



Rethinking the FAN for grid automation

Pairing private LTE with IP/MPLS beyond substations

White paper

With new market forces, green environmental regulations and disruptive energy technologies, the energy industry landscape is changing and utilities are facing an array of challenges. To continue flourishing in this environment, many are modernizing their grids and bolstering customer relationships. Underpinning these efforts is a shift in the communications technologies utilized in the field area network (FAN). An emerging FAN architecture is to couple a private LTE network using dedicated spectrum with BGP/MPLS services extended to the FAN edge. This new FAN enables convergence by providing a ubiquitous service and management environment for secure, reliable connectivity of smart grid applications that monitor, control and automate distribution grids today. This paper describes a private, converged FAN architecture grounded in the two strong technology pillars of LTE and IP/MPLS, and its capabilities, benefits and flexibility.

Contents

As the grids evolve, communications networks must expand	3
Converged FAN architecture essential characteristics	6
1. Reliable and cost-effective broadband access	6
2. Versatile, resilient and secure converged communications services network	7
3. Scalable network	8
4. Seamless end-to-end grid communications	8
5. Flexibility for future growth and innovations	8
The converged FAN architecture	9
A. LTE RAN	11
B. Packet Core	14
C. Mission-critical IP/MPLS network	15
Converged FAN solution offered today	16
Conclusion	17
Abbreviations	17
References	18

As the grids evolve, communications networks must expand

A confluence of new market forces, green environmental regulations¹ and disruptive energy technologies is prompting momentous changes in the utility industry. On the one hand, as part of grid modernization efforts, utilities are starting to widely implement distribution automation (DA) in the medium voltage and low voltage grids to improve electricity reliability, enhance operational efficiency and optimize grid performance. On the other hand, with rapid development of new technologies such as distributed energy resources (DER), storage, microgrid and electric vehicles, the way energy is generated and consumed is also changing. Responding to these challenges, utilities are evolving their grids to become more intelligent and automated. They are adopting grid applications to monitor, control and automate the grids.

Grid applications acquire power line data such as frequency, voltage and current levels continually, process them, and send control and command signals if necessary. This requires seamless and secure connectivity between field devices (also known as intelligent electronic devices [IEDs]) and information and control systems. In the centralized approach, the information and control systems such as the distribution management system (DMS) or SCADA server are hosted in a grid control or operations center. They coordinate automated equipment operations among the multiple feeders when necessary. With the widespread installation of DER, the power flow in the grid becomes bidirectional, which compels the adoption of a distributed approach to complement the existing centralized approach. A distributed approach allows local control systems to operate automated equipment on the feeders according to preprogrammed switching logics. The result is a shorter response time to ensure grid stability and power quality. This requires the build out of field area networks (FANs) to extend communications connectivity beyond substations to remote devices in the feeders.

Utilities have typically deployed private, application-specific FANs to extend network reachability. These FANs have been based on a variety of wireless networking technologies including narrowband and broadband point-to-multipoint radio and wireless mesh, as well as wireline technologies such as power line carrier (PLC) and optical ground wire (OPGW) (see Table 1).

¹ Governments worldwide are setting up legislation to encourage adoption of new energy-related technologies. For example, the Europe Union's [Renewable Energy Directive](#) sets a target of 20 percent final energy consumption from renewables by 2020. The U.S. Department of Energy has also a range of [microgrid activities](#) to drive microgrids into the mainstream. The Ontario government is also offering a [monetary incentive](#) to increase the number of electric vehicles on the road.

Table 1. FAN networking technologies comparison

Technology		Benefits		Drawbacks
Unlicensed wireless mesh	Broadband IEEE 802.11s Wi-Fi mesh at 2.4/5.8 GHz	Low cost, fault recovery, high bandwidth	Private network (total utility control)	Prone to interference, short range
	Narrowband IEEE 802.15.4g/ ZigBee/Wi-SUN RF mesh at 868 MHz (Europe), 915 MHz (the Americas) and 2.4/5.8 GHz (worldwide)	Very low cost, fault recovery		Prone to interference, low bandwidth, short range, limited talent pool
	Narrowband proprietary RF mesh at 915 MHz (the Americas) and 868 MHz (Europe) e.g. Landis+Gyr, Elster	Very low cost, fault recovery		Prone to interference, low bandwidth, short range, vendor-specific, few technology enhancements, no open path to IoT adoption, limited talent pool
Unlicensed P2MP	Broadband point-to-multipoint (P2MP) IEEE 802.11a/b/n Wi-Fi (2.4/5.8 GHz)	Medium to high bandwidth		Prone to interference, short range, no path redundancy
	LoRa®	Very low cost, long range		Prone to interference, low bandwidth, no path redundancy
	Narrowband vendor-specific P2MP radio at 868 MHz (Europe) and 915 MHz (The Americas/Australia) e.g. CalAmp, Freewave Technologies	Low cost		Prone to interference, line of sight (LOS) path only, short range, no path redundancy, few technology enhancements, no open path to IoT adoption, limited talent pool
Lightly licensed	WiMAX (lightly licensed 3.65 GHz)	High bandwidth, wide coverage (LOS/NLOS)		Weak interference protection, small ecosystem, LOS path typically required when >2 km, limited worldwide deployment
Licensed wireless	Licensed narrowband vendor-specific P2MP radio (150/220/450/900 MHz) e.g. CalAmp, GE	Low cost		Spectrum cost, LOS path only, low bandwidth
	Licensed point-to-point microwave (6 – 23 GHz)	High bandwidth		Spectrum cost, LOS path, fading
Wireline	Fiber (OPGW, ADSS and GPON)	Very high bandwidth		Last-mile wireless coverage still required
	Power line carrier (PLC)	Capitalize on existing grid infrastructure, high bandwidth possible (broadband over PL)		Mostly deployed in medium voltage section only, last-mile wireless coverage still required

