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CIGRE US National Committee
2018 Grid of the Future Symposium

Leveraging Private LTE Networks in the Electric Utility

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SUMMARY

As utilities transition to features and capabilities of the Smart Grid[1] and the grid modernization initiative[2], the need for reliable and secure broadband wireless communications is rapidly increasing. Several network communication solutions relied on in the past, suffer from obsolescence, lack of reliability, or inadequate performance. T-1 leased lines are being decommissioned or the monthly cost to maintain them is increasing. Microwave links are costly to deploy and maintain and are affected by weather conditions. Fiber has been the preferred solution for generation and transmission, but it is not a cost-effective solution for distributed generation. Wideband wireless solutions are often narrowband and proprietary and will not meet the requirements of a digitized grid. Layer 2 and Layer 3 IP network service provider solutions can be expensive and complicated options that come with inherent risks such as network traffic storms if misconfigured. In addition, the proliferation of application centric networks has created an operational complexity that utilities can no longer afford.

Private LTE networks operating on licensed spectrum have never been as affordable and available as they are currently. They are uniquely positioned to provide the critical communications infrastructure needed by electric utilities to consolidate the many disparate point-to-point and point-to-multipoint communications links that are in use today. Private LTE networks offer several core benefits that make them an ideal solution for the critical needs of electric utilities:

1. **Licensed spectrum**
   Operating on licensed spectrum provides the network operator with recourse in the event of interference. Violators must comply with FCC mandates or be prosecuted and fined for non-compliance.

2. **Private network** (not a virtual partition of a common carrier network)
   A Private LTE network provides a utility the assurance that its traffic traverses only its infrastructure. In the same way applications for critical infrastructure are rarely hosted in public cloud service providers such as Google, utilities will be in control of their

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infrastructure and their traffic management policies and not subjected to traffic policies implemented by a common carrier[3].

3. **Inherent security**
   Mutual authentication between user equipment (UEs) and base stations (eNBs) and the use of proven encryption schemes are two of the major improvements of LTE[4] over its predecessor mobile wireless technology. Overlaying LTE with accepted security measures such as virtual private network (VPN) tunnels that encrypt and authenticate provides the level of security needed for critical infrastructure.

4. **Traffic consolidation by leveraging LTE bearer circuits with assured quality of service (QoS)**
   Combining traffic from multiple applications, which have different requirements for priority, throughput, and latency is exactly what the QoS class identifier (QCI) features of LTE were designed for.

5. **Broadband technology**
   Compared to wideband technology, LTE provides greatly improved spectral efficiency to achieve high data rates and permits multiple users to share a common channel.

6. **LTE Narrowband low power wide area (LPWA) Internet of things (IoT) technology**
   LTE spectrum can be shared among broadband LTE applications and narrowband IoT (NB-IoT) applications. NB-IoT is ideal for monitoring or controlling very large quantities of devices or equipment that generally require relatively low uplink and downlink data rates.

7. **Mobility**
   Within the utility field area network (FAN), instruments or devices used by mobile workers can automatically connect into the private LTE network and provide seamless access to vital backend resources.

KEYWORDS

LTE
Private network
Smart grid
Grid modernization
Licensed spectrum
Wireless
Broadband
Field area network
QoS
LPWA

1. Migrating the Field Area Network to Private LTE Broadband

Existing utility communications infrastructure is a collection of solutions that address a variety of needs using disparate networks and communications technologies, as shown in Figure 1. As the grid undertakes grid modernization initiatives, the need for more network connections with various traffic profiles increases substantially. Today, utility IP field area network (FAN) traffic is backhauled over a variety of point-to-point network connections (fiber, leased lines, MPS services, metro Ethernet, microwave, wideband wireless) to or between routers. Configuring and maintaining many disparate network connections is at least challenging and at most increases the cost (e.g., variety of spare devices, software upgrades, security patches) and probability of a network failure. As distributed energy generation, electric vehicle charging stations, and distributed automation are added to the grid, the need for more network connections increases rapidly. Existing network connection solutions are not designed to scale up easily, and critical performance requirements can be complicated to manage and maintain.

