is an IP-based, global radio standard for an integrated voice and data (IV&D) LMR network designed to meet the mission critical needs of CI. Developed in North America under local, state and federal representatives and Telecommunications Industry Association (TIA) governance, P25 has gained worldwide acceptance for utilities, public safety, security, public service, military and commercial applications.[15] P25 is an open, user-driven standardization process with technical and operational requirements established through the participation of its stakeholders, including public safety practitioners from different countries and representing different levels of government. The standards published by TIA establish the basis upon which manufacturers develop, implement and competitively offer P25 equipment and systems; recognized laboratories conduct P25 compliance testing; and users specify, procure and operate P25 radios and communications infrastructure. Many vendors support the mature P25 standard, providing for a robust marketplace of vendors and a strong support ecosystem. In addition, P25 systems have been deployed globally in the VHF, UHF, 700, 800 and 900 MHz bands. There are two phases of P25 development:

- Phase 1 FDMA was published in 1989 and specifies 12.5 KHz equivalent bandwidth,
- Phase 2 TDMA standard was published in early 2011, and specifies 6.25 KHz equivalent bandwidth.

Leveraging TDMA on a 12.5 KHz channel to allow better spectrum efficiency by using two slots per channel, giving two voice paths on a single 12.5 KHz channel, benefits a greater number of users. Phase 2 TDMA systems offer 2:1 efficiency gains over analog systems and have been selected by many utilities in North America.

Radio equipment that demonstrates compliance with the P25 standard is able to meet a set of minimum requirements to fit the needs of mission critical users. To comply with the P25 standard, at a minimum, the radio system must provide interoperability with two mandatory standard components: The Common Air Interface (CAI) and the Advanced Multi-Band Excitation (AMBE+2) Vocoder or the Improved Multi-Band Excitation (IMBE) Vocoder. The CAI specifies how information is coded, transmitted and received over the air. It enables users to interoperate and communicate digitally across networks, agencies and vendors. The ABME+2 and IMBE Vocoders convert speech into a digital bit stream.

P25 supports both low powered portables as well as high powered mobiles, thus allowing for high site / high powered designs. This type of design minimizes the number sites required in a system while maximizing the coverage provided by each site, keeping the total cost of ownership low. Because of its high site / high powered design, typically channels can be reused every 6-8 sites. Given the scarcity of narrowband channels, especially in urban and suburban areas, the ability to reuse existing channels without having to acquire new channels is a significant advantage to high powered systems. The P25 standard also supports simulcast, around which many analog systems have been designed, making it a suitable replacement technology.

TERRESTRIAL TRUNKED RADIO (TETRA)

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[15] "Project 25 Technology Interest Group - Content - General - What is Project 25?". project25.org. Project 25 Technology Interest Group. Archived from the original on 2009-02-10. Retrieved 2014-06-06.

As a global, mature standard, many vendors support TETRA providing a robust marketplace of vendors and a strong support ecosystem. Developed by the European Telecommunications Standards Institute (ETSI), TETRA is a standard first published 1995 and has been designed to meet the mission critical needs of CI. TETRA uses TDMA with four user channels on one radio carrier and 25 KHz spacing between carriers. Both point-to-point and point-to-multipoint transfer can be used. Digital data transmission is also included in the standard at multiple data rates, depending on spectrum availability and implementation.

There have been two releases of the TETRA standard:

- TETRA Release 1: This was the first release of the TETRA radio standard.
- TETRA Release 2: This release of the TETRA radio standard finished in 2005. It introduced a number of new features into the TETRA radio standard:
    - TETRA Enhanced Data Service (TEDS)
    - Trunked Mode Operation (TMO) Range Extension
    - There are three different modes in which TETRA radio systems can be run:
        - Voice plus Data (V+D)
        - Direct Mode Operation (DMO)
        - Packet Data Optimized (PDO)

Unlike the other radio standards that can operate in a 12.5 KHz channel, TETRA can only operate in 25 KHz channel and offers 4:1 TDMA. It supports both half and full duplex communications and is supported in VHF, UHF and the 800 MHz bands. TETRA deploys these UHF products worldwide and has deployed some 350 MHz in China, and some in 450-470 MHz and 800 MHz spectrum, mostly in Asia and Latin America. However, because of the spectrum limitations in the USA, TETRA is only supported in very specific UHF bands and 800 MHz bands.

TETRA systems require clean spectrum, which may not be available from the relevant regulatory authority. This is in part because TETRA channels cause interference on existing analog channels and in part because the standard is optimized for when transmit and receive frequencies of a channel are at least 10MHz apart. For example, if the transmit frequency is 381.0000MHz, the receive frequency must be 391.0000MHz. TETRA does support 5MHz separation in some implementations and recently in North America where UHF frequencies most commonly have 5MHz or less separation.

The most commonly used mode is integrated voice & data (IV&D). It allows switching between speech and data transmissions, and can even carry both by using different slots in the same channel. Full duplex is supported with base station and mobile radio unit frequencies normally being offset by about 10 MHz to reduce interference levels between the transmitter and receiver in the station to an acceptable level. In North America, most UHF bands require only 5 MHz offsets and VHF typically only has 1 MHz offsets, making TETRA implementations more complicated. Direct mode operation (DMO) is used for direct communication between two mobile units and supports both voice and data. However, full duplex is not supported in this mode and only simplex is used. This is particularly useful as it allows the mobile stations to communicate with each other even when they are outside the range of the base station. The third mode, packet data optimized (PDO) is optimized for data-only transmissions. It has been devised with the idea that much higher volumes of data will be needed in the future and it is anticipated that further developments will be built upon the TETRA mobile radio communications standard.

TETRA is a low site / low power cellular design compared to technologies like P25 or DMR. When deploying a TETRA wide area system, design can be challenging as it requires approximately 20 channels to do a reuse plan. Given the low power / low site nature of a cellular design, a TETRA system can require from 2x - 4x the number of sites as a P25 or DMR system. Since most private LMR systems in the U.S. were designed as high site / high powered analog systems, the movement to a TETRA system can be costly when the additional land acquisition, tower construction and battery/fuel costs are taken into account. However, one of the tremendous gains of a TETRA system by using a greater number of lower powered sites comes in the form of much greater overall system capacity. High site / high power systems have the ability to talk great distances covering lots of territory – and number of assets. Low site / low power systems sub-divide the coverage and capacity into smaller coverage cells with the same amount of capacity. If in a particular design a TETRA system needs 3x the number of sites as a DMR system and if the capacity of a cell were equal, then the TETRA system would have approximately 3x the capacity as a DMR system.