Current FAN deployments that are providing benefits for specific applications today will have the following limitations as the grid evolves:

1. The disparate deployed FANs aim to provide connectivity for discrete applications and their associated field devices. For example, utilities may deploy one FAN for advanced metering infrastructure, another one for power quality monitoring and a third one for protection, all based on different networking technologies. This segregated paradigm causes higher operational and maintenance costs. It also hampers control and communications among grid applications, becomes a barrier to applications integration and stalls future innovations.
2. Most FANs are designed to backhaul application traffic to servers in a data center or operations center, fitting well with a centralized automation model. As automation control becomes more distributed, local FAN communications to facilitate connectivity between the local logic in various IEDs in the same feeder circuit, or across feeder circuits, are required. For example, a centralized voltage and volt-ampere reactive (VAR) optimization (VVO) application only require segregated backhaul connectivity for capacitor banks and voltage regulators in the feeder, line tap changer (LTC) in the substation, with a DMS in the operations center. In a distributed model, flexible local communications in the FAN among these three IED types are required as control logic is distributed among all three IEDs.
3. Some FAN deployments are based on narrowband wireless technologies. With a typical channel size of 12.5 kHz or 25 kHz in the 900 MHz spectrum (in the Americas), 868 MHz (in Europe) or lower spectrum, data throughput remains in the range from 9.6 kb/s to several hundred kb/s. Newer technologies such as IEEE 802.15.4g²/ZigBee³ can utilize the upper spectrum of 2.4 GHz and 5.8 GHz. They are ideal for communicating collected data from household meters to a field collector. However, they lack sufficient bandwidth to accommodate significant application enhancements and additional new grid applications, which inhibits the future grid communications evolution. For example, microgrids' operating conditions tend to vary rapidly with incremental load or generation; hence more frequent monitoring (up to 60 samples per second) is required, which triggers the requirement for more bandwidth.
4. Some wireless technologies such as Wi-Fi[®] mesh (IEEE 802.11s) and proprietary point-to-multipoint (P2MP) wireless operate using unlicensed spectrum. These will face an increasing risk of interference as industries, consumers and governments connect an increasing quantity of their Internet of Things (IoT) devices using the same unlicensed spectrum.
5. Some older commercial cellular networks such as 2G (GSM/GPRS and CDMA) and 3G are gradually approaching end of life.⁴ Utilities that use commercial cellular services for their FAN today will need to devise a migration plan in time.

Consequently, the current FAN model does not render utilities a scalable, reliable and economic path to evolve forward. Therefore, utilities are looking for a new converged FAN architecture to fully support new distribution automation, seamless DER integration and other energy innovations driven by market and regulatory forces.

² IEEE 802.15 WPAN™, Task Group 4g (TG4g), Smart Utility Networks

³ ZigBee Alliance

⁴ Mobile service providers are at different stages of retiring their 2G and even 3G networks:

- [Our 2G Network Is Closing](#)

- [Verizon is killing off 3G](#)

Converged FAN architecture essential characteristics

To overcome the limitations, utilities need to transition to a converged FAN with the following key characteristics.

1. Reliable and cost-effective broadband access

Utilities need a FAN that can reliably and cost-effectively cover thousands (if not more) of square kilometers of their service territory, possibly including remote and even unpopulated areas, extensively. This makes wireless technologies an effective last-mile access method for a FAN. The wireless technology adopted in a converged FAN must provide high availability under all circumstances. Hence, it is vital to utilize licensed spectrum to reduce the risk of interference. It is also imperative to support high data throughput for support of future grid applications evolution.

Long Term Evolution (LTE),⁵ the 4th generation (4G) mobile broadband technology defined by 3GPP,⁶ is considered to be well suited for a FAN buildout. It attains high spectral efficiency with cutting edge digital communication techniques such as orthogonal frequency-division multiple access (OFDMA), turbo coding, as well as multiple-input and multiple-output (MIMO). It can operate in numerous frequency bands and accommodate different channel size, catering to different spectrum availability situations and applications. While it is still a relatively new technology to utilities, it has been widely deployed by mobile service providers offering data and voice communications for billions of subscribers worldwide.

However, using commercial LTE services from mobile service providers does not render utilities complete network control such as maintenance schedule, assured radio access during an emergency and the required performance or quality of service (QoS). A private LTE network using dedicated spectrum, which is similar to their TETRA- or P25-based land mobile radio network is preferred. Full control of their communications by utilities helps address regulatory compliance and security audits. Infrastructure operators in other mission-critical segments such as public safety and mining are already planning and deploying private LTE networks.⁷ In the utilities space, efforts are continuing to acquire the necessary spectrum. In Europe, the European Utilities Telecom Council (EUTC)⁸ is actively engaging ETSI and the ITU to seek a dedicated spectrum.⁹ In the US, there is a new option for utilities to build and own their own private LTE network with the AT&T and Nokia private LTE network solution. This offers utilities the opportunity to lease the 2.3 GHz WCS block C and D private spectrum from AT&T, and to build a private LTE network,¹⁰ free from unwanted interference often found in unlicensed wireless networks. It also offers superior throughput and lower latency when compared with the older generation of cellular technology such as 3G HSPA and HSPA+ (see Table 2).

