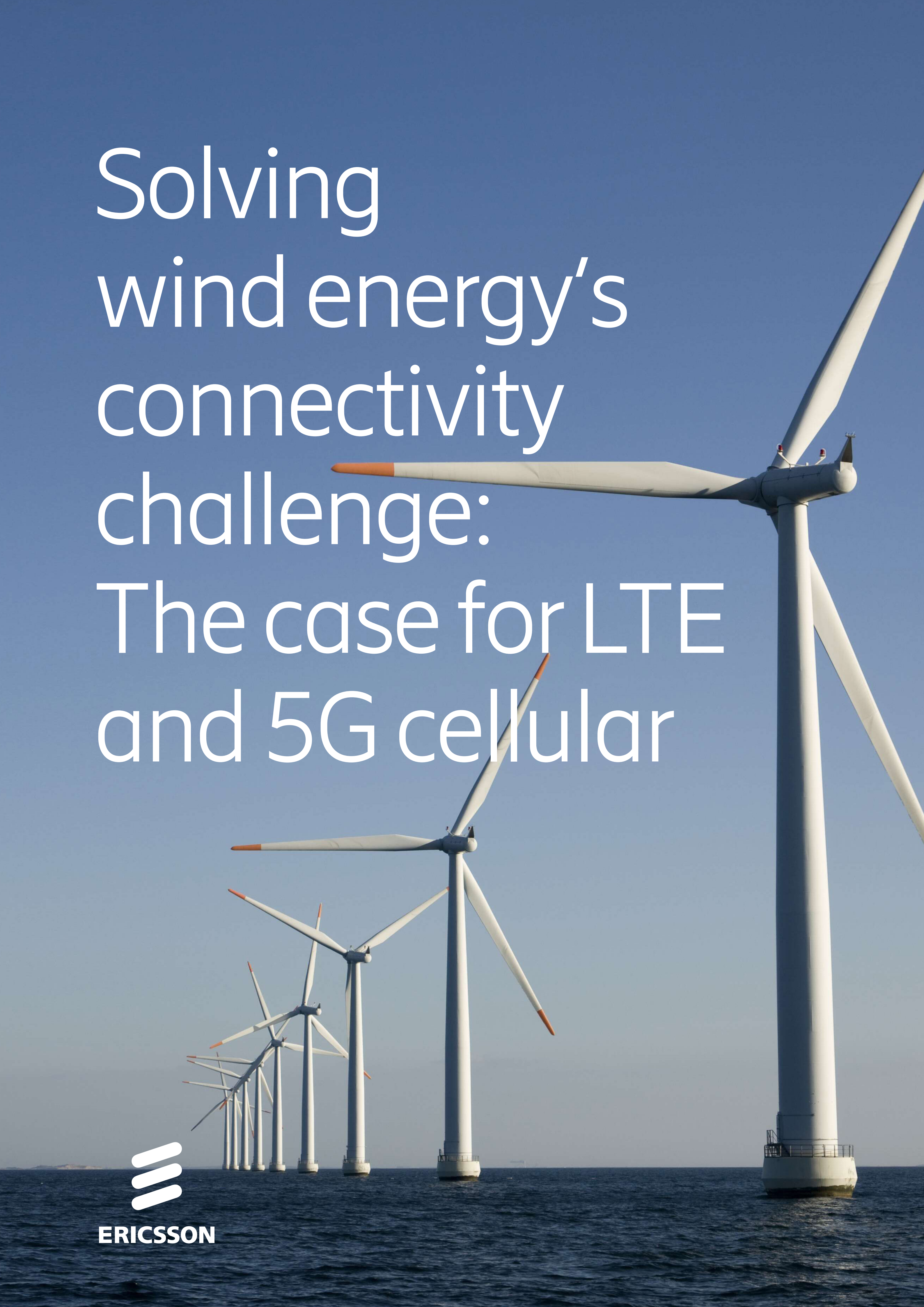
Solving wind energy's connectivity challenge: The case for LTE and 5G cellular



ERICSSON

Wind energy is on the upswing. The Global Wind Energy Council predicts that the global wind energy market will grow at a rate of 8.5 percent annually, eventually making up nearly 70 percent of all renewable power production. To capitalize on the potential of wind energy, we must solve multiple challenges, from scaling the distance to the remote locations of wind farms to efficiently and safely operating, monitoring, maintaining and servicing the turbines. Connectivity is critical for a wide range of purposes, including monitoring and control, communications between on- and offsite workers and the day-to-day welfare of employees at the sites. LTE/5G cellular networks provide the necessary coverage, reliability and reach along with the low latency, throughput and scale required for current and future wind farm use cases.

Table of contents

Introduction

According to the International Energy Agency (IEA), energy decarbonization is being driven by renewable energy generation, accounting for almost 90 percent of power producers' portfolios by 2050.[1] Wind energy will be an important factor in this transition, with offshore wind making up the majority of new wind power capacity awarded.

The sustained growth that is forecasted and desired for wind energy will require a strong communications network. Robust cellular-based, 3GPP standards-driven, wireless connectivity will be a key factor for keeping these complex, costly projects on schedule, on budget, safe and productive—while also achieving long-term Levelized Cost of Energy (LCOE) that is competitive with non-renewables.

At a height of 13 to 16 stories and a wingspan as wide as a football field, a wind turbine can be quite magnificent.

