LTE/5G pervasive industrial wireless and the digital transformation of port terminals

Strategic white paper

Communications technologies, particularly wireless, play a key role in the digital transformation of terminal operations. In this paper, we survey the state of terminal communications and conclude that the current level of complexity calls for simplification and consolidation of the various networks. The strongest candidate for the communications platform of the future all-digital terminal are the 3GPP mobile technologies, 4.9G/LTE today, and 5G tomorrow. We look at the features and characteristics of these industrial-strength wireless technologies and the use cases they will enable in the terminal operations of the future.

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Evolving terminal operations

Volatile global markets, shifting transport routes and growing vessel sizes are challenging terminal operators to adjust to dynamic volumes and the doubling of container traffic by 2050. Today's high-pressure supply chains demand greater agility and faster turnaround times including improved coordination with truck and rail operators and the ability to communicate instantly with all terminal stakeholders.

With all this additional pressure across berth, yard, truck and train operations, there is a growing appetite for digital or "Industry 4.0" technologies such as IoT, machine learning and AI. They will play an increasingly critical role in meeting these challenges, partly by enabling the automation of terminals, which will, in turn, provide greater flexibility and operational savings. However, automation and increased adoption of digital technologies will not be attractive if they increase complexity and decrease reliability and predictability

Fortunately, it is now possible to simplify the digital transformation of terminal operations by consolidating many of these digital applications onto a single, secure wireless network that will lay the foundation for further automation and significant productivity gains. Today's 4.9G/LTE technology and the soon-to-arrive 5G technology have the features and capabilities to meet the needs of many, if not all, terminal applications and use cases. As well as reducing the capital and operational costs associated with purchasing, installing and running multiple networks, consolidating onto a single network technology will also reduce the complexity, reliability and security of terminal communications.

Current terminal communications

Having implemented successive waves of digital technology over the last few decades, most terminal operations have a variety of wireless network technologies deployed. These application-specific communications include a professional mobile radio (PMR) platform based on TETRA or Project 25 (P25), wireless sensor networks (WSN), low-power wide area networks (LPWA) and proprietary wireless technologies to support Machine-to-Machine (M2M) communications and industrial Internet of Things (IoT), and transponder networks for automatic guided vehicles (AGVs).

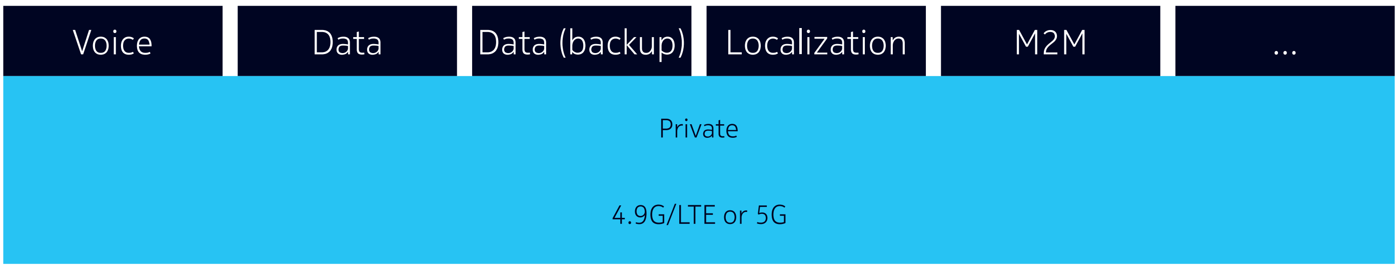
While most of these wireless technologies have specific applications, for general wireless data communications and especially for supporting the Terminal Operations System (TOS), most port terminals today have implemented Wi-Fi. A public 3G or LTE service of a mobile network operator may be leveraged as fallback option for general wireless data communications.

Figure 1. Typical wireless networks of port terminals today.

Voice	Data	Data (backup)	Localization	M2M	...
Private	Private	Public	Private	Private	...
PMR (TETRA/P25)	Wi-Fi	3G / LTE	Transponder network	Proprietary	...

A single port terminal may consequently be hosting five or even more separate wireless networks. Such fragmentation of wireless systems will be simplified with today's 4.9G/LTE technology, which will function as a converged platform for mission- and business-critical voice, data and video services. Besides mobile broadband, the latest release of LTE has also implemented NB-IoT and LTE-M to support M2M communications, IoT sensors and other low-powered devices. A future upgrade path to 5G is defined.

Figure 2. Converged wireless networks with cellular (LTE / 5G) as technology of choice.



This inhibits not only use cases of today's terminal operations but will also enable a variety of new, next-generation applications. Each of these use cases has its unique characteristics in terms of coverage, capacity, latency and criticality. Unlike public LTE services of mobile network operators designed to serve the masses, a 4.9G/LTE network in a port terminal is deployed in a private manner for solely use of the terminal operator. It is custom-built to meet specific use cases and coverage requirements.

Terminal operations is more reliable when supported by mobile and consistent wireless connectivity. It cannot afford to suffer breaks in communication as container handling machinery moves through the yard and navigate the constantly changing topography of container stacks. The degree of mobility inherent in terminal operations but also the radio reflections caused by the metal surface of containers and interferences with neighboring wireless networks present a challenge for existing wireless systems – such as Wi-Fi - in terms of reliability and predictability.