⁵ For more detailed LTE information, please visit [Nokia Networks/LTE](#)

⁶ Visit the [3GPP web site](#) for more information on 3GPP.

⁷ In public safety, [FirstNet](#) in the US and the [Ministry of Interior in Qatar](#) are two examples of early pioneers.

⁸ [EUTC](#)

⁹ Central and Eastern European countries including Austria and Hungary have allocated 450 MHz for utilities.

¹⁰ [AT&T and Nokia Introduce a New 4G LTE Wireless Network Solution for Utilities](#)

Table 2. A comparison of target LTE performance using 2.3 GHz spectrum with similar cellular technologies

Category		4G LTE 6 MHz, MIMO	3G HSPA 5 MHz	3G HSPA+ 5 MHz, MIMO
Downlink (DL) throughput (Mb/s)	Peak*	~23	~14.4	~21
	Average	4.5-9.1	1-4	3-6
Uplink (UL) throughput (Mb/s)	Peak*	~12	~5.7	~11
	Average	2-5	0.5-2	2-4
Latency** (one-way)	Average	10-40 ms	70-100 ms	70-100 ms

* * Theoretical peak rates

** Dependent on antenna type, transport network, application server proximity

Furthermore, the wide and global LTE ecosystem offers economies of scale. As a result, it is the ideal choice for a FAN.

2. Versatile, resilient and secure converged communications services network

Since field devices typically have a life span of 10 to 20 years, grid applications in a FAN have a wide range of communications service requirements, ranging from TDM circuit emulation to Ethernet bridging to IP routing; and require a broad range of communication interfaces such as legacy serial RS-232/V.24, packet-based Ethernet interface and Wi-Fi. Since a converged FAN supports multiple applications with different delay and jitter requirements, network QoS capability is pivotal to ensure the required performance, particularly for protective applications.

The converged FAN also needs to flexibly provide connectivity. Centralized applications such as SCADA and DMS require connectivity between the device and the operations center, while newer distribution automation applications are likely to adopt a decentralized approach, also known as distributed computing. For example, a local control computer needs to acquire line data from voltage/current sensors and operate grid devices such as switches accordingly. Therefore the FAN needs to provide local connectivity between the computer, sensors and switches to facilitate short response time.

Since these applications are crucial to the operation of the grid, data transport needs to be robust and secure. The end-to-end communications path needs to be resilient to provide reliable connectivity. With electric grids becoming high-profile targets for cyber attacks, it is also imperative to deploy necessary security features such as encryption to safeguard the network.

IP/MPLS, a field-proven networking technology, is well suited to support these service requirements. It has a full suite of MPLS services to support point-to-point (P2P) and multipoint TDM, Ethernet and IP virtual private networks (VPNs), to provide needed communications to connect remote field device (via the FAN), substation and operations center without constraints. Every MPLS service uses its own virtual forwarding instance, ensuring network resource segregation to form a dedicated VPN for each smart grid application and preventing applications from accidentally interfering with each other as a result of a device misconfiguration or malfunction. Its QoS capabilities deliver deterministic network performance that can reliably transport differential protection relay signal traffic. Inherent strong recovery mechanisms provide SONET/SDH-like resiliency. Bolstered by new innovations such as Network Group Encryption (NGE)¹¹, it also protects in-flight traffic over different transport media, wireless or wireline with no performance degradation.

¹¹ To read more about NGE, read the Nokia paper, "Network group encryption: Seamless MPLS encryption for missioncritical networks"

3. Scalable network

Modernizing the distribution grids will require a massive number, potentially millions or more, of field devices to be deployed over a large geographic area. Consequently, the FAN footprint needs to scale in coverage and in the number of managed services. Dynamic IP/MPLS networking, with automatic route distribution and local router intelligence, is ideal for an expansive network. The usage of BGP as the MPLS service signaling plane further boosts the scalability of both the FAN and services.¹² The network management system also has to scale to effectively support the provisioning and day-to-day operations of the FAN and BGP/MPLS services.

4. Seamless end-to-end grid communications

In addition to the FAN, communications network modernization is also revamping networks that support transmission and distribution grids. To reach everywhere in the grid, utilities need to resourcefully utilize communications assets and connectivity methods. Consequently, adopting a networking technology that can operate atop different types of network access media, ranging from optical fiber to microwave to leased lines to LTE, is pivotal so that common service provisioning and operational procedures can be used everywhere. Whether it is an automatic recloser on a pole, a phasor measurement unit (PMU) in a distribution substation or a protection relay in a transmission substation, through different access media, an MPLS service can provide consistent, seamless connectivity to attain the utmost network operations synergy.

5. Flexibility for future growth and innovations

Utilities are on the cusp of a significant transformation. Use of energy technologies including DER, storage, microgrid and electric vehicles is just the starting point. As these become pervasive and more of the new innovations on the horizon are deployed, it is certain that utilities will continue to evolve the FAN to adapt to new networking technologies. Advanced IP network technology such as IPv6 and multicast could become instrumental to scale applications and optimize data distribution. Software-defined networking (SDN) might be added in the future to render new FAN capabilities such as self-optimization and service chaining.