[1] https://www.iea.org/reports/net-zero-by-2050

A growing opportunity, with considerable challenges

Today, wind energy represents about 9 percent of the electricity mix in the US[2] and approximately 7 percent of the electricity mix around the world.[3] That may not sound large, but it's significant: The U.S. Energy Information Administration (EIA) tweeted that wind generation, at 2,000GWh in a 24-hour period, was the second-largest producer of electricity for the US after natural gas.[4] The Global Wind Energy Council predicted that from 2020 to 2024, the global wind energy market is expected to grow at rate of 8.5 percent annually, with China and US leading those installations.[5] In the US, at least 20 wind farms are planned across the Atlantic seaboard.[6]

Wind and solar power both hit milestones globally in recent months: The two combined contributed 10 percent of global electricity for the first time in 2021. This figure rises to 38 percent when taking all clean energy sources into account.[7] Wind energy continues to be a key piece to the global answer to climate change. Wind farms and their construction, ongoing maintenance and operational needs are ever more important to the energy industry and to the global targets set forth by various governments for sustainability and net zero.

To capitalize on the potential of wind energy, we must solve multiple challenges. Wind farms are typically located in remote, underserved rural areas within the country, or tens of miles offshore where access to wireline telecommunications is generally unavailable or prohibitively expensive to deploy. Reliable communications are critical not only during the construction phase, but also for ongoing monitoring and control, safety, servicing, training and maintenance as well as the day-to-day welfare of workers at the sites. The communication network, in fact, is the underpinning to the entire system, enabling multiple use cases beyond traditional operations. Operations teams could gather information from nearby sensors that are measuring wind, humidity and emerging weather patterns and act to prevent costly and dangerous damage to the equipment or injury to workers. Safety teams could monitor their workers remotely for risk of heat or cold exposure, high heart rate and exact location, among other attributes.

A capable and robust wireless system that can scale the required distances with resilience and performance would be part of a wind farm's end-to-end communication system for multiple applications such as voice, video and data.

[2] https://cleanpower.org/facts/wind-power/
[3] https://wwindea.org/worldwide-wind-capacity-reaches-744-gigawatts/
[4] https://www.yahoo.com/news/in-a-first-wind-power-is-second-leading-us-source-of-electricity-in-one-day-220541187.html
[5] https://www.energylivenews.com/2020/11/09/wind-energy-industry-set-for-continued-growth-in-the-next-five-years-despite-covid-19/
[6] https://www.energy.gov/sites/default/files/2021-08/Offshore%20Wind%20Market%20Report%202021%20Edition_Final.pdf
[7] https://www.yahoo.com/finance/news/tech-accelerating-wind-energy-revolution-190000783.html

3GPP-based cellular networks answer wind energy's needs

In this paper, we examine how cellular-based, 3GPP standards-driven communication networks offer a singular solution for the wind farm industry. 3GPP is the accepted standard that billions of people around the world rely on for personal, business and critical industry communications. While other technologies, such as Tetra for two-way voice communication and Long Range Radio Wide-Area Network (LoRaWAN) for Internet of Things (IoT) sensors have a place in industrial enterprises, cellular communication is uniquely qualified to be the foundational wireless connectivity for the wind industry.

In addition to providing both coverage and reach, cellular provides strong built-in security measures, generation of high throughput, low latency and adaptability to existing technologies including LoRaWAN and Wi-Fi. More importantly, cellular-based technology benefits from a well-developed ecosystem built around a single standard. The wind industry shares many of the same applications —drones, IoT sensor connectivity, connected workers and cameras—already in use by peer industries such as manufacturing, oil and gas and logistics.

We will explore multiple facets of the role cellular-based communication can play in the wind energy industry.

First, we look at the performance characteristics of cellular communications technologies, specifically around security, throughput, latencies and existing connectivity adaptability. In addition to spelling out those characteristics, we'll compare and contrast it with existing technologies in use, including LoRaWAN (LoRa) and Wi-Fi, to provide perspective (see Figure 1).

Next, we further examine the benefits of a single standard and the enablement that it affords to the industry. An established standard would allow the industry to focus on the "stuff it does best," the production of clean energy.

Lastly, we define the many challenges that face wind farms, both onshore and offshore. We discuss how various cellular-based use cases can specifically help solve those challenges.

5G/LTE characteristics and how they apply to wind farms

Marketing and advertisements constantly remind us that 5G is all around us. One may ask, what is 5G exactly? To your teenage son or daughter, the concept of 5G might be watching the latest YouTube video or uploading the latest Tik-Tok video for their friends. To them, 5G is all about throughput speeds and ensuring that a video won't buffer as they are enjoying or creating it. The focus, for these consumers, is the downlink and uplink attributes, where 5G technologies can significantly outperform current LTE commercial capabilities.

Increased connectivity and smart automation are enabling manufacturing, logistics and other industries to evolve into a new era we're calling Industry 4.0.[8] For Industry 4.0, 4G/LTE and 5G provide crucial advantages beyond faster throughput. Industrial use cases such as wind farms have more varied use cases and more stringent requirements than consumer applications:

- a high level of security
- Quality of Service (QoS)
- reliability
- latency
- coverage and reach
- the ability to scale

Dedicated to digital transformation: Industry 4.0 will be built on dedicated private networks
Private networks are powering innovation across all industries, allowing businesses to unlock exponential growth. 5G was designed specifically with the IoT in mind. Only high-performance private networks can provide the robust, reliable connectivity required to suit any need and use case, both today and tomorrow. Mining, manufacturing, ports, airports, power utilities and offshore and processing industries are just some of the industries innovating new capabilities with dedicated private networks.