TETRA Phase 2 TEDS (TETRA Enhanced Data Service) feature promises very high data rates. However, one of the important factors to note in a TEDS system is that to achieve these data rates multiple contiguous channels are required, which is extremely difficult to obtain in the United States.

Combined with the vast number of channels required to create a cellular design, TEDS is extremely difficult, if not impossible, to implement in the United States. TETRA was designed to take advantage of the higher potential data rates from 25 KHz channels and linear devices, giving up some coverage for this additional capacity.

DIGITAL MOBILE RADIO (DMR)

DMR is an open digital standard used primarily for business users, specified in the European Telecommunications Standards Institute (ETSI), and used in products sold throughout the world. It was not designed to be a mission critical radio system but rather to meet the needs of business critical or operations critical users. The standard was first published in 2005. Products built to the DMR standard also comply with the FCC mandates in the United States for the use and certification of 12.5 KHz and 6.25 KHz narrowband technology (for systems covered by Part 90 regulations). Designed as a low-cost entry level radio system for commercial use, DMR is not typically considered as a mission critical communications platform. However, manufacturers can implement it as a mission critical platform using proprietary features.

In North America, many vendors support DMR. Because of its newness to the market, the standard continues to evolve and interfaces have not been fully developed to the same levels of maturity as P25 and TETRA. DMR features a robust marketplace of vendors and a strong support ecosystem. There are three tiers of the DMR standard:

- **Tier 1**: for license free use, VHF and UHF frequency bands, 500mW transmitters – targeting personal & recreational users, not critical infrastructure. (Note: because it's use of unlicensed frequencies, the attributes discussed in this paper relating to DMR supporting M2M are specifically for Tier II and Tier III systems.)
- **Tier II**: for licensed conventional communications systems operating between 66 to 960 MHz frequency bands. This tier specifies two channel spacing at 12.5 KHz using TDMA for spectral efficiency and integrated IP services.
- **Tier III**: for trunking systems operating between 66 to 960 MHz frequency bands. This tier specifies 2:1 TDMA at 12.5 KHz using as well as integrated IP and short messaging services.

The DMR standard's primary goal is to specify a digital system with low complexity and low cost. DMR provides voice, data and other supplementary services. The DMR standard covers both conventional, trunked operations and simulcast, albeit not in all tiers, but the vast majority of DMR implementations are conventional.

Unlike the other standards, DMR does not mandate a vocoder that is necessary for any digital interoperability. In each region, vendors choose how much to emphasize interoperability. Most vendors in North America and Europe have standardized on the same vocoder (AMBE). There are very few features considered "mandatory" in DMR, thus, allowing for customization. However, the tradeoff for a low-cost system may be a lack of interoperability (see section on interoperability).

	P25 Phase 1	P25 Phase 2	DMR Tier 2	DMR Tier 3	TETRA Release 1	TETRA Release 2
Physical Channel Needed	12.5 KHz	12.5 KHz	12.5 KHz	12.5 KHz	25 KHz	25,50,100,150 KHz
Multiple Access Scheme	FDMA	FDMA & TDMA (2 slot)	TDMA (2 slot); FDMA	TDMA (2 slot); FDMA	TDMA (4 slot)	TDMA (4 slot)
Modulation Scheme	C4FM	CQPSK	4FSK	4FSK	DQPSK	D8PSK, 4QAM, 16QAM, 64QAM
Channel Operation	Trunked; conventional	Trunked (2:1); conventional	Conventional	Trunked (2:1); conventional	Trunking (only)	Trunking; Dedicated Data
Channel Data Rate	9.6kbps (per 12.5 KHz channel)	9.6kbps (per 12.5 KHz channel)	4.8kbps (per slot)	4.8kbps (per slot)	7200 kbps (per slot)	28.8kpbs in 25 KHz; higher rates w/ TEDS in 50 KHz, 100 KHz & 150 KHz channels
Codec (Vocoder);	IMBE	AMBE +2 (Full and Half)	Vendor Specific (most common listed) AMBE+ (Full and Half)	Vendor Specific (most common listed) AMBE+ (Full and Half)	ACELP	ACELP
Encryption	DES/AES	DES/AES	ARC4/DES/AES	ARC4/DES/AES	ETSI – TEA (TETRA Encryption Algorithm 1,2,3,4	ETSI – TEA (TETRA Encryption Algorithm 1,2,3,4

Fig 3: Standards Comparisons

ABOVE THE STANDARD

There is a difference between what a standard allows or supports, and what is commonly implemented. There are features that are required to be compliant with the standard and features that are optional in the standard. Each vendor chooses optional features to offer based on their individual business model. In all three standards (P25, TETRA, and DMR) vendors have the ability after they implement the features required by the standard and to offer optional, value-added features. Many of the value-added features in private LMR systems were added at the customer's request. These features still allow for the basic interoperability defined in the standards between different vendors and subscribers but the features that are above the standard are not interoperable.

It is important to note that the practice of providing features that are above the standard is not unique to any specific vendor. This flexibility is also found with carrier-based technologies and vendors. Consider all the features that Apple® with iOS, Google® with Android, and Samsung® with their innovations in smartphone hardware have added to phones that help differentiate them from other vendors but still support a standard.

THE DECISION POINTS FOR VOICE AND DATA

Selecting a digital radio technology to support an organization's existing LMR needs as well as their new M2M communication needs involves multiple considerations. Each of the three standards, P25, TETRA and DMR, offers robust features, making them very suitable to almost any operation. However, the availability of features is not the key differentiator between the standards. Rather, it is the way those features are implemented in accordance with the utility's needs that determines one system's performance to be superior over another system. For instance, all three of these standards address encryption. However, it is the way that encryption is addressed in the standard (and in fact, the way the individual LMR manufacturer has chosen to implement it) that really differentiates the standards. It is not only the "what" but rather the "how" that is important. Depending on the requirements, available spectrum, budget or other key decision criteria, the choice will be narrowed down to the one most appropriate for the organization.

Choosing a technology platform is a process with many decision points. It is important to realistically understand the starting parameters that will guide the decision. This section will introduce a number of these parameters in a suggested order that could be used for making such a decision. If any one of these parameters eliminates a technology choice, then the decision should be targeted to the remaining technology platforms. These parameters are divided into three key categories: 1) Preliminary Considerations, 2) Feature Considerations, and 3) Financial Considerations.