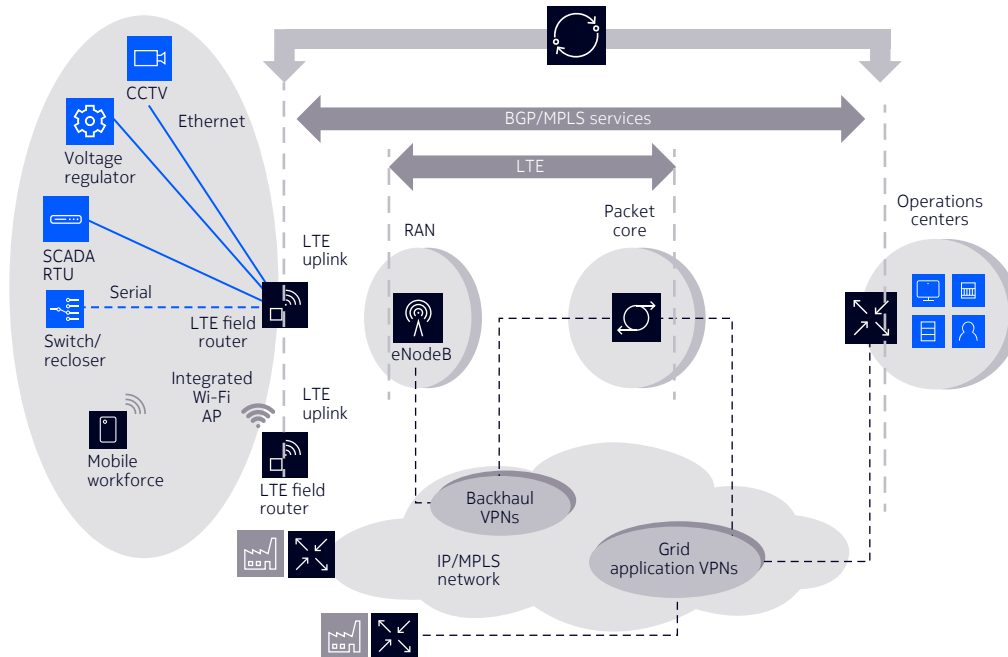
¹² BGP/MPLS service is a MPLS-based service using BGP as the control plane to scale up in a FAN. Typical examples are:

- [RFC 4761, VPLS using BGP for Auto-Discovery and Signaling](#)
- [RFC 6624, Layer 2 Virtual Private Networks using BGP for Auto-Discovery and Signaling](#)
- [RFC 4364, BGP/MPLS IP Virtual Private Networks \(VPNs\)](#)

The converged FAN architecture

The converged FAN architecture in Figure 1 contains all essential characteristics just discussed. Based on global networking standards, the FAN architecture offers a common network for all grid communications, providing necessary connections among all field devices, control systems and application servers. It enables open but secure interconnection to other IP networks if necessary.

Figure 1. The converged FAN architecture

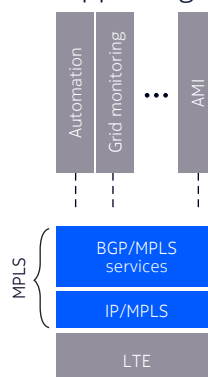


Two technology pillars

The converged architecture is grounded in two strong pillars of global standards-based networking technology (see Figure 2):

- IP/MPLS with BGP service control plane
- Private LTE

Figure 2. Converged FAN's two technology pillars supporting all grid applications



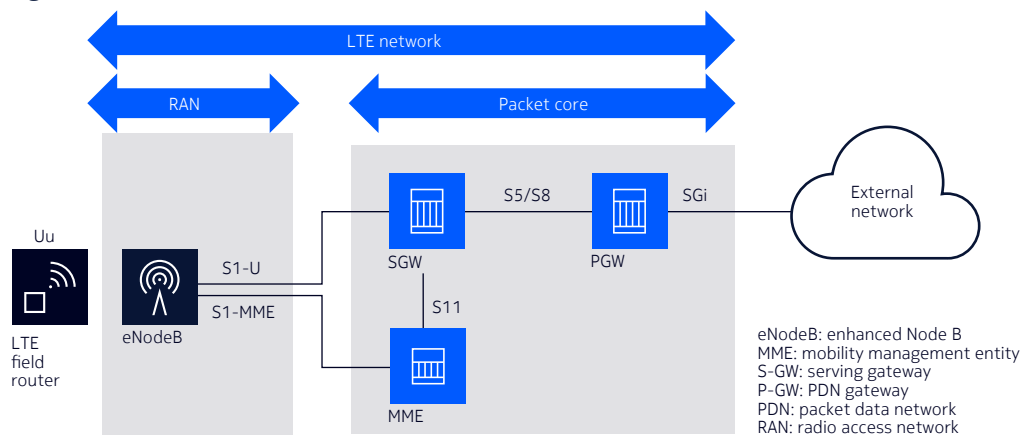
The end-to-end network and services layer in this FAN architecture is based on a dynamic IP/MPLS network overlaid with BGP/MPLS services in which highly scalable BGP is used as the service control plane. This provides highly scalable end-to-end managed services and reliable data transport with QoS and security. Each application is bound to a custom BGP/MPLS service that flexibly connects field devices in the FAN, and as required with servers in the operations centers and IEDs in substations.