5G and 4G/LTE are both based on the Third Generation Partnership Program (3GPP), which is the global cellular-based standard. Though 4G/LTE and 5G are technically different, they are cut from the same cloth. The standards have been written to allow graceful coexistence and upgrade capabilities for those using cellular-based products. Some network equipment vendors, including Ericsson, and most ecosystem device manufacturers make their products compatible to both. This is especially important for wind farm IT managers who need to consider future-proofing when planning for their infrastructure.

Seamless mobility

- Cellular has standardized mobility features reducing outage time close to zero ms in Rel-16.
- Cellular provides better mobility because of more sophisticated link adaptation within base station coverage area.

QoS support and performance

- Cellular networks have sophisticated traffic shaping and QoS capabilities where packet delay budgets, error rates and guaranteed bit rates can be configured.
- The mechanisms are designed to work at high load through admission control and preemption.

Predictable latency

- Cellular provides low and predictable latency and is robust to varying network loads.
- Cellular technologies provide adequate support for Industrial IoT, such as Time-Sensitive Networking (TSN).

Security/Trustworthy

- Cellular products undergo extensive testing for most standardized functionality, including performance.
- Cellular provides a full security stack, encryption and access control per device.

Spectrum and efficiency

- Cellular technologies use licensed spectrum.
- Cellular technology has higher spectral efficiency yielding high capacity.

Figure 1: Benefits of cellular and its characteristics

[8] https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution

Security

Let's start with some of the commonalities between LTE and 5G that make them ideal for the wind industry. First and foremost is security. Security is especially important because the wind industry, as an electricity provider, is part of the national infrastructure, requiring heightened security measures. LTE and 5G networks are designed with security embedded in the 3GPP standards that govern these technologies, including device and user. Encryption and security keys can only be deciphered through the physical presence of a SIM card on the user device. The physical possession of the SIM cards would reside with the IT staff of the farm.

Control protocols are separated from user data, and advanced firewalls protect the core against unauthorized access or denial of service. Private network deployments can also be completely independent of the public 4G/5G network offered by public cellular service providers, creating a closed system. LTE and 5G networks, through private network architectural deployments, are completely self-contained within the wind farm's IT network, protecting the wind farm's wireless network from exposure to attack through multiple paths or vulnerable access points.

Quality of Service and reliability

A second characteristic that stands out for LTE and 5G technologies is reliability and service guarantees. This includes the ability to enable end-to-end Quality of Service (QoS) assignments to different services and streams within the LTE/5G network. With deterministic scheduling and QoS controls within the framework of the 3GPP standard, LTE and 5G technologies can adjust for the relative importance of services representing various use cases to prioritize one over the other during periods of congestion.[9]

Figure 2 shows the scheduling mechanism differences between licensed cellular technology like LTE and 5G versus unlicensed technologies like Wi-Fi. Additionally, guaranteeing the reliability or robustness of a particular connection is also built into the standard, with various checkpoints observed to keep survivability of the data transmission. Both characteristics are especially important in critical communications services and applications like voice communications or Mission-Critical Push-To-Talk (MCPTT).

LTE and 5G communications can provide prioritized voice services in the form of Voice over LTE (VoLTE) and MCPTT communications in addition to high-speed data. VoLTE provides the dial-up voice capability we are all very familiar with, and MCPTT gives us the group chat, business-style communication that is predominantly used in many industries and historically referred to as "two-way radio" services.

The wind energy industry typically deploys separate two-way radio systems, such as TETRA and Land Mobile Radio (LMR) for its voice communication. Wind farm operators must ensure that voice communication takes precedent on the wireless network, which is shared by traffic such as video feed from cameras, IoT device communication and other application traffic. As a comparison from public wireless networks, consider the voice capability used in cell phones. It is designed as a prioritized service over the LTE network, more familiarly called VoLTE, and incorporates higher standards of both reliability and prioritization.[10] The VoLTE traffic takes precedent over the rest of traffic such as YouTube or internet surfing traffic.

Public safety departments, like police and fire, similarly prioritize voice over LTE and 5G public cellular networks. The traffic generated from these first responder departments takes precedent over the traffic of citizen mobile users.[11] Vendors like Ericsson have made it very simple for an IT department's wireless personnel to be able to select and configure these prioritized services within their private network solutions to meet business and safety needs for wind farm operations.

With LTE and 5G, these services can expand beyond the standard walkie-talkie voice, offering users the ability to switch from voice to video conferencing and other more dynamic applications because the network affords the ability to prioritize voice services across the network while leveraging additional bandwidth for adjacent services on PTT. A dedicated network for voice is unnecessary; rather, it is just one of many other applications that rides on the foundation of an LTE/5G network.

Peak throughput speeds

The third advantage of LTE and 5G standards is throughput. Top LTE speeds can get up to 2Gbps, as demonstrated by Ericsson in February 2018, in cooperation with Ericsson's customer provider Telstra, chipset maker Qualcomm and device maker Netgear.[12] In comparison, top 5G download speeds were demonstrated at close to 6Gbps, utilizing millimeter wave (mmW) spectrum.[13] Millimeter wave spectrum is spectrum that is above 6Ghz. For US frequencies, this typically corresponds to spectrum in the 24Ghz, 28Ghz and 39Ghz bands.