The Preliminary Considerations deal with foundational issues that dictate technology availability, such as the frequencies supported and country-specific regulations on standards and spectrum. Feature Considerations evaluate the must-have features specific to the individual customer and industry. These may include: the availability of a diverse support ecosystem, the need for solution interoperability, the importance of security encryption and the level of ease required for a smooth migration from an existing system. Finally, Financial Considerations, including the total cost of ownership (TCO) as well as the coverage and capacity ROI, should also be considered. Among the considerations involved in selecting the most suitable technology platform are:

1. Basic System Considerations
    a) Frequencies/Spectrum Supported
    b) Business or Mission Critical
    c) Coverage & Capacity Needs
    d) Conventional vs. Trunking
2. Technical Considerations
    a) Security
    b) Prioritization and Call Queuing
    c) Reliability, Resilience and Availability
    d) Interoperability
    e) Suitability for M2M Data Transmission
3. Financial Considerations

BASIC SYSTEM CONSIDERATIONS

Preliminary considerations deal with foundational issues that dictate technology availability, such as frequencies supported and country-specific regulations on standards and spectrum. Therefore, they act to prohibit the use of certain technologies that fail to comply. Those technologies not prohibited by supported frequencies or country-specific regulations are available, provided they meet the feature considerations and financial constraints of the end user.

FREQUENCIES SUPPORTED

Radio frequencies need to be managed to avoid parties interfering with each other. To provide order, all governments administer spectrum and allocate frequencies to meet government, military and civil needs in a society. Organizations either need to buy a license to use a specific radio frequency or use a radio frequency that is already assigned for a specific use in a band that is designated for general use. Similarly, radio spectrum is coordinated between the world's governments through the International Telecommunications Union.

	NORTH AMERICA UTILITIES FREQUENCIES SUPPORTED		
	DMR	TETRA	P25
VHF	✓	✗	✓
UHF	✓	✓	✓
800MHz	✓	✓	✓
900MHz	✓	✗	✓

Fig 4: Frequencies Supported ✓ *Supported* ✗ *Unsupported*

Radio spectrum is managed in a clear legal hierarchy with spectrum rights treated like property rights. This is necessary, because radio frequency spectrum is the fundamental real estate for the development of a wireless solution.[16] Without an appropriate allocation of a radio frequency or band of spectrum, a wireless solution cannot be

[16] A Layman's Guide to Radio Communications by Emergency Services Telecommunications Authority, January 8, 2010, page 5.

built. To complicate matters further, each radio frequency band has its advantages and disadvantages for mobile communications. The common bands used by mobile radio wireless solutions are:

1) Very High Frequency (VHF, between 30 and 300 MHz),
2) Ultra High Frequency (UHF, between 300 and 520 MHz), and
3) 800 MHz frequencies
4) 900 MHz frequencies

For voice systems, P25, TETRA and DMR all support 6.25e, which means one voice path per 6.25 KHz of spectrum. P25 and TETRA have dedicated control channels which slightly impact spectrum per site. TETRA uses one timeslot (roughly 6.25 KHz of spectrum), P25 uses a full 12.5 KHz for the control channel, and DMR uses a floating control channel. After that, each technology supports the same number of voice users in the same amount of spectrum. If 12.5 KHz technology is deployed in 12.5 KHz physical channels or 25 KHz technology is deployed in 25 KHz channels, they are each considered 6.25e. There are some cases where legacy 25 KHz channels have not been narrowbanded to 12.5 KHz. In these cases, while the technology is efficient, the implementation may not be. Recently, a newer way of deploying two 12.5 KHz radios in a single 25 KHz channel (works for both P25 and DMR) was developed that may be used and result in the same efficient use of spectrum. All in all, the availability of spectrum will dictate the LMR technology available for the M2M solution.

DECIDE WHETHER THE APPLICATION IS BUSINESS CRITICAL OR MISSION CRITICAL

Assuming the spectrum is available to the utility, the next decision point is whether a mission-critical or a business-critical application is needed. This decision is important, because it raises a variety of other issues that need to be considered, including security, mobility, prioritization, resilience and availability needs of the end user. These attributes and others are used when evaluating how well a system meets the mission critical requirements of a utility. All too often, when evaluating and comparing systems, the focus is placed on high-level features instead of the underlying architecture or framework, which can significantly impact how those features are implemented. It's how some of these systems have enacted features that really determine if the system is mission critical or not.

Mission Critical

When discussing communication systems, the term "mission critical" refers to systems in which failure to provide service has a direct impact on life, safety or property. A mission critical radio system must function and be always available, wherever users have access to the network. Mission critical networks consider redundancy both at the system level and at the box level to ensure that the failure of any single component will not stop communications from occurring. Since field crews work in some of the most dangerous weather and situations, utilities have long required their private LMR voice communication networks to be mission critical. In many ways, the communication system is their lifeline should they ever need to call for help. Networks must recognize the most important calls (distress/call for help) and pre-empt other communications, so that the most critical communications can go straight through. Additionally, the networks and devices must be secure both physically and electronically, protecting against intentional and unintentional attacks. Many other factors go into a network's architecture to earn the right to be called mission critical. In many ways, it's a subjective decision when evaluating how a system delivers the necessary performance to be considered mission critical for the intended use case. However, a side-by-side comparison between two systems will objectively show the differences. Within critical infrastructure, the need for mission critical communications becomes the table-stakes for many CI organizations.

Just as field crews require their voice communication network to be mission critical, electric utilities understand which of their fixed data applications for the grid are categorized as being critical or non-critical. Until now, the options for enabling the critical applications on the grid were limited to fiber/wire, which were only brought to specific high value assets. Unfortunately, the options for a licensed wireless alternative were limited, mainly to microwave multiple address systems (MAS). Since no other low cost options existed to enable communication to these applications, utilities looked to leveraging the unlicensed AMI networks, in which they had just invested. Despite having various levels of security, utilities are put into a precarious position because these networks are in the unlicensed band, where their use is shared with garage door openers, Internet Service Providers (ISP) and many other uncontrolled applications, and because their architectures were designed for business critical, best effort performance – not high availability. However, given the limited licensed wireless options that are available, these business critical networks are now being used for some of a utility's critical applications. The good news is that utilities now have a new option to consider for their critical applications – their digital LMR network. With the movement to a digital platform, private mission critical LMR networks can now offer the ability to support these M2M mission critical applications on a network that was designed for mission critical performance.