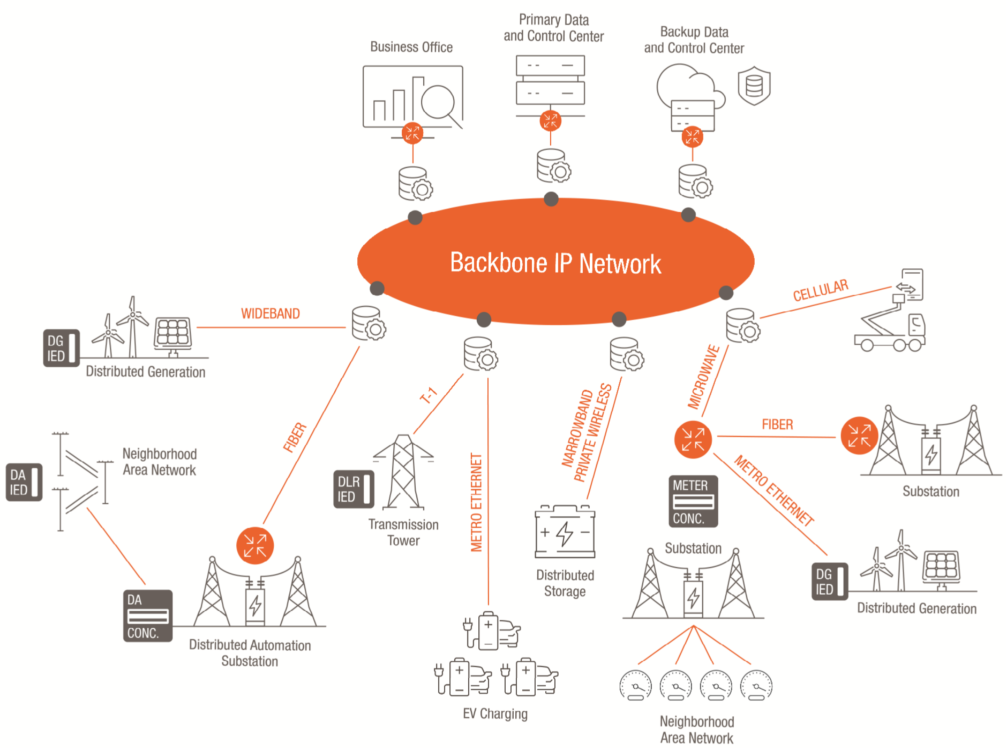

Figure 1. Utility Network Utilizing a Variety of Field Area Network Connections [5]

To consolidate the variety of FAN connections, they are replaced with private LTE broadband connections as shown in Figure 2. They connect the grid back office and control center IP network to the remote substations, distributed energy generation partners, charging stations, etc. This greatly reduces network connection complexity, increases scalability, and is ideally suited for meeting the privacy, security, and performance requirements of the utility infrastructure applications. Redundancy and automatic failover to an LTE common carrier assures reliable communications in the event of a network connection failure. The private broadband network also provides redundancy and automatic failover where fiber connections are the primary link.