The 5G technology specification was built specifically to take advantage of this category of spectrum and the abundance of channels and channel spacing in this range. The 5G standard is expected to ultimately get to top upload speeds of 10Gbps and download speeds of 20Gbps with future advancements in the 5G 3GPP specification.[14] By cutting time to download, transport and upload data, these data rates can deliver significant time and cost savings to corporations and enterprises.

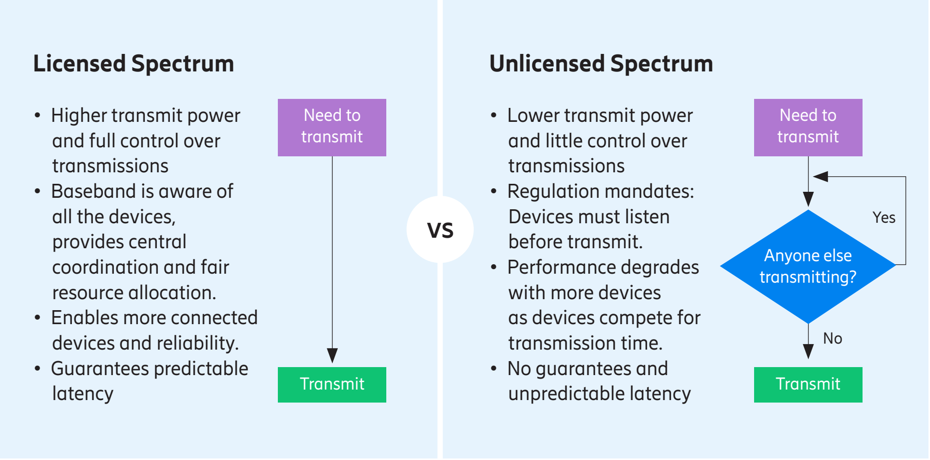


Figure 2: Scheduling: LTE and 5G cellular technology versus Wi-Fi

[9] 5G NR QoS (Quality of Service) | 5G QoS as per 3GPP NR Standard (rfwireless-world.com)
[10] https://www.ericsson.com/49d361/assets/local/reports-papers/white-papers/wp-voice-and-video-calling-over-lte.pdf
[11] https://www.firstnet.com/coverage/qpp.html
[12] https://www.ericsson.com/en/press-releases/2018/2/telstra-ericsson-qualcomm-and-netgear-achieve-2gbps-speeds-in-live-demo
[13] https://www.ericsson.com/en/press-releases/2/2022/5/vi-records-top-download-speed-of-5.92-gbps-during-the-ongoing-5g-trials-in-pune
[14] https://www.ericsson.com/en/reports-and-papers/white-papers/5g-wireless-access-an-overview

Some industrial applications could require these high rates of speed. For example, lacking wireless, wind farms often manually transfer large amounts of data on a USB stick or storage device from one point to another—an inefficient and expensive method.[15] In offshore environments, that data has to be transported via ships and ferry, requiring complicated logistics scheduling and expense. LTE and 5G's high throughput capability would enable real-time data transfer, at little extra cost.

Now, let's compare this to Wi-Fi. A Wi-Fi 5 system tops out at 3.5Gbps. Wi-Fi 6 is expected to get to a theoretical ~10Gbps[16], which would be similar to 5G peak speeds. Wi-Fi spectrum, however, is very much public and ubiquitous, with a significant risk of interference from other nearby Wi-Fi systems and users. With LTE and 5G, the devices on the private cellular network system within a wind farm, such as smart phones, IoT sensors, cameras, drones and gateways, don't necessarily share the 4G or 5G spectrum with nearby systems and their respective users. They don't face the possibilities of encroachment from other nearby networks.

A wind farm with cellular-based LTE and 5G private networks would most likely use licensed or lightly licensed spectrum, like Citizens Broadband Radio Service (CBRS), and therefore be better protected than it would be with Wi-Fi spectrum. For onshore deployments of private cellular networks on legacy and new wind farms, CBRS could be an excellent choice to achieve peak speeds of over 100Mbps in the downlink. Additionally, LTE already works on CBRS, with many private networks already deployed for a few years. Ericsson is in the midst of helping test 5G on CBRS with some of its customers and the technology will be available soon.[17]

Coverage and reach

Another significant characteristic of LTE/5G networks is its reach. Cellular-based networks are typically defined to transmit a considerable amount of power to reach the end device destination, expanding coverage to the wind farm using fewer towers than other high-speed technologies. Whereas Wi-Fi technology was designed as a Local Area Network (LAN) technology, with limited power output and therefore limited distance, typical findings show that a typical CBRS-based LTE node provides the same coverage area as four equivalent Wi-Fi Access Point (AP) nodes.[18]

We must consider not only the costs of the equipment like the Wi-Fi APs and LTE nodes themselves, but the cost of the services to deploy these nodes as well. This includes climbing towers and integrating each node, as well as the cost of the towers and poles themselves. Moreover, LTE networks may be faster to deploy, since fewer towers and radio transmit points are needed on the premises.

To reach equipment and nodes like turbines that are more than a few hundred feet away, wind operators have relied on point-to-point communication via microwave hops. These are individualized links, with dishes and electronics equipment on either end of the link to form the data transmission connection. Cellular can potentially eliminate the need to establish these links. Deploying a microwave point-to-point solution can cost tens of thousands of dollars. In contrast, a simple LTE or 5G device at the end point node locations can establish a similar type of data connection for no more than a few hundred dollars, incrementally.