Business Critical

Business critical systems are those where a failure or disruption will cause a failure in business operations. The impact to a failure of a business critical system is financial, due to loss of revenue. However, there are also effects to the reputation and the company's brand. Advanced metering infrastructure (AMI) is one example of a business critical application. If the AMI network were to fail, the operations of the electrical grid would continue. However, the impact to the business would come from consumers being inconvenienced as the information about their energy use would be delayed, leading to possible disappointment with the utility. The trick with business critical networks is that they can appear to have similar features as a mission critical network, giving the illusion that they will perform the same as a mission critical network. However, as in most technical evaluations, details matter, and it is not in the "what" the feature is but rather in the "how" the feature works, how it was architected and implemented. However, when seconds count, it's the underlying implementation of how the system was architected, reacts, prioritizes and executes during times of failure or in an emergency that really highlight if it was designed for supporting life, safety and property or if it's for business functions only. These same considerations must be made when evaluating leveraging the LMR network for M2M purposes to enable communications to critical applications on the grid.

Business and Mission Critical

Within an organization, there are operations that are considered business critical and those that are considered mission critical. One of the challenges that all customers face is times when communications needs to be extended to groups or organizations beyond the original intended use case. Mission critical systems are typically more expensive. Providing radios on this system to business critical users could be an expensive proposition, because many of the features could be overkill for the non-mission critical users. On the other hand, business critical systems are less expensive and organizations tend to extend the use of these systems to their mission critical users. Just as in any job, the right tool is required for the right job and utilities need to evaluate the needs of mission critical versus business critical use cases for not only their voice needs but, now, also for their M2M needs.

DETERMINE COVERAGE AND CAPACITY NEEDS

Although coverage and capacity may seem independent from one another, they are actually very interdependent. A user who is in a coverage cell that is overloaded with calls may believe that he/she is having a coverage issue because the user isn't able to connect, and vice versa. Whether it is for voice or M2M data, when designing an LMR communication system many factors surrounding coverage and capacity must be considered to create a robust design that meets the needs.

Power equates to coverage. From a coverage perspective, a system using high-powered base stations and subscribers requires fewer sites than a system using low-powered base stations and subscribers. However, from a capacity perspective, a low-powered system will have greater capacity compared to a high-powered system. As an example, let's consider that, for a particular voice messaging profile and M2M messaging profile, an RF channel could support up to 300 users. Now consider a case where one high-powered site with one RF channel provides coverage to a territory that has 300 users. In this case, all the users would share that one channel and its capacity with no room for growth. However, if three sites were required to provide the same coverage from a low-powered system, each site would only have 100 users per site, leaving additional capacity for other applications. High-powered LMR systems typically are less costly when compared to their low-powered LMR equivalents. This is because land acquisition, tower construction and the site build-out costs, with all the back-up generation and fuel costs, can drive system costs exponentially. These tradeoffs between coverage and capacity must be taken into consideration because there is a direct financial impact.

A customer should determine if it's more important to fulfill high traffic needs or a large coverage area. While TETRA is designed to support high traffic volumes with small cells and a large number of channels, DMR and P25 work with large cells similar to analog systems.

There is often a tradeoff of coverage for capacity. If coverage is the main requirement, then high-powered systems, such as P25 or DMR, will require fewer sites than TETRA and prove a lower overall cost option. Typical TETRA portable radios are between 1W and 1.8W, though the standard supports up to 3W. Comparable portable P25 and DMR radios are 5 - 6W in VHF/UHF and 3W in the higher bands (700 / 800 / 900 MHz). The difference is even more significant in mobile radios. TETRA mobiles are typically 3W, which P25/DMR mobiles support up to 50W, with most implementations being 25 - 30W.

If capacity is the main requirement and the plan places sites closer together, the capacity of the overall system goes up. This is partly the premise behind a microcell design, such as with TETRA, which can accommodate more total users/calls/traffic per site and may prove a lower overall cost solution depending on the applications and number of subscribers on the system. TETRA designs are typically cellular in nature, requiring many low sites to cover an area, which provides greater overall system capacity. TETRA systems also require many more channels to do a frequency reuse pattern which, when combined with the greater number of sites, can make it considerably more costly than a DMR or P25 system. This needs to be considered in the overall ROI when evaluating an LMR system for both voice and M2M needs.

Depending on the number of M2M devices and their corresponding messaging profile, it may be possible that the existing LMR design may support both voice and M2M needs without any changes to sites or design. However, if it's determined that the capacity needs are greater than that of an individual coverage cell or the system then options for additional sites, additional channels or possibly a different system should be considered.

CONVENTIONAL RADIO VERSUS TRUNKING

Trunked radio, or trunking, is a term derived from telephone networks, where a group of lines between two points are shared or trunked and assigned one at a time as users request them[17]. The main benefit of a trunked radio system is to provide greater utilization efficiency of the available frequencies so that all frequencies can be shared between all users in real-time. This results in an increased carrying capacity of users for each radio system. Thus, trunking automatically and dynamically assigns a small number of communications frequencies or channels among a relatively much larger number of users.

[17] About Two Way Radio Blog, available online at: http://www.about2wayradio.com/Trunked.htm

On the other hand, conventional radio systems use a dedicated channel (frequency) for each individual group of users, while trunking radio systems use a pool of channels that are available for a great many different groups of users. In a trunked system, users in a given geographical area are not assigned a dedicated channel but, instead, are members of a talk-group entitled to draw upon the common resources of a smaller pool of channels. Trunked radio takes advantage of the probability that with any given number of user units, not everyone will need channel access at the same time and, therefore, fewer discrete radio channels are required. From another perspective, with a given number of radio channels, a much greater number of user groups can be accommodated.

Channel capacity is a function of the user channel access protocol. To maximize voice capacity, users of conventional systems listen and then transmit. As the channel load increases, the chance of conversations colliding increases. At that time, a greater number of messages are lost and effective channel throughput is reduced. Users that are more impatient will "transmit when ready," colliding with other messages and degrading the system performance. At this point, users typically abandon or do not attempt calls that are not essential, prioritizing their own calls based on the situation as they understand it from monitoring the radio traffic.

Trunked LMR systems make use of electronically controlled access to multiple channels in the system. Users are prevented from causing a message collision because the system controls channel access. When all channels are active at peak usage periods, trunked systems are able to prevent message collisions and minimize retries. At those times, trunked systems provide greater network capacity than conventional systems, because they provide a greater message throughput. At lower traffic periods, however, trunked systems inherently have a longer call setup delay.