LTE plays a pivotal role to render broadband connectivity for BGP/MPLS services in the FAN. As an LTE system is based on IP, its backhaul fits seamlessly into an IP/MPLS network, attaining full network synergy. An LTE system consists of two major parts (see Figure 3):

- Radio access network (RAN): The RAN comprises LTE base stations called enhanced Node Bs (eNodeBs) along with attached user equipment (UE), typically an LTE modem, or an LTE field router in this architecture. A RAN handles radio communications between the UEs and the LTE packet core.
- Packet core: The packet core consists of the following elements: serving gateway (S-GW), packet data network gateway (P-GW), and mobility management entity (MME). It is responsible for the control and connection establishment of the UE throughout the LTE network. The SGi interface is a standard IP interface that connects to external IP networks.

It extends the MPLS network and service coverage economically to the edge of the FAN.

Figure 3. LTE network architecture



Three architectural components

The converged FAN comprises three architectural components:

- Radio access network (RAN)
- Packet core
- IP/MPLS mission-critical network

A. LTE RAN

The RAN is the front end of an LTE network, facing the UE. It extends the BGP/MPLS services toward the LTE field router to provide field devices with reliable connectivity to application servers, control systems and other field devices. Key RAN attributes include:

1. Ubiquitous and cost-effective LTE access

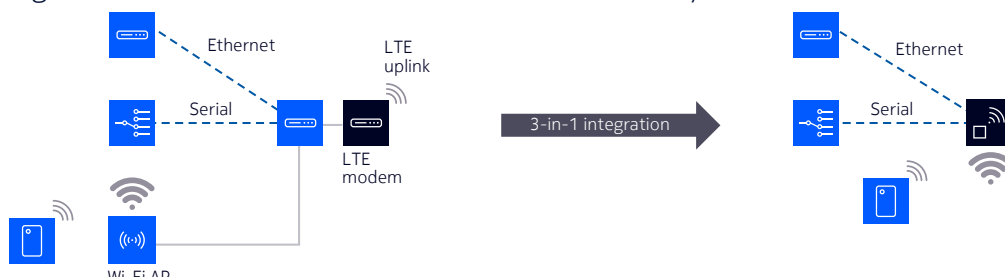
To support distributed grid intelligence on a large scale, ubiquitous connectivity between any two locations in the FAN as well as to the operations center is essential. Economically achieving such connectivity with a wireline technology is a daunting challenge. Wireless technology is ideal as it can provide the connectivity without the presence of a cable. Among the wireless technologies, LTE enjoys significant economies of scale resulting from a broad ecosystem, and is the broadband wireless technology of choice to expansively extend communications beyond substations into the FAN.

In this converged FAN architecture, BGP/MPLS services are extended over the FAN via the LTE radio interface (Uu interface) in the RAN to the LTE modem. Services can provide connectivity between two local field devices in the same FAN subnetwork, or with a device in another subnetwork, a substation or operations center. Field devices connect to the services via a serial or Ethernet interface to an IP/MPLS service router, or a Wi-Fi access point (AP) connected to the router. The service forwards traffic to another local interface on the IP/MPLS router or to the LTE modem using the Uu interface.

A typical configuration calls for three separate devices: an LTE modem, IP/MPLS service router, and Wi-Fi AP. This could prove to be unwieldy as three separate devices incur higher equipment costs, more space, power and installation effort, as well as greater management complexities, impeding ubiquitous deployment.

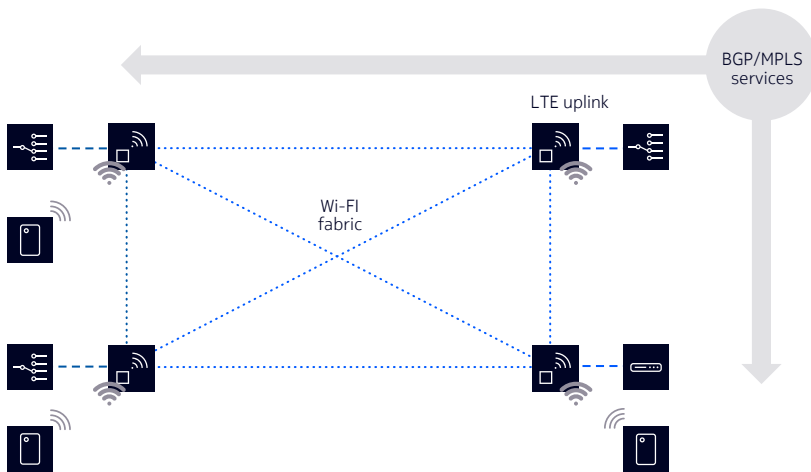
An innovative product concept, amalgamating an LTE modem, a Wi-Fi AP and a full-fledged IP/MPLS service router in the form of an LTE field router is the cornerstone of this converged FAN (see Figure 4). This 3-in-1 integration reduces installation and management complexities, resulting in speedier rollout and enhanced life-cycle efficiency. Powered by BGP/MPLS services, it collects FAN traffic from connected field devices, and forwards it to another local interface or radio uplink (Uu interface).

Figure 4. A 3-in-1 LTE field router enhances efficiency



The integrated Wi-Fi capability can be used to build a Wi-Fi fabric, acting as a collector network, to further extend the services (see Figure 5). This provides additional capability to extend the FAN reach. Standards-based Wi-Fi encryption is utilized for over-the-air security while NGE over Wi-Fi provides the end-to-end network security expected.