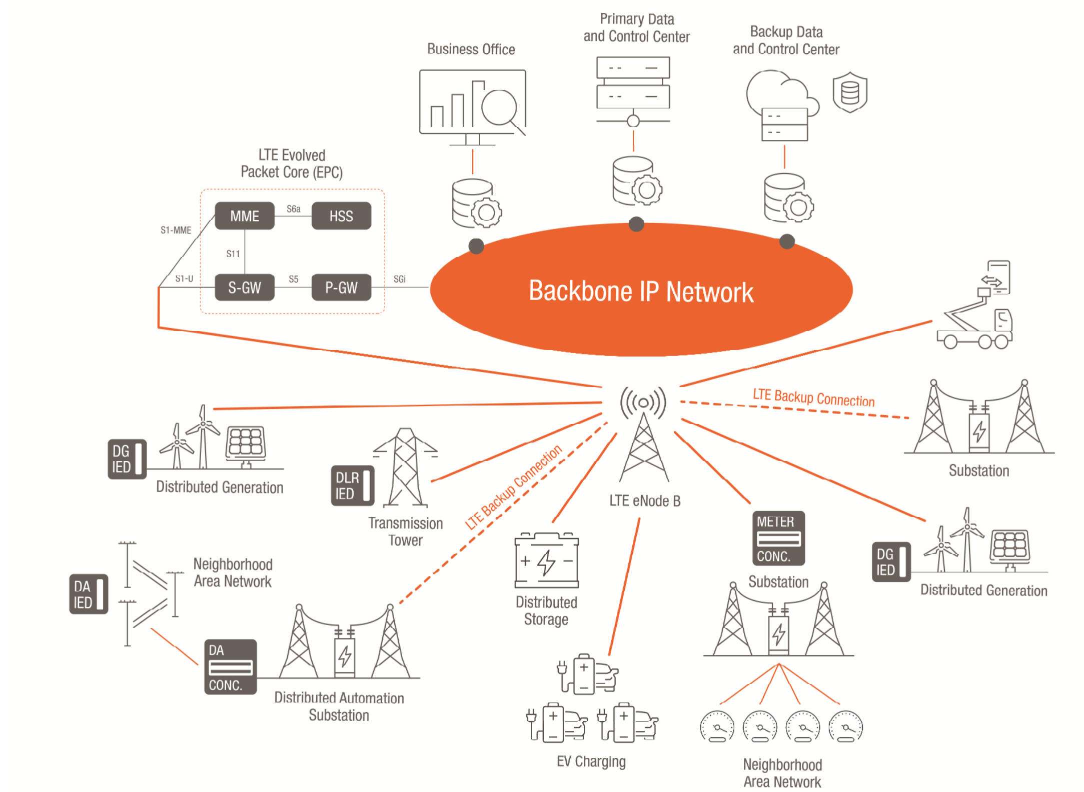

Figure 2. LTE Consolidation of Field Area Networks [5]

2. Assuring Network Quality and Performance

2.1. Application QoS Requirements

There are many different use cases and associated applications. Some have critical latency requirements while others require assured minimum throughput requirements. LTE and IP networks have built-in mechanisms that are ideal for meeting these use case QoS requirements. The Department of Energy provides some base guidelines electric utility application use cases and the associated QoS as shown in Figure 3.

Application	Network Requirements				
	Bandwidth	Latency	Reliability	Security	Backup Power
AMI	10-100 kbps/node,500 kbps for backhaul	2-15 sec	99-99.99%	High	Not necessary
Demand Response	14kbps-100 kbps per node/device	500 ms-several minutes	99-99.99%	High	Not necessary
Wide Area Situational Awareness	600-1500 kbps	20 ms-200 ms	99-99.9999%	High	24 hour supply
Distribution Energy Resources and Storage	9.6-56 kbps	20 ms-15 sec	99-99.99%	High	1 hour
Electric Transportation	9.6-56 kbps, 100 kbps is a good target	2 sec-5 min	99-99.99%	Relatively High	Not necessary
Distribution Grid Management	9.6-100 kbps	100 ms-2 sec	99-99.999%	High	24-72 hours

Figure 3. Smart Grid Functionalities and Communications Needs [6]

2.2. IP Traffic QOS

The IP traffic associated with one application has requirements that differ greatly from the requirements of another application as shown in Figure 3. To accommodate various traffic priorities, the traffic prioritization over the IP network is performed by the differentiated services [7] (DiffServe) codepoint (DSCP) [8] field in the IP header. This field was previously known as the ToS[7] (Type of Service) bits. The DSCP is configured per application in the IP network equipment by the IT department of the utility. When IP traffic is queued, the DSCP is taken into consideration by the router's queueing algorithm. For example, phase measurement units (PMU) provide a periodic (but not constant) stream of data that is sensitive to latency and requires substantial bandwidth, while AMI (Advanced Metering Infrastructure) data is low bit rate and tolerant of large latency. SCADA (Supervisory Control and Data Acquisition) monitoring data may not be time critical and at a lower bit rate, but the SCADA control traffic is often time-critical and of utmost priority (e.g., circuit protection). Figure 4 shows the table of IP DSCP values and their associated relative priority.

DSCP value	Hex value	Decimal value	Meaning	Drop probability	Equivalent IP precedence value
101 110	0x2e	46	Expedited forwarding (EF)	N/A	101 Critical
000 000	0x00	0	Best effort	N/A	000 - Routine
001 010	0x0a	10	AF11	Low	001 - Priority
001 100	0x0c	12	AF12	Medium	001 - Priority
001 110	0x0e	14	AF13	High	001 - Priority
010 010	0x12	18	AF21	Low	010 - Immediate
010 100	0x14	20	AF22	Medium	010 - Immediate
010 110	0x16	22	AF23	High	010 - Immediate
011 010	0x1a	26	AF31	Low	011 - Flash
011 100	0x1c	28	AF32	Medium	011 - Flash
011 110	0x1e	30	AF33	High	011 - Flash
100 010	0x22	34	AF41	Low	100 - Flash override
100 100	0x24	36	AF42	Medium	100 - Flash override
100 110	0x26	38	AF43	High	100 - Flash override

Figure 4. Differentiated Services Code Point Values[9]

2.3. LTE Traffic QOS

There are two types of LTE connections (bearers)[10] These are GBR (guaranteed bit rate) and non-GBR. GBR[10] bearers are used by applications that constantly send traffic (like voice or video). Non-GBR bearers are used by applications that send data. A GBR bearer emulates at circuit connection, whereas non-GRB bearers are statistically multiplexed with other non-GBR traffic. Within each type of bearer, there are a variety of priority, latency, and maximum packet loss rate QoS class identifiers (QCI)[10]options, as shown in Figure 5.