When it comes to M2M use, conventional systems and trunked systems both have their advantages and disadvantages. When considering leveraging the LMR system for M2M services, it's important to work closely with the manufacturers to model both the coverage and capacity of the proposed system using the voice loading and the data loading for the M2M applications that are being considered for the system. With some systems, it's possible to dedicate a channel in a trunked system to just data, and each manufacturer should discuss what options exist to maximize the data capacity of the system in which the utility is interested.

TECHNICAL CONSIDERATIONS

DETERMINE THE SECURITY NEEDS

Utility organizations are required by law to protect the consumer data they gather. When leveraging LMR to support M2M, utilities must consider what levels of protection are needed to ensure the data is secure from tampering. In many cases, security for voice systems is an afterthought and not part of the implemented system. If not addressed sooner, this weak link could impact the successful adoption of M2M within the organization. Encryption of voice and data traffic is the first line of defense. A strong authentication method is the next. The good news is that all three system types, P25, TETRA and DMR, offer a form of authentication and encryption. However, they vary in their approaches and levels of protection. Since M2M services operate using the IP protocol, ensuring the highest level of security and authentication is mandatory.

P25 Security[18]

In a P25 radio system, authentication services are handled by an authentication facility. Depending on the system manufacturer, the authentication facility could be a standalone server or an application service running on an existing system device. Authentication uses a secret key that is stored in the radio system and subscriber radio. Each subscriber radio has its own unique authentication key, which is associated with the subscriber radio unit ID. For subscriber radios that are operating with multiple systems or multiple unit IDs, multiple authentication keys are assigned.

[18] RELM Wireless Corporation, April 24, 2013, available online at https://www.facebook.com/RelmWirelessCorp/posts/498140946906591

The P25 radio system initiates authentication of a subscriber radio by sending a challenge to the subscriber unit. The subscriber radio returns a response to this challenge, which requires knowledge of the authentication key. The radio system then compares the subscriber radio's response, and if correct, the authentication is successful and the subscriber radio is considered valid. If authentication fails, then the subscriber radio is denied access to the radio system. Of course, the system will not interfere with an authenticated subscriber in the event that an invalid radio attempts to authenticate using the same radio ID.

The P25 authentication standard also provides support for mutual authentication. Authentication services in P25 systems utilize the Advanced Encryption Standard (AES) with a key size of 128 bits. This provides a high level of cryptographic security, offering many possible authentication key combinations. AES-128 is also approved for use in FIPS-140-2 validated cryptographic modules. P25 offers other benefits, like the ability to use AES 256 bit encryption and share encryption keys. P25 transmissions can be protected by digital encryption. Because the vocoder produces a digital bit stream, it is relatively easy to encrypt. Two major advantages of this type of encryption are that it does not affect speech intelligibility and the system's usable range. The P25 standards specify the use of the Data Encryption Standard (DES) algorithm with a 56 bit key and the AES algorithm with a 128 or 256 bit key. Some P25 vendors also provide for the ability to encrypt M2M data.

TETRA Security[19]

TETRA supports terminal registration, authentication, air-interface encryption and end-to-end encryption, making it among the most secure two-way radio platforms available today. The TETRA standard specifies a large number of air interface security features. However, it stipulates only that security measures should be in place. The standard does not specify how and when to implement these features, or how to store and distribute security keys in a safe way. This is less of a problem when only one manufacturer and one network is involved. When a number of different manufacturers supply equipment for the same TETRA system, it is necessary to draft agreements to ensure interoperability of security features.

The TETRA standard also supports end-to-end encryption using a variety of encryption algorithms as deemed necessary by national security organizations. The TETRA standard supports four AIE TETRA Encryption Algorithms (TEAs) - TEA1, TEA2, TEA3 and TEA 4. However, TETRA does not support North American encryption standards, such as AES and DES. Besides these core security capabilities, TETRA can also support a wide range of security management capabilities, such as those used to control, to manage and to operate the individual security mechanisms in a network. The most important of these is encryption key management, which is fully integrated in TETRA standard functions. Even though security functions are integrated in a network, this does not automatically imply that a network is fully secure. However, what is normally achieved is that the security risks are "condensed," i.e. they are concentrated to specific elements in the network, which can be adequately controlled.

DMR Security

The DMR standard does not specify how security is to be implemented for voice and data. Encryption is not part of the standard. However, encryption can be added as an external application and doing so may result in interoperability problems when using radios from multiple vendors on a common system. From a standards point of view, the lack of a specified method for authentication and encryption, along with some other important features like stun/kill, key management, a standardized vocoder optimized for high noise environments, and no design target of minimum call set-up times in the user requirement can render DMR unsuitable for mission critical or business critical users, if implemented

[19] **Setting the standard for communications security, TETRA Today, Issue 4, July 1, 2011**

in accordance with the standard.[20] However, while the standard does not mandate these mission critical features, manufacturers create proprietary solutions to implement them. Since 2011, the DMR Association Technical Working Group has been working to develop higher levels of security and a common implementation of security features between suppliers.[21] To achieve interoperability, it is necessary to agree which encryption algorithms will be supported plus a common secure framework for key transport. The working group recently created a common definition for security that supports the ARC4, DES and AES (with key lengths of 128/256) algorithms. Once these common security definitions are adopted by all DMR manufacturers, then security could eventually compare to P25 and TETRA for interoperability.

DETERMINE IMPORTANCE OF PRIORITIZATION AND CALL QUEUING

Digital integrated voice and data systems like P25, TETRA and DMR have inherent ways to prioritize voice communications over data transmissions or, in some cases, prioritize data transmissions over other data transmissions. LMR systems connect into corporate systems through a variety of transport and enterprise networks, each with their own quality of service method. Traditionally, when voice was the only application being used on the LMR network, setting the priority levels was fairly straight forward. However, as the LMR network is leveraged for new applications like M2M to connect to capacitor banks, line switches, reclosers and other DA applications, a complete end-to-end view must be taken to ensure that the applications are prioritized properly over the various network types.

Another way to look at prioritization can be done during the system design. Depending on the manufacturer's implementation, it's possible that for a given system that channels can be allocated specifically for data, and if a channel is busy, the data will sit in queue and continue to attempt sending until the data is successfully transmitted.

EVALUATE RELIABILITY, RESILIENCE AND AVAILABILITY

Critical networks are created to ensure the availability of communications that responders require, especially during a crisis. A critical communications network must be resilient, reliable and maintainable. Based on the level of availability needed, there are different levels of resilience and reliability can build into the M2M system (box, transport, core and system level).