Figure 5. A Wi-Fi fabric serving as a collector network with an LTE uplink

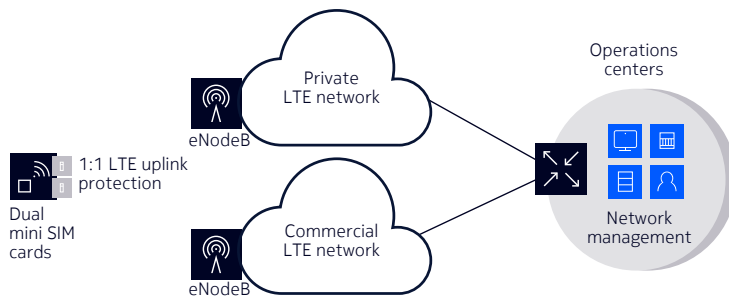


2. Highly available LTE uplink

The LTE field router can also utilize a commercial LTE network service for 1:1 uplink protection to provide a high availability option for critical sites. Upon detection of a loss of connectivity to the private LTE network, the router can restore connectivity to remote endpoints by using a subscribed commercial LTE network service (see Figure 6). Consistent management of this mobility session such as subscriber authentication can be maintained through an agreement with the commercial LTE service provider for the utility's private LTE network core to control these functions. The subscribed commercial LTE network service might be used initially to provide the required connectivity prior to the deployment of the private LTE network. Once the private network connectivity is restored, the LTE field router will automatically utilize it as the primary path without the need to dispatch a technician.

The LTE field router and the private LTE network can also offers utilities a new back-up path option for critical sites.

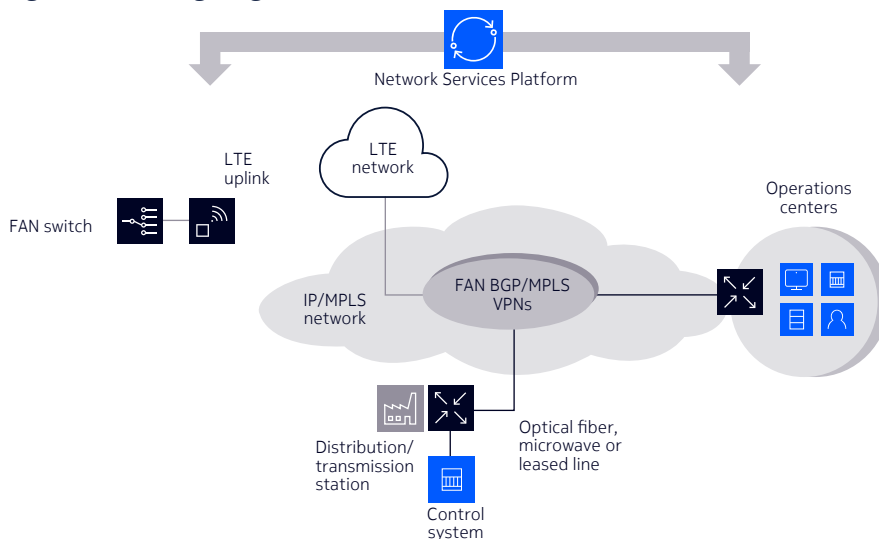
Figure 6. A resilient FAN with redundant LTE uplink



3. Scalable, seamless grid-wide VPN connectivity

BGP/MPLS services not only accommodate different types of VPN communications ranging from P2P serial to multipoint Ethernet and IP, it can also offer flexible grid-wide connectivity to smart grid applications and their field devices deployed in the FAN, IEDs in substations and servers in the operations centers, using the same network management system (see Figure 7). These VPNs can utilize LTE access in the FAN, optical and microwave transport and/or leased lines to reach field devices, substations and the operations centers, to provide grid applications with anywhere communications as needed. To support a large number of routers (from thousands to tens of thousands) over an expansive FAN, a robust and scalable control plane is needed. BGP, an Internet-scale protocol with advanced mechanisms such as route reflection,¹³ has the elasticity to support the number of routers and VPNs required.

Figure 7. Managed grid-wide BGP/MPLS VPNs



4. QoS

There is a diverse set of applications in the FAN. Real-time applications such as protection are highly critical and require strict QoS. Metering applications have less restrictive QoS requirements. In a converged FAN, it is necessary to consistently deliver each application's QoS requirement to ensure its required performance level is realized. The LTE field router combines the use of differentiated services (DiffServ), MPLS traffic class and LTE QoS to attain the required end-to-end QoS between the FAN and the operations center .