Cellular reach technology can especially come in handy when a wind farm wants to establish new turbines for the farm or expand the farm farther into adjacent lands or waters (in the case of offshore). Some of this expansion could possibly be accommodated with existing LTE or 5G radio infrastructure already in place. Alternatively, the wind operator can add a single radio expansion, or a limited few, that can point towards the new expanded areas and instantly cover many turbines. Adding LTE or 5G-based radios to an existing network would be similar to adding Long Range Radio (LoRa), Wi-Fi or TETRA Access Points.

Latency

Lastly, many of the use cases on a wind farm require not only high speeds but also low latency. LTE can typically provide a realistic best latency of about 20ms. 5G is expected to provide latencies close to 2ms and even 1ms.[19] Wi-Fi, in ideal conditions, can provide latencies similar to 5G. More often than not, Wi-Fi can get saturated, and the resulting buffer usage can lead to much longer latency times. Here, again, the more deterministic nature of the standards written for LTE and 5G can help with latency thanks to more efficient scheduling of the resources of the air interface. In Figure 3, the illustration shows how latency can be affected with higher data tonnage loads.

Applications in wind farms that can benefit from lower latencies include machine control for things like protection relays, high voltage transformer monitoring, breakers and reclosers and load shedding, along with field services-enablement applications such as drone control and payload, security and surveillance cameras, MCPTT and connected worker streaming live feeds for remote expertise.

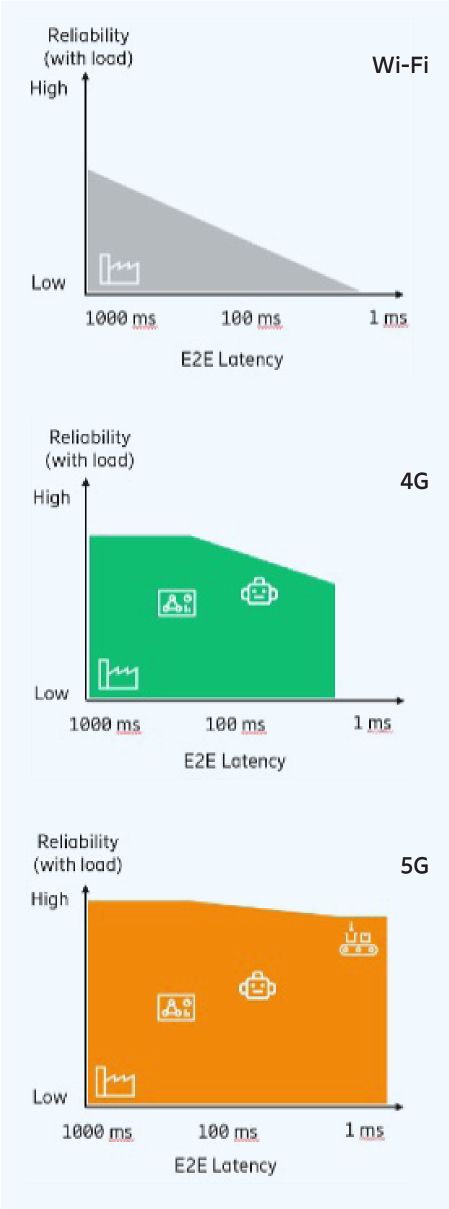


Figure 3: The move towards 5G and effects on network latency

[15] https://www.tp-link.com/us/blog/100/what-is-10gbe-and-what-can-you-do-with-it-/
[16] https://www.minim.com/blog/wifi-4-vs-wifi-5-vs-wifi-6
[17] https://www.verizon.com/about/news/verizon-5g-ultra-wideband-availability-cbrs-spectrum
[18] https://www.minim.com/blog/wifi-4-vs-wifi-5-vs-wifi-6
[19] https://www.thalesgroup.com/en/markets/digital-identity-and-security/mobile/inspired/5G#:~:text=5G%20technology%20offers%20an%20extremely,1%2F1000%20of%20a%20second

The value of a single underlying standard

These are some of the most common characteristics of LTE and 5G systems in contrast to more universally understood technologies such as LoRa and Wi-Fi. Today, most applications in wind industry may be perfectly suited for the characteristics that a typical LTE system can provide. As the industry communications ecosystem continues to push the limits of capabilities of devices and applications, 5G cellular connectivity will become more and more required in these farms. Let's take look at other reasons the industry should coalesce around a single cellular wireless standard.

Scale

A single standard, specifically one based on cellular, will allow the wind industry to take advantage of the large scale of the cellular IoT and enterprise-based ecosystem that serves many different industries. Most importantly, wind farm owners would be able to take advantage of a lower cost per unit on things like end devices, given the scale of the cellular ecosystem. This ecosystem includes chipset makers, device makers, module makers, application, software providers and 3GPP network equipment vendors like Ericsson.

Many of the components, software and products made by these different segments are reused across various industries like mining, manufacturing, oil and gas and logistics. The wind industry can reuse many of these devices, from gateways, IoT sensors and cameras to tablets and phones. Even better, this ecosystem includes not only industrial, but also ordinary consumer devices. According to Statista, in 2022 there are 15 billion cellphone-based devices expected to be deployed.[20] Many of the Industrial IoT and gateway devices share chipsets with consumer-based phones. The wind industry can take advantage of this scale, benefiting from the higher quality and lower costs.