M2M communications are vital in delivering data from remote assets to enable smart decision-making in times of need. Therefore, it is essential that the communications network chosen to deliver the data is always available. Availability measures the percentage of time that a system is working. A key requirement in ensuring system availability is enhancing the reliability of individual components at the box level or at the system level to minimize the chance a communication will fail. Comparing the availability of P25, TETRA and DMR from a standards perspective is difficult because it is not defined in the standards but, instead, is a system-level design that is integral to the architecture implemented by the manufacturer. In some respects, P25 and TETRA have an advantage over DMR because the systems have been more tested and have adapted to support a variety of scenarios, proving themselves repeatedly over time.

One key advantage to P25 over TETRA is that you can phase it in. Because it's backward compatible, you don't have to replace your entire system all at once. That backward compatibility also helps meet the goal of interoperability. When agencies from another area or on a different system roam into a P25 system — for a mutual aid response, for example — the connectivity is seamless.

One important factor in system availability that is often overlooked is related to service and how quickly an item can be repaired once it has failed. Additionally, to ensure maximum availability, a system should also be resilient. The purpose of providing resilience is to safeguard critical communications against circumstances that potentially could result

[20] Comparison of DMR and TETRA: Current and predicted future functionality by Analysis Mason, available online at http://www.dmr-applications.com/13064/analysys-mason-comparison-of-dmr-and-tetra-pdf
[21] DMR Association Technical Working Group, available online at http://dmrassociation.org/1-2/

in a network failure. A resilient system will continue to offer service even in the presence of faults. This can be achieved through the use of duplicated/redundant modules and subsystems configured in a warm/hot/fault-tolerant configuration.

When reliability, redundancy, availability, recoverability and fallback operations are built into the system, the communications will be more likely to be available when personnel—and the citizens protected—are in greatest need. If the LMR network is being use for M2M operations, enabling efficiencies to be gained, then the LMR network absolutely needs to be reliable, redundant and available at all times.

DETERMINE IMPORTANCE OF INTEROPERABILITY

Interoperability is the ability of making systems and subsystems work together. When vendors work to agree upon standards, customers enjoy a choice of suppliers, which drives down prices and improves quality. However, simply because a standard defines interoperability does not mean that the standards implement interoperability equally. Systems and devices that may be compliant with a standard may not be interoperable with other vendors' solutions, thus, limiting the support and equipment ecosystem for the customer. Some of the standards, being more mature than others, have well defined system test plans. [22]

There are two types of interoperability to consider: intra-system interoperability and inter-system interoperability. Intra-system interoperability ensures that the ecosystem of vendors have products that work together, providing some basic level of interoperability and enabling customers to swap out specific sub-components from one vendor for another. These changeable sub-components are usually ancillary equipment to the system – like consoles or subscribers. Examples of the kind of sub-components that could be interoperable as defined by the P25 standard are listed below. Not all these interfaces are necessary or required, and this is evaluated on a case by case basis by each vendor:

- Common Air Interface (CAI)
- Inter RF Subsystem Interface (ISSI)
- Data Network Interface
- Subscriber Data Peripheral Interface
- Fixed Station Subsystem Interface (FSS)
- Digital Fixed Station Interface (DFSI)
- Console Sub-System Interface (CSSI)
- Network Management Interface
- Telephone Interconnect Interface

Inter-system interoperability refers to the solution's ability to be connected directly to another company's solution, albeit from the same or different vendor, usually through a firewall enabled gateway, thus, enabling some basic or enhanced operation between the connected systems. An example of this is when two separate utilities connect their P25 systems together via an ISSI, thus, enabling the visiting utility to communicate with the host utility in their territory to support restoration activities. One exception to the well-defined inter-system interoperability rules are communication gateways that provide a very limited subset of features to allow basic communication between disparate systems via donor radios. Gateways provide talk group interoperability but do not address unit-to-unit interoperability.

Interoperability across multiple technologies is often desirable. Take analog, conventional communications as an example. As mentioned previously, P25 and DMR were built on a base where backward compatibility to analog and conventional systems is required. Thus, it is possible for P25 and DMR to have some interoperability between disparate vendor's systems. TETRA supports neither of these modes and offers no interoperability to these legacy systems. Digital voice interoperability is more complicated because each digital technology encodes (via vocoders) analog to

[22] **Why Can't We Talk: Working Together to Bridge the Communications Gap to Save Lives by the U.S. Department of Justice, February 2005, available online at: https://www.ncjrs.gov/pdffiles1/nij/204348.pdf**

digital differently. Data interoperability to support services like M2M is well defined. However, it is not a guarantee that the data devices will automatically work on another vendor's system unless they have been tested and certified. As more mature standards, both P25 and TETRA have considerably better interoperability testing plans that have enabled vendors to test basic voice and data functionality across platforms. Since vendors sometimes provide enhancements to the standard to meet specific customer requested functionality that isn't part of the standard, the enhanced features would not be supported across platforms. All vendors offer some "above-the-standard" features in their offerings and having a clear understanding of these features is important to ensuring interoperability expectations are properly set.

P25 and TETRA mandate interoperability as part of compliance with the standard. DMR does not mandate interoperability to be compliant with the standard. Additionally, interoperability is enforced through an independent standards body that can test equipment to ensure interoperability for both P25 and TETRA. No such standards body inspects DMR equipment or enforces DMR interoperability. While DMR does define minimal requirements for interoperability these features are very basic and there is little rigor to the testing/validation requirements.

A formal certification testing process has been defined for P25 called CAP testing (Compliance Assessment Program) which is run by the Department of Commerce and is based on rules established by the TIA (Telecommunications Industry Association). Of the 3 standards, P25 has the most mature and comprehensive interoperability process. Some vendors have built labs for performing interoperability tests where competing vendors can schedule time to perform interoperability tests. Generally, these standards and tests ensure a robust set of features will be implemented in a common, interoperable way across vendors. The TETRA Association has a very mature and well defined Interoperability Certification process with detailed testing plans enabling vendors to perform very specific and encompassing interoperability tests. The DMR Association has created the DMR Interoperability Process (IOP) which provides interoperability testing. However, compliance is vendor specific and the overall breadth, depth and overall maturity of the process is not yet to the levels of P25 or TETRA interoperability.