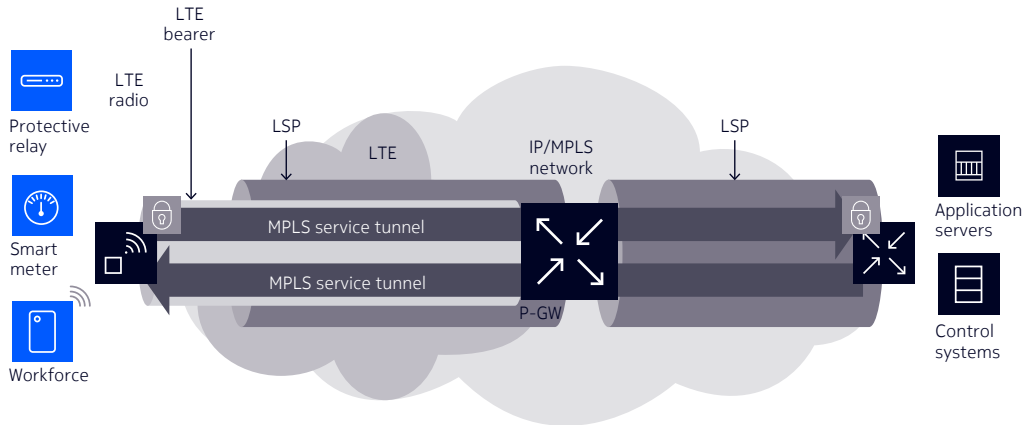
5. Universal end-to-end encryption

Network encryption technology protects confidentiality, integrity and authenticity of data while traversing a network (see Figure 8). It is important to note the data can traverse two network domains: 1) the LTE domain comprised of the RAN and packet core and 2) the IP/MPLS network situated between the LTE network egress edge (P-GW) and application servers. Employing disparate encryption schemes in the two domains will result in cumbersome management and operation complexities. NGE, an end-to-end encryption scheme, is ideal for safeguarding the data from the LTE field router radio interface to the egress IP/MPLS router connecting to the applications servers. This encrypted traffic transparently passes through the P-GW over the MPLS service tunnels. It operates seamlessly at the MPLS layer transparent

¹³ RFC 4456, BGP Route Reflection

to data types. It also fully interoperates with the standard 3GPP security architecture.¹⁴ Furthermore, this protection is consistently extended to the LTE field router connected at the edge of the network using a private LTE network FAN link and commercial service provider LTE service.

Figure 8. NGE provides seamless end-to-end security



6. High management scalability and provisioning speed

While IP/MPLS technology and the BGP control plane are designed to scale a network, its management, including VPN service provisioning, service performance, alarm management and OAM operation, also need to scale. Template-based infrastructure and network service provisioning, highly scalable real-time and historical statistics collection and network-wide OAM test scheduling are just a few examples of advanced management capabilities to help operators effectively manage a large-scale network.¹⁵ Capabilities such as automated service instantiation and network optimization through an SDN-capable service platform¹⁶ can be added to this solution to enable utilities to efficiently manage a large-scale FAN.

B. Packet Core¹⁷

The Packet Core provides the necessary secure access and connectivity management for delivering services that traverse the LTE network from the FAN to the operations center. With the inexorable growth of FANs fueled by distribution automation and renewable/microgrid integration, the Packet Core will be required to support a massive number of devices such as the LTE field router.

To meet these demands, it is necessary for the Packet Core to have the flexibility to address a number of key dimensions around architecture, growth projections, planning and economics.

Harnessing the flexibility of the cloud, a cloud-native Packet Core provides unique versatility to meet these requirements. It can be deployed on different platforms suiting each deployment's unique environment:

¹⁴ 3GPP TS 33.401 System Architecture Evolution (SAE) Security Architecture

¹⁵ To learn about these management capabilities and more, please read the Nokia paper, "Nokia 5620 Service Aware Manager portfolio for power utilities: Going far beyond traditional network management"

¹⁶ To learn more about the Nokia SDN-enabled Network Services Platform, please visit the [Nokia Network Services Platform web site](#)

¹⁷ To learn more, please visit the [Nokia Cloud Packet Core solution page](#)

1. Cloud NFVI-based platform

Network functions virtualization infrastructure (NFVI) is a collection of infrastructure components such as servers and operating systems in a data center, on which a cloud-based virtualized packet core system is hosted. With the packet core system hosted on an NFVI, it can scale immensely and dynamically by allocating necessary compute resources to accommodate tens of millions or more users. This deployment model is currently used by commercial mobile operators.

2. Pre-integrated platform

For some deployments and applications that do not require a whole NFVI solution platform, an attractive cloud-based alternative is a pre-integrated solution on a server. This is ready for deployment in either an operations center or a local data center near the FAN. The solution is equipped with resiliency options that address the specific needs of the range of applications and services being deployed.

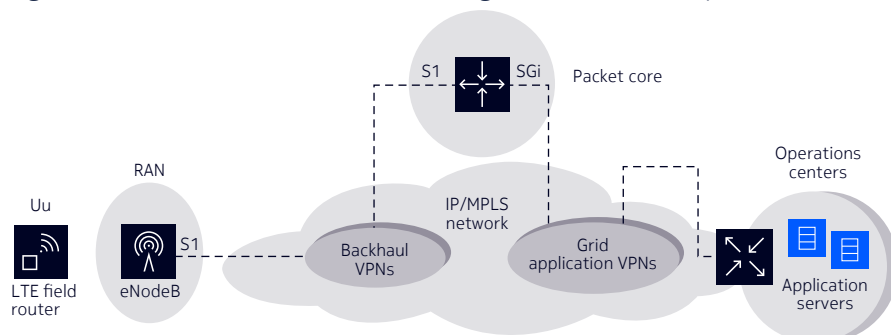
3. Custom hardware-based platform

This is the traditional physical network function implementation of the Packet Core solution functional elements. It is based on purpose-designed telecommunications systems with dedicated hardware, often with more limited resiliency options, but matches the service, application and commercial deployment requirements.

C. Mission-critical IP/MPLS network¹⁸

The mission-critical IP/MPLS network (see Figure 9) provides the essential backhaul VPN connectivity between the RAN and the Packet Core. In addition, it also supports the necessary VPNs to serve all grid applications. As shown in Figure 1 earlier, this IP/MPLS network can also be the same operation network that connects substations and operations centers today.