Focusing resources

Uniting around a single standard will not only bring cost efficiencies by taking advantage of the mass scale of the ecosystem, it will also allow the wind industry and those who support it to focus on research and development of wind industry-specific applications and devices. For instance, having readily available off-the-shelf modules and chipsets could allow a new and upcoming start-up device maker to focus on orienting elements of its design and application to the requirements related to wind turbines.

If there were two or three or even four competing but similar standards options for connectivity, the start-up device maker would have to expend extra effort to research, evaluate and then implement for each of these different connectivity standards. Having one standard lets device makers spend less time on connectivity and more on core wind industry requirements, saving resources and costs and freeing firms to pursue other innovations. There are other advantages, too, such as higher quality and greater variety of products to choose from in the marketplace.

Let's learn from the past

We've seen the importance of having a single standard before. Take VHS versus BetaMax. When the industry chose VHS over BetaMax, video player companies like Panasonic and Sony were able to focus their business rather than splitting their efforts on competing standards. Another example, closer to the subject at hand, is LTE.

In the 1990s, a few wireless service providers in the US market and others following the US market deployed CDMA (Code Division Multiple Access) technology for 2G standard, while the rest of the world deployed GSM (Global System for Mobile Communication). Initially, it was difficult for phones to work on both standards. Even within the US, companies like AT&T Wireless and T-Mobile were using GSM, while Verizon and Sprint were using CDMA. Phones of the AT&T and T-Mobile subscriber base were not able to use Verizon and Sprint coverage areas and vice versa.

That all changed with LTE. In late 2000s, the world united on a single standard for 4G communications—LTE. As a result, life became much simpler for device makers and chip makers supporting phones on international carriers. A smaller amount of processing space was required on the chips that went into mobile devices. The lower cost of production and design helped lower the cost of the final device for the consumer.

[20] https://www.statista.com/statistics/245501/multiple-mobile-device-ownership-worldwide/

LTE/5G solves many wind industry challenges

While the wind farm industry is relatively new, wind farms have actually been around for over 40 years,[21] Those in the US are a bit newer, mostly built in the 1980s.[22] A lot of development and modernization have happened since the mid-1970s when the earliest wind farms were planned and developed. These modern windfarms are much more advanced and efficient today.

They also have many more requirements than their predecessors to ensure they are operationally as efficient as possible and that they are maximizing both the investment and the potential of the energy harvested during operation. Onshore and offshore environments differ, as well. Specific use cases and characteristics might be more relevant for one environment than for the other. In addition, requirements and characteristics change at different phases of a wind farm's life, from construction to continuing operations and maintenance to future deployments and growth, when newer, advanced technologies will play a larger role.

Enhancing operations and maintenance with LTE/5G connectivity

As we pointed out, wind farms are typically located in rural areas within a country or many tens of miles offshore, where access to cost-effective communication and wireless connectivity is a challenge.[23] Over the course of the life of a wind farm and its turbines, utility employees and vendors who comprise the turbine ecosystem will need to physically visit for service calls. They must be able to communicate with their teams and their supervisors, access documentation and consult with experts from the field as they service and troubleshoot a turbine. Wind farm operations staff must have connectivity to the wind turbines for maintenance, workflows and record keeping—ensuring communications can be even more challenging in the offshore environments.

Onshore, a worker can usually drive to a particular turbine and find at least limited coverage by a Mobile Network Provider (MNO). Offshore, however, there is no possibility of coverage from the major MNOs. Yet, connectivity is even more critical for workers and staff, who are deployed on offshore vessels for a month or more at a time. They sleep, live and eat during their non-working hours in these vessels. In addition to work-related communications, reasonable recreational connectivity becomes essential for employee health and morale.

Many offshore vessels have satellite communications, but satellite can sometimes be too expensive or have significant performance issues. Wind farm connectivity based on private LTE/5G network connectivity, with the non-tariffed nature of private architecture, provides the necessary dedicated high throughput employees need and expect.

Keeping the workforce happy and efficient

A typical LTE/5G private network deployment utilizing spectrum in both low-band and mid-band can provide average sector speeds of roughly 300Mbps downlink and 75Mbps uplink. Peak speeds could go up as high as 450Mbps/125Mbps uplink. Support vessels can easily augment their external connectivity from their satellite link communications to readily available LTE gateways that connect to their onboard IT infrastructure.

Onshore, wind farm operators could provide workers with Wi-Fi hotspot or USB-related devices that can convert from LTE (on their private network) for an always-on connection for work activities such as tablets for record keeping, collecting information or downloading documentation. The greater throughput could handle the wide range of workforce enabling technologies including phones, tablets and walkie-talkie style two-way radio systems used by the wind farm industry and many other Industry 4.0 applications.

[21] https://www.power-technology.com/analysis/oldest-operating-wind-turbine-tvindkraft/#:~:text=Wind%20turbines%20have%20an%20average,wind%20turbine%20in%20the%20world

[22] https://www.palmspringslife.com/palm-springs-is-home-to-oldest-wind-farm-in-u-s/

[23] https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy#:~:text=Although%20wind%20power%20plants%20have,flying%20into%20spinning%20turbine%20blades

Expanding the network's reach
In addition to providing broadband for workers, LTE and 5G networks in the middle mile of the IT network ensure the reach of a wind farm's network with a common connectivity platform. Sensors and monitoring points on a wind turbine have varying protocols, such as Bluetooth Low Energy (BLE) or Long Range Radio (LoRa), which can all be connected via LTE gateways. These protocols are designed to be "light," meaning that they help to save battery life, and offer some limited range.[24] Cellular-based networks, however, reach far greater distances on a per-node basis. They can play a key role as a middle mile network, or seen another way, as an underlying wide area wireless connectivity layer network. See Figure 4, which shows some of the differences between BLE, LoRa and LTE.