Associated with LTE bearers are LTE QoS class identifiers (QCI) that provide critical traffic management features. LTE offers the ability to provision multiple bearers to one device, each with different traffic handling characteristics such as priority and latency control. Provisioning multiple bearers to a cell site results in virtually having multiple transmission paths to that site, whereas with existing technologies there may be only one transmission path. Public carrier LTE networks rarely provide more than one or two bearers and more importantly do not enable utilities to choose their bearer QCI to control the priority of their traffic.

QCI	Resource Type	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	GBR	2	100ms	10−2	Conversational Voice
2	GBR	4	150ms	10−3	Conversational Video (Live Streaming)
3	GBR	3	50ms	10−3	Real Time Gaming, V2X messages
4	GBR	5	300ms	10−6	Non-Conversational Video (Buffered Streaming)
65	GBR	0.7	75ms	10−2	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66	GBR	2	100ms	10−2	Non-Mission-Critical user plane Push To Talk voice
75	GBR	2.5	50ms	10−2	V2X messages
5	non-GBR	1	100ms	10−6	IMS Signalling
6	non-GBR	6	300ms	10−6	Video (Buffered Streaming) TCP-Based (for example, www, email, chat, ftp, p2p and the
7	non-GBR	7	100ms	10−3	Voice, Video (Live Streaming), Interactive Gaming
8	non-GBR	8	300ms	10−6	Video (Buffered Streaming) TCP-Based (for example, www, email, chat, ftp, p2p and the
9	non-GBR	9	300ms	10−6	Video (Buffered Streaming) TCP-Based (for example, www, email, chat, ftp, p2p and the like). Typically used as default bearer
69	non-GBR	0.5	60ms	10−6	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70	non-GBR	5.5	200ms	10−6	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79	non-GBR	6.5	50MS	2-Oct	V2X messages

Figure 5. LTE QoS Class Identifier Values [10]

3. Aligning IP and LTE QoS

LTE transmission is the ideal companion to IP networks because LTE bearer QCIs can be aligned with IP DSCP settings, resulting in the QoS traffic policy to be conveyed through the network from end to end. For example, the IP traffic from a PMU will flow over an LTE bearer that will assure the throughput and latency requirements are met. Similarly, low priority monitoring IP traffic will flow over an LTE bearer with a lower priority and QoS class identifier. If more bearers are needed because a new application with different priority is to be deployed, a new bearer can be provisioned in the private LTE network. With LTE, a substation can connect to both the inter-substation [11] network and the operations backhaul network on separate bearers, thus avoiding the need to deploy two separate transport circuits.

As shown in Figure 6, provisioning three non-GBR bearers between the connected end point and the backbone network simplifies LTE network provisioning. Backhaul IP traffic performance requirements can be accommodated by provisioning the router network such that the DSCPs of the IP packet are associated with the appropriate LTE bearer QCI. If, for example, there are two applications that require low latency, then both IP traffic types can be associated with the one bearer that has a low latency QCI.