Figure 9. IP/MPLS network connecting all network components



Due to its critical role, the IP/MPLS network needs to exhibit the following crucial attributes:

1. High resiliency

As grids become more automated, uninterrupted communications are ever more crucial. Any network failure could affect reachability to a plethora of field devices and cause grid performance degradation, potentially leading to service outage. Therefore the network should be architected to have no single point of failure. Protection mechanisms including hot control card protection, non-stop routing and signaling, label-switched path dynamic restoration, and pseudowire redundancy capabilities play a seminal role in maximizing network availability, even in multi-fault failure scenarios.

¹⁸ For a more detailed discussion on mission-critical-grade IP/MPLS networks, read the Nokia paper [“MPLS for mission-critical networks: Converging robust, reliable services for critical applications”](#)

2. Rigorous security

Critical infrastructures such as electric grids are becoming high-value targets for cyber attacks. Consequently, it is imperative to secure the IP/MPLS network with an in-depth and multi-layer defense framework, through security capabilities including seamless MPLS encryption with NGE and QoS-enabled firewall.¹⁹ The IP/MPLS router should also have a rich set of nodal security features to thwart cyber attacks in the control and data planes.²⁰

3. Deterministic network performance

To attain high grid availability and efficiency, it is necessary for applications to continually monitor the grid assets in real time, process alarms and respond to faults in real time without exception. As a result, it is important to ensure the network can consistently deliver the appropriate level of performance. An IP/MPLS router has the advanced QoS capabilities, such as hierarchical traffic shaping and per-service QoS policy, to engineer flexibly and precisely the performance level for each application.

4. Deployment versatility

Since a utility's service territory typically encompasses urban, suburban and rural areas across inclement terrain, the flexibility to use available transport network assets is necessary. IP/MPLS operates consistently with a mix of optical transport, microwave hops and copper access, over the full range of narrowband (n x 64 kb/s) to broadband (10/100/400 Gb/s) speed, and seamlessly atop all network topologies including linear, tree, ring and multi-ring. This flexibility affords utilities the capability to reliably and economically build the IP/MPLS network to connect eNodeBs, the Packet Core, substations and operations centers.

5. Precise synchronization distribution

Precise synchronization is critical to the LTE RAN. While an on-site GPS receiver is usually available, there is growing concern about the vulnerability of GPS to accidental or intentional interference. Therefore, much consideration is being given to the use of network-wide synchronization distribution as a backup to local GPS reception.

Converged FAN solution offered today

AT&T and Nokia have introduced a private LTE network solution for US utilities, catering to the need for a next-generation FAN. This innovative solution combines Nokia LTE network and IP/MPLS technology with the lease of AT&T 2.3 GHz spectrum. Its end-to-end security approach, coupled with the ability to utilize AT&T's commercial wireless network, where and when a utility's own private network is inaccessible with consistent mobility subscriber capabilities managed by the utility's LTE core, will deliver exceptional service continuity for today's critical grid applications along with true broadband capacity as the future distribution grid evolves. This solution provides a new option for US utilities to build and own private, highly secure, reliable and high-capacity LTE networks, and extend BGP/MPLS services to reach devices deep in the distribution network.

¹⁹ For a detailed discussion on mission-critical network security, please read the Nokia paper "[Impregnable network defense for critical infrastructures: Protection with a defense-in-depth approach](#)"

²⁰ For a detailed discussion of securing mission-critical networks with 7705 SAR, please read the Nokia paper "[Nokia 7705 Service Aggregation Router SAR: Security overview for power utilities](#)"

Conclusion

As utilities facing an array of new market forces, green environmental regulations and disruptive energy technologies, there is a pressing need to modernize their grids. A private converged FAN will be the communications foundation for their modernization efforts. Extending broadband data connectivity reliably everywhere with a combined LTE and IP/MPLS network solution using licensed spectrum provides the required communications for distribution systems monitoring, control and automation. As utilities continue the modernization journey with their IoT deployment, this converged, private FAN will remain pivotal to operating a responsive and green grid.

Abbreviations

3GPP	3rd Generation Partnership Project
AP	access point
BGP	Border Gateway Protocol version 4
CDMA	Code Division Multiple Access
DER	distributed energy resources
DiffServ	Differentiated Services
DMS	distribution management system
eNodeB	enhanced Node B
ETSI	European Telecommunications Standards Institute
EUTC	European Utilities Telecom Council
FAN	field area network
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
HSPA	High Speed Packet Access
HSPA+	Evolved High Speed Packet Access
IED	intelligent electronic device
IoT	Internet of Things
ITU	International Telecommunication Union
LTC	line tap changer
LOS	line of sight
LTE	Long Term Evolution
MIMO	Multiple-input and multiple-output
MME	mobility management entity
MPLS	Multiprotocol Label Switching

NFVI	network functions virtualization infrastructure
NGE	Network Group Encryption
NLOS	non-line of sight
OAM	operations, administration and maintenance
OFDMA	orthogonal frequency-division multiple access
OPGW	optical ground wire
P2MP	point-to-multipoint
PDN	packet data network
P-GW	PDN gateway
PLC	power line carrier
QoS	quality of service
RAN	radio access network
SCADA	Supervisory Control and Data Acquisition
SDH	Synchronous Digital Hierarchy
SDN	software-defined networking
S-GW	serving gateway
SONET	Synchronous Optical Network
TDM	Time Division Multiplexing
UE	user equipment
VAR	volt-ampere reactive
VPN	virtual private network
VVO	volt VAR optimization
WCS	wireless communications service

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Nokia Oyj
Karakaari 7
02610 Espoo
Finland
Tel. +358 (0) 10 44 88 000

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