Instead of having to deploy a full LoRa or BLE network throughout the wind farm, now operators only need to deploy the LoRa network and its gateways at the end points. The wind farm operator can leverage the LTE network to cover the distance from the central portion of the network, where the servers are, to the individual turbines. This same principle can apply to Bluetooth/BLE-enabled devices, as well. Not limited to Bluetooth/BLE or LoRa, the LTE ecosystem offers many different conversion possibilities for end protocols. Wi-Fi-enabled gateways are very popular in LTE. Even extensions to the Ethernet system can be offered with physical Ethernet connector gateways, USB gateways and RS232 gateways. All of these can be put on the LTE network for the middle mile and brought back to the central IT facilities. In this role, cellular networks have the considerable flexibility of both reach and adaptability to other existing, wireless-enabled protocols that a typical wind farm may be using.

Voice, video and other media communication
Voice communication—the simple act of being able to talk to the larger team—is the life blood of any business. LTE and 5G communications have a few different options for offering voice and Push-To-Talk (PTT) communications. For basic voice communications, there is the VoLTE standard used by the public networks today. This service natively prioritizes the voice path through the entire LTE end-to-end network, over all the other types of communication.

PTT communication is the group chat, business-style communication predominantly used in many industries, and historically referred to as "two-way radio" services. With LTE and 5G, this service can expand beyond the standard walk-talkie voice. Because the LTE network affords the ability to leverage additional bandwidth for adjacent services on PTT, users are able to switch from voice to video conferencing and other more dynamic applications. Taking it a step further, Mission-Critical Push-To-Talk prioritizes voice over the rest of the traffic on the network. Ericsson recently partnered with Southern Linc, a private utility-based telecom provider

in the southern US, to launch the first dedicated mission-critical LTE network in the US.[25]

LTE and 5G networks afford significant flexibility to wind energy clients. Whether it's VoLTE-based, PTT or even an over-the-top voice application like Voice-over-Internet Protocol (VoIP), the voice service is just one application of many that an LTE/5G network can carry. The IT manager no longer needs to maintain separate networks for voice, data and other applications.

Training workers with Assisted and Virtual reality (AR/VR)
In a rapidly developing industry like wind energy, training workers and keeping their skills up to date are essential. The nature of training—and of work itself—has evolved tremendously, accelerated by the pandemic. Worker flexibility is key to attracting and retaining new talent.[26] For wind farms, that means considering new and more flexible training approaches.

Assisted reality (AR) and Virtual reality (VR) technologies can help. Through AR/VR, field technicians can easily engage remote experts for input and valuable information. AR/VR headsets also allow remote and new-hire workers to train with field technicians by allowing them to be able to "see what I see," avoiding the high amount of cost, time and resources it takes to transport workers to offshore locations. Notably, these headsets typically have an LTE modem externally attached or in-built to the headsets.

Attribute	Cellular-based 4G / 5G	LoRA	Bluetooth LE
Setup difficulty	Medium to Hard	Easy	Easy to Medium
Range	Longest Range	Medium to Long	Short
Battery life	Short to Medium	Long	Long
Data throughput	100Mbps – 1+Gbps	1kbps – 50kbps	10kbps – 1Mbps
Latency time	Low Latency	High Latency	Medium Latency
Security	High	High	Low
Spectrum usage	Assigned / Lightly Shared	Public / Shared	Public / Shared

Figure 4: Connectivity: BLE versus LoRa versus LTE

[24] https://www.eseye.com/resources/iot-explained/lora-vs-cellular-for-iot/
[25] https://www.ericsson.com/en/cases/2022/southern-linc-and-ericsson
[26] https://www.airswift.com/blog/attracting-net-zero-workforce

Sensors and predictive maintenance

Wind farms face unique operational and maintenance challenges. Prime among them is the unpredictability of component failure. With big machinery like wind turbines, the components are expected to be replaced or inspected on a cyclical timetable, which could be every two weeks, two months, two years or 20 years. One thing you can predict, though: Some components will fail well before an inspection or update replacement. On the other hand, wind farm owners don't want to prematurely replace components that actually have more useful life left. In both scenarios, the wind farm owner is losing money, whether from downtime or unnecessary labor and replacement cost.

Predictive maintenance and equipment monitoring enabled by LTE and 5G can prevent these losses. IoT sensors and data collection gateways placed on the wind turbine components and around the turbines themselves can continuously generate data from their environment or from their connected assets. Through the LTE/5G network, the data collected is transmitted wirelessly to the wind farm's IT office, where the data is collected, stored and processed. Analytics engines take the data collected over periods of time and provide predictive recommendations on these assets using Artificial intelligence (AI) and Machine learning (ML). LTE/5G is a key piece in a continuous, proactive maintenance process.