TECHNOLOGY MUST BE SUITABLE FOR M2M DATA NEEDS

Among the most important considerations of a private radio network's suitability for M2M communications is the method used for data transfer. Data rates specify the rate at which data can be transferred from one machine to another. The data rates that an M2M unit requires for its output to be displayed on a tablet would be much higher (in Mbps) when compared to that of a monitoring device (in Kbps), because the information transfer is different. Data rates are usually measured based on two parameters:

- Raw data rate – the over-the-air (OTA) data transfer rate, which is quoted as speed
- Throughput data rates — rates at which data can be transferred that reflect the latencies within the system

The main goal is to squeeze as much data into the spectrum that has been assigned for that standard. That objective, known as spectral efficiency, measures how quickly data can be transmitted in an assigned bandwidth. The unit of measurement is bits per second (bps).

Standard	Channel Bandwidth	Modulation	Raw Data Rate per TDMA Slot or FDMA Channel	Aggregate Channel Data Rate (All slots)
DMR	12.5 KHz	2:1 TDMA	4.8 Kbit/s	9.6 Kbit/s
P25 Phase 1	12.5 KHz	FDMA	9.6 Kbit/s	9.6 Kbit/s
P25 Phase 2	12.5 KHz	2:1 TDMA	9.6 Kbit/s	9.6 Kbit/s
TETRA	25 KHz	4:1 TDMA	7.2 Kbit/s	28.8 Kbit/s
TETRA – Multi slot	25 KHz	4:1 TDMA	7.2 Kbit/s	7.2, 14.4, 21.6 or 28.8 Kbit/sec
TEDS	50, 100 or 150 KHz	4:1 TDMA	7.2 Kbit/s	77 – 691 Kbit/s

Fig 5: Data Summary

P25 Data

Phase 1 and Phase 2 P25 both offer a raw data rate of 9.6 Kbit/s with confirmed and unconfirmed data services in a 12.5 KHz channel. Both Phase 1 and Phase 2 P25 systems support mission-critical voice and low-bandwidth data applications and offer options to optimize data efficiency for smaller packets, which are ideal for M2M data applications which tend to be shorter, less frequent messages that aren't latency sensitive. P25 supports IPv4 and does not mandate IPv6, but rather allows vendors the flexibility to implement it within their system architecture. With a raw data rate of 9.6 Kbit/s, a Phase 2 TDMA P25 system can be leveraged to support a variety of distribution automation applications including capacitor banks, voltage regulators, capacitor banks, line switches, reclosers and more.

TETRA Data

TETRA has 3 packet data offerings: single slot data, multi slot data and a higher speed data offering called TEDS. In the single slot data mode, each user transmission is restricted to a single timeslot that has a raw packet data rate of 7.2 Kbit/s per timeslot. Multislot packet data can aggregate multiple timeslots together to make one super packet data channel. Since there can be up to 4 timeslots each with a raw data rate of 7.2 Kbit/sec the aggregate data rate of a multi slot TETRA packet data channel is 28.8 Kbit/sec. The number of timeslots that can be combined together is determined by the voice loading on the channel.

TETRA has a feature known as TEDS (TETRA Enhanced Data Services) and is part of TETRA standards Release 2. Although TETRA operates in a 25 KHz channel, TEDS is an advanced offering which requires 50 KHz, 100 KHz or 150 KHz of contiguous spectrum providing a wideband data solution with data rates between 77 Kbit/s to 691 Kbit/s. TEDS is considered a wideband solution which offers data rates faster than narrowband solutions but less than broadband data solutions. In a 50 KHz channel the raw data rates range between 77 Kbit/s – 230 Kbits/s, between 154 Kbit/s – 461 Kbit/s in a 50 KHz channel and from 230 Kbit/s – 691 Kbit/s in a 150 KHz channel. The barrier to deploying TEDS, especially in North America, is obtaining multiple contiguous channels across the service territory. Given TETRA's micro site design, the additional sites required compared to P25 or DMR and the number of channels to do a reuse plan, implementing TEDS on a wide area basis can be a very expensive and almost improbably proposition on a wide area basis. Given its European roots, TEDS has only been deployed in a couple of locations using 50 KHz configurations so even in areas where channels are more readily available it has had very limited deployment.

In summary, it is important to remember that M2M devices frequently send or receive small amounts of data at pre-determined times or report only when an incident has occurred (i.e. report by exception). In practice, P25, TETRA single slot and DMR would be comparable for the small, frequent data needs of M2M applications for utilities supporting key distribution applications including capacitor banks, voltage regulators, line switches, reclosers and more.

DMR Data

DMR is based on a 2:1 TDMA scheme and each timeslot has a raw data rate of 4.8 Kbit/s. Although DMR may be marketed as being 9.6 Kbit/s, which is the aggregate data rate of both timeslots, a user may only occupy one timeslot at a time so the end user data rate is limited to 4.8 Kbit/s. As an IP based packet data system, DMR supports both IPv4 and IPv6 packet data services as well as short data/status messaging applications. DMR's data rate of 4.8 Kbit/s is considerably less than P25 and TETRA but it is suitable for some distribution automation applications. However, because of its decreased data rate DMR is limited to the type and quantity of distribution automation applications that can be supported.

FINANCIAL CONSIDERATIONS

Financial considerations evaluate the ROI and value delivered by the technology solution. Financial decision points include the coverage and capacity delivered by the technology as well as the costs of installation and maintenance. Significant costs savings can be achieved by implementing an M2M solution on an existing LMR structure. In that case, the purchase of an M2M gateway and RF modems would be the only additional infrastructure cost. If no radio infrastructure exists, then examining the total cost of ownership is the final consideration for evaluating radio technologies for M2M applications.

The TCO is related to the initial capital investment and the on-going operational expenses over the life of the investment. If the utility is starting from scratch or considering adding M2M to an existing LMR radio network, then the following considerations should guide the evaluation:

- Leveraged Capacity: Utilities have long relied on their LMR systems for communications with their employees to help ensure their safety. If the utility has migrated to a digital platform that uses TDMA, then the additional channel capacity can be used for new services like M2M.
- Mature Vendor Ecosystem: Though a variety of proprietary solutions exist, the industry has moved to requiring standards-based solutions. This leverages the ecosystem of multiple vendors, ensuring that they are price competitively, and 3rd party suppliers to provide alternatives to key components within the system framework. However, mature standards like P25 and TETRA offer the advantage that the ecosystem has been well vetted, providing a higher degree of confidence in their operation and reliability. A captive vendor ecosystem would lead to increased costs because fewer vendors could install and service equipment. Without the backing of the industry and a large vendor ecosystem, the utility risks "going it alone," especially if the vendor goes out of business, leaving the utility without a support option.
- Secured Property Interest: Leveraging the LMR network for M2M can provide a long-term financial gain. The FCC recently assigned a significant portion of the unlicensed 900 MHz band to a private user, rocking the CI industry, which uses this band for many of their AMI, SCADA and other Smart Grid applications. Unless it's unused, private licensed spectrum isn't unknowingly taken away and reassigned by the FCC, and wouldn't force the utility to consider replacing it with alternative licensed radio solutions.
- Low Data Rates: Critical distribution automation applications that aren't latency sensitive offer low data rate requirements and are mission critical. Thus, they are ideally suited for the private LMR radio networks that are designed for high reliability and high availability, which may not be the case when using public networks or networks that use unlicensed spectrum.
- Longer Life Span: Private radio network providers typically support their systems for 10-20 years, whereas the typical lifecycle for an unlicensed or public network could be as low as 3-7 years.
- Site Costs: TETRA requires more sites (2x-4x) to achieve the same coverage as high-powered P25 and DMR systems. Because it isn't prevalent in North America, moving to TETRA requires more sites and additional spectrum. Not only is the cost of spectrum on the third-party market high, but the cost to acquire land, build towers, shelters and install backup power/generation for the infrastructure can be more costly than the system itself.
- Security Costs: Some standards offer higher levels of security and a comprehensive information assurance framework while others don't. For those that do not offer higher levels of security, additional costs are incurred to achieve this security when required.

CONCLUSION

Having been burdened by driving efficiency into distribution operations and not having the necessary licensed broadband spectrum to create a private M2M network, utilities can look to today's digital LMR networks as a strong platform they can leverage for their M2M needs. Designed as mission critical networks and already providing coverage throughout the entire service territory, LMR networks are uniquely positioned to be leveraged for applications beyond voice. Until recently, LMR networks have been relegated to just providing voice services and any data supported over them was trivial. However, with the advent of digital technology and the development of the TDMA channel access method, the new digital systems available today provide at least 2x the channel capacity as previous analog systems. This additional channel capacity can be leveraged for M2M applications like SCADA, capacitor banks, reclosers, line switches, voltage regulators and other DA applications that have low bandwidth requirements and aren't latency sensitive – without affecting the voice capacity. Since voice services are mission critical to supporting the utility's safety objectives, the decision which standard to choose for M2M should still be based on the voice requirements.

Just as one needs the right tool for the right job, LMR networks have the ability to support key critical applications on a highly reliable and available network with the security they require. Many factors go into selecting either a new digital LMR technology platform or using an existing digital LMR platform for M2M communications needs. Digital LMR networks based on global standards like P25, TETRA and DMR offer a large ecosystem of vendors that provide solutions and products to meet a variety of coverage, capacity, security and interoperability needs. As similar as some of the standards may sound, the composition of the standards themselves varies greatly. Standards like P25 and TETRA are considerably more mature than DMR because they've been in the market for several decades or longer and have well defined interfaces and processes. P25 is a U.S.-based standard and is driven by actual users of the equipment, while TETRA and DMR are European standards and are driven by the manufacturers in ETSI. An evaluation of key features and requirements will most often result in one technology over another but, in some cases, multiple technologies are viable. In that case, pricing, feature differences, interoperability and customization within the standard and across vendors, will be the deciding factors. An important point to remember when comparing multiple radio technologies to one another is that many of the features will look similar. However, it is the way these features are implemented and executed that separates whether the system qualifies as mission critical or business critical. To date, utilities have required their LMR networks to be mission critical because the life and safety of their employees is at stake during both normal operations and storm restoration times. Though applications like AMI don't rank as being mission critical to a utility's operations, many distribution automation applications are classified as critical and can benefit directly from leveraging M2M services while operating on a mission critical radio network.

By optimizing the business value of a private LMR system, a utility will be able to maximize its investment and leverage its radio assets for multiple applications. In addition, utilities can minimize the rapid growth in operating expenses by leveraging infrastructure that is already managed and supported. By utilizing LMR systems for M2M applications such as SCADA, demand response, telemetry, distribution automation and other suitable applications, utilities can reduce carrier services, more fully utilize their existing service management capabilities and optimize both capital and operating expenses.

APPENDIX A

Essential Communication Requirements of Smart Grid Applications

Source: Department of Energy, “Communications requirements for Smart Grid Technologies,” October, 2010.

Application	Description	Required Communications Infrastructure	Data Rate	Latency	Reliability	Security	Mission Critical
Advanced Metering Infrastructure (AMI)	Two-way communication capabilities for tracking energy consumption data for grid, outage and billing management	Multitier hierarchical network comprising Home Area Network Smart Meters, Data Aggregation Point, Utility Head end (802.16 applies to several tiers)	10-100 kbps per node (500kbps for back-haul)	2-15 sec	99-99.99%	High	No
Demand Response (DR)	System for reducing energy consumption by consumers in repose to price and system load, such that peak loads can be managed.	DR systems may share the AMI infrastructure (802.16 is relevant in multiple areas)	14-100 kbps/per node/device	500 ms-several minutes	99-99.99%	High	Yes
Wide Area Situational Awareness (WASA)	Technologies for improving monitoring and control of utility grid across a wide area. Use of synchrophasors to improve real-time monitoring over wide area, in addition to localized Supervisory Control and Data Systems (SCADA)	Challenging for wireless technologies to meet latency and reliability for real-time, wide area monitoring.	600-1500kbps	20-200ms	99.999-9.9999%	High	No
Distribution Energy Resources and Storage (DER)	Integrate renewable energy sources, small scale sources (electric vehicle batteries, uninterrupted power supply, etc.,), larger scale wind-farms etc. into Grid. Will require real-time monitoring and control of DER sources.	May reuses AMI networks w/ potential for 802.16, although other technologies such as point-to-point micro-wave links, satellite communications may be required.	9.6-56kbps	20ms-15sec	99-99.99%	High	Yes
Electric Transportation	Charging Plug-in Hybrid Electric Vehicles (PHEV) as well utilizing them as storage devices.	Can reuse AMI networks with added need for mobility, due to roaming vehicles.	9.6-56kbps (target 100kbps)	2sec-5mins	99-99.99%	Relatively High	No
Distribution Grid Automation (DA)	Automate monitoring and control of distribution grid for effective fault detection and power restoration	Can reuse AMI networks. Wireless technology is important to avoid hazardous locations. Challenging latency requirements.	9.6-100kbps	100ms-2sec	99-99.999%	High	Yes