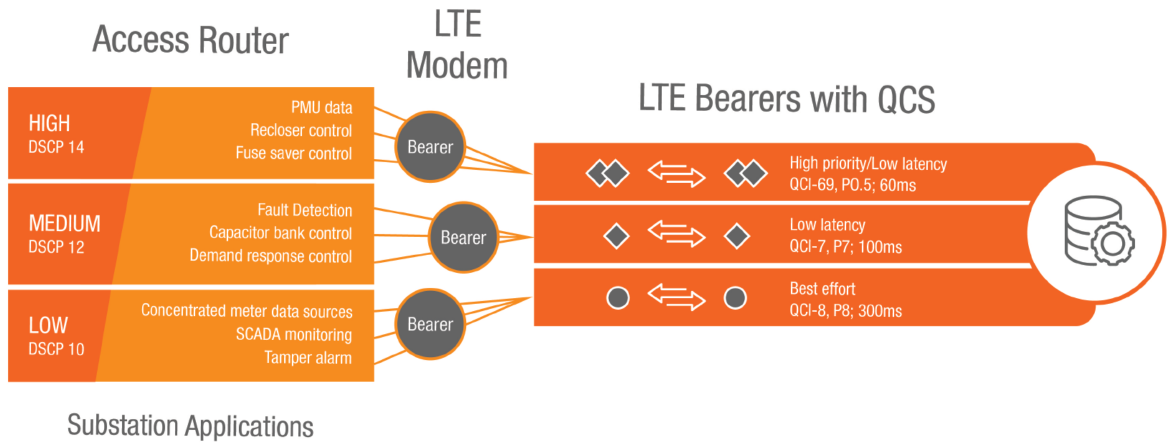

Figure 6. Aligning Applications, DiffServ DSCPs, and LTE Bearer QCIs

Traffic priority management via IP DSCP allows utilities to configure which IP packets get handled first when multiple streams of traffic contend for access to an LTE bearer. Once the IP traffic is on the LTE bearer, LTE QCI controls which bearer traffic gets priority within the LTE network. For example, phasor measurement unit (PMU) traffic has priority over meter data or SCADA monitoring data in the uplink. Once the high priority IP traffic is on the high priority LTE bearer, it will be delivered within the specified LTE QoS settings. Likewise, the control of a recloser or fuse saver takes priority over control of a capacitor bank or control of demand response in the downlink.

4. The Cost of Private LTE

Regulated utilities in the USA are authorized to recover the cost of approved capital expenditures. Operating expenses that continually grow are more challenging for the utility business model. For example, installing a cellular connection in every meter on every business and household greatly increases the number of monthly cellular device subscriptions and thereby increases operating expense. As a result, the AMI market has responded by offering one controller for a string cellular meters. The meters connect to the controller using unlicensed spectrum, which is unprotected from interference. While this approach reduces the cellular subscription portion of the operating expense, it does so at the expense of reliability, performance, and security. First, unlicensed spectrum is not managed and protected from others using the same spectrum. Second, when one controller fails, many meters can no longer be controlled. Third, when utility traffic traverses a public carrier network, it is merged with all other consumer generated traffic without any prioritization. This traffic is no longer within the bounds and control of the utility, therefore it is not suitable for mission critical use cases

With the proliferation of distributed generation, the number of end devices sensing and controlling, the grid will grow exponentially. These devices will demand more stringent requirements for latency, prioritization, security and reliability than commercial public networks or narrowband proprietary solutions using unlicensed spectrum can offer.

Investing in a private LTE network using authorized capital expenditures enables the utility to connect as many devices to the network as is needed. This removes the recurring operating expense component from the decision making and results in a network that is designed for performance, reliability, and security.

A private LTE network is a communications platform that can expand to accommodate utilities' growing need for connected end points as they digitize and automate grid operations. It fits utilities business model, reduces the operational cost and eliminates the current operational and technical complexities of managing a diverse set of application-centric networks.

5. LTE Private Networks – A solution ready to deploy

The LTE ecosystem is robust and vibrant. Hundreds of commercial networks are deployed worldwide. The challenge of deploying LTE private networks is the ability to find licensed spectrum.

In the US, licensed spectrum is becoming available for critical infrastructure and enterprises to deploy their own dedicated private networks. 900 MHz (3GPP band 8) and 3.5 GHz (CBRS band) are examples of bands that are ideal for the growing needs of the smart grid.

According to the Global Mobile Suppliers Association, there are 3,487 devices that operate on 900MHz 3GPP band 8 as of February 2018 as shown in Figure 7. pdvWireless has tested many of the devices that are suitable for electric utility use cases and verified their compatibility.

LTE FDD Band	Number of Devices
1800 MHz band 3	7,731 devices
2600 MHz band 7	6,974 devices
2100 MHz band 1	6,282 devices
800 MHz band 20	4,558 devices
850 MHz band 5	3,876 devices
900 MHz band 8	3,487 devices
AWS band 4	3,113 devices
1900 MHz band 2	2,990 devices
700 MHz band 17	2,171 devices
700 MHz band 13	1,1,63 devices
APT700 band 28	1,211 devices
700 MHz band 12	1,058 devices
1900 MHz band 25	581 devices

Figure 7. LTE Ecosystem Snapshot [12]

Combining mature technology, a robust roadmap and available spectrum dedicated to utilities, makes realizing the value of private LTE networks a business decision rather than an aspirational goal.

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