Monitoring

Owners and operators of commercial power production farms must stay informed about specific aspects of the wind turbines and their environment. To monitor the individual turbine speeds, the status of the motors and various systems, and the incoming weather, they need "eyes on the ground." The ability to have fixed cameras pointing at a few different angles of each turbine and sensors to predict flocks of birds, sensors to gauge humidity in the air can provide more insight to the operators, taking the guesswork out of their decision-making, and thus making for a more precise operational environment. In the near future, drones will be able to provide light robotic tasks, reducing the time personnel will have to spend high in the air outside the turbine. This in turn, reduces excess costs, risk of injury or damage and loss of optimal operating power generation efficiency.[27]

Inspections

Inspections, especially unscheduled inspections due to outage or a failed component, are very costly and time consuming. Sending crews, often at the last minute, to help perform the inspection is tedious and expensive anywhere. Onshore, a trip to a failed turbine could take upwards of a few hours for the technician to travel. Offshore, it's even harder, requiring extra steps to coordinate with transport and support vessel companies to get crews out to the failed turbine.

Today, wind farm operators are relying more and more on drones to provide "eyes on the ground" and conduct these urgent inspection tasks. In the future, some of these drones will be able to do some limited light robotic tasks using robotic arms and fingers. A recent report by Offshore Renewable Energy (ORE) Catapult estimated that an 18 percent to 26 percent savings can be realized with drones for operational tasks like inspections.[28]

Most drones with video capabilities can operate in LTE networks. Some of these more advanced and layered applications, like light robotics, will require speeds greater than what LTE can offer. In these cases, 5G networks, with high throughput speeds and low latencies, will readily enable these extra capabilities. Operators can invest in a handful of drones to support the facility, thereby avoiding the risks and the costs of deploying crews.

The benefits of drones apply not only in the event of an unscheduled failure of a wind turbine but for regularly scheduled inspections as well. For instance, a wind farm may require four regularly scheduled visual inspections. Replacing two of these with drone inspections halves the number of in-person inspections needed. Offshore wind farm owners reap even bigger benefits, given the high costs and timelines to schedule resources to travel to the offshore wind farm.

Keeping workers safe

We finally turn to the challenges associated with worker and equipment safety. We've seen that remote inspection capability reduces staff exposure to dangerous conditions and limits the chance of these workers falling from the heights of these turbines.

Still, site visits are often unavoidable, and workers have to climb the turbines. Operations managers must be able to monitor the immediate health of their workers as they hang on the outside of a nacelle. Cellular-based LTE networks can allow safety and health teams of wind farms to use wearable devices that can track vitals and health statistics of their workers. With the extra knowledge, operations managers can help predict if a worker may be at risk. The operations manager can preemptively ask the worker to take an action such as coming back inside, pausing and resting or stopping to perform the task at hand. Wearable gear that can track all these metrics give the wind farm operator the tools to monitor the health and welfare of their employees who are potentially in harm's way.

Quite a few companies make wearable gear that can track all these metrics. In some instances, the gear supports real-time communication utilizing standards such as Bluetooth, Bluetooth Low Energy (BLE), LoRa, Wi-Fi or LTE. In all cases, though, many devices in the market can perform the protocol conversion to LTE and help transport that communication link back to the central IT system and into the hands of the operations manager.

The company must also make sure the workers on wind turbines have their safety equipment on at all times. Computer vision, using cameras with backend analytics based on AI and ML, can allow the wind farm operator to quickly recognize if workers have taken their safety gear off or left it some distance away from the areas where they are critically needed. The cameras produce high amounts of continuous data transmission that only LTE or 5G can handle. Similarly, in emergencies, connectivity can enable remote personnel to walk workers through extra safety steps in real-time. All these examples are enhanced and supported by LTE and 5G cellular technologies.

[27] https://windeurope.org/intelligence-platform/product/wind-energy-digitalisation-towards-2030/
[28] https://innovateenergynow.com/resources/drones-and-robotics-in-offshore-wind

Conclusion

To power the future of wind energy, rely on LTE/5G networks
We have looked at LTE and 5G-based private networks and seen how they can be applied to help extract business, safety and operational value to a wind farm.

Cellular communication is uniquely qualified, with its ability to generate high throughput at low latencies, inherent enabled security and architecture and high device density connections. It is the only current standard that benefits from both industry and mass consumer acceptance as a single worldwide standard. Ecosystem vendors and partners are continuing to further develop even smarter gateways and end devices and collectively pushing the boundaries towards making LTE and 5G the most efficient and cost-effective connectivity standard. By adopting the cellular standard, the wind farm industry will drive an industry consensus and enable a common device ecosystem to be built to support the industry.

In the US, President Biden's ambitious goal of 30GW of Offshore[29] Wind Energy by 2030 is driving significant growth for the industry and the wind industry, especially offshore. To achieve its goals, the wind industry will need to utilize all the tools in its tool chest. This means drawing from wind energy experiences from around the world. Cellular-based private network technologies must be one of those tools. The benefits of this connectivity technology, from safety to security to efficiency to mass scale, are too significant to ignore.

About the author

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Viren is responsible for supporting the US and Canadian market for oil & gas and alternative energy companies to overcome their communications challenges by finding the right packaged solution. He helps businesses understand how private networks using LTE and 5G can help their middle-mile or last-mile connectivity challenges in the Energy Sector. Viren has over 20 years of experience working in network engineering, technical solutions and business development roles.

[29] https://dailyenergyinsider.com/news/29720-biden-administration-announces-30-gw-offshore-wind-plan/#:~:text=In%20a%20major%20push%20to,offshore%20wind%20deployment%20by%202030.

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