A private 4.9G/LTE network will provide reliable and predictable wireless broadband and low-latency connectivity. The standardized 3GPP LTE technology is ideal, designed to reliably handle moving vehicles at up to 350km/hr and communications in dense urban centers with many high-rise buildings. The terminal operator has full control of all data traffic and applications. Usage of specific spectrum limits interferences.

Comparing a private 4.9G/LTE network to each of the existing technologies on a per application basis may generate a comparable list of costs and benefits depending on the use case. But viewed overall, there is enormous advantage in simplifying everything on a single converged wireless communications platform that meets the various transmission requirements of the terminal while increasing reliability and predictability of the operations. It reduces the points of possible failure, more easily integrates digital technologies such as analytics and machine learning across the entire workflow, and it can be managed and secured from a single pane of glass. Also, higher output power of LTE access points compared to Wi-Fi allows to cover a similar terminal area with fewer equipment (factor 5-10x).

Industrial-grade wireless arrives

Although LTE has been available for almost a decade, it has mostly been monopolized by mobile network operators who licensed the spectrum for use by LTE mobile networks worldwide. Some of those public carriers have leased the spectrum for industrial applications, but the cost was usually too high to justify its use. Thus, the widespread reliance on Wi-Fi, which was never designed as anything other than a best-effort network technology, unsuitable for business- or mission-critical applications. Unfortunately, it was the only wireless networking option for most enterprises.

Fortunately, there has been widespread pressure placed on governments, who are responding by freeing up spectrum for use by enterprises in industrial and other applications from healthcare to mining. As well, 4.9G/LTE vendors have developed solutions that use unlicensed (e.g., Multefire) or 'lightly' licensed spectrum. Nokia, for instance, has also develop enterprise-sized versions of the technology that are no more difficult to install and maintain than a standard LAN or Wi-Fi network. The result is that terminal operators now have better choices as they plan for their digital futures and can benefit from the technical advantages of 4.9G/LTE by building out private LTE networks covering their container terminals.

Figure 3. 4.9G/LTE combines the best of Wi-Fi and fixed technologies, e.g., Ethernet, and adds high-speed mobility.

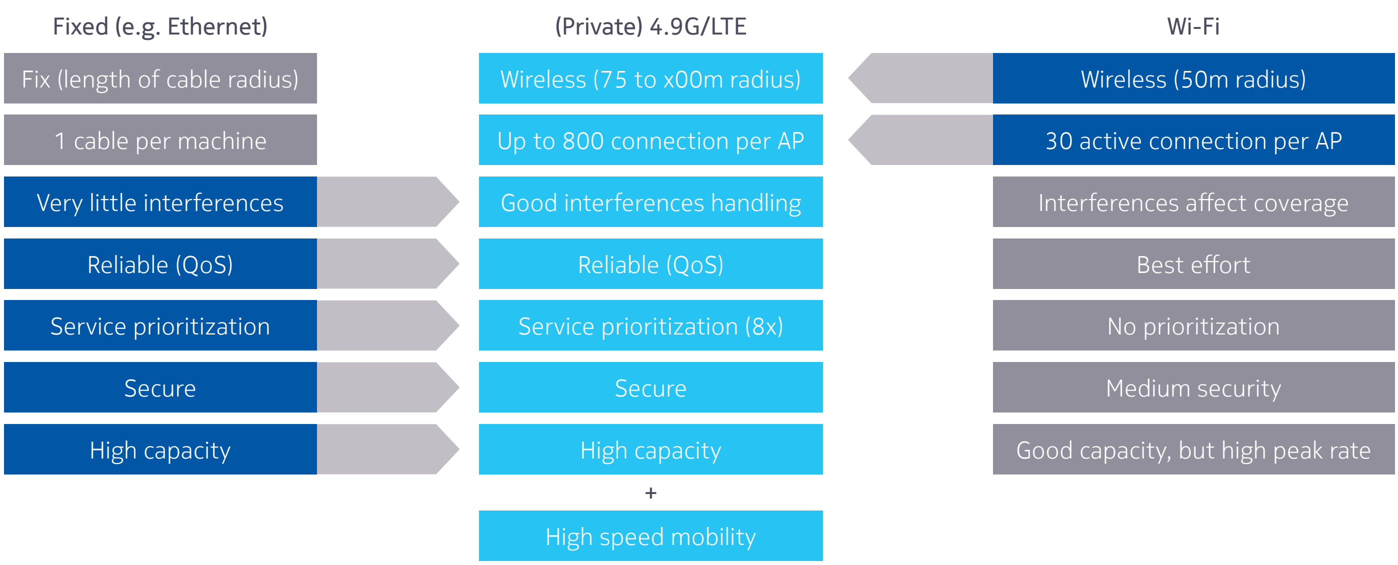


Figure 3 presents a summary of the advantages and disadvantages of fixed technologies, such as Ethernet, and Wi-Fi as compared to an LTE network. 4.9G/LTE can provide Ethernet-levels of service in terms of interference handling, reliability, service prioritization, security and capacity, without the need for cabling. And it exceeds the wireless capabilities of Wi-Fi in terms of coverage, number of active connections per access point and support for high-speed mobility.

4.9G/LTE has the ability to create slices within the network to securely separate applications and provide specific quality-level controls (QoS) for each application. Thus, for instance, IT can allocate higher bandwidth for video on one slice, NB-IoT or LTE-M for handling low-power IoT sensors on another, and time-sensitive low latency for automated or remotely controlled operations on a third.

Although operationally speaking the terminal has only one wireless network to install, manage and maintain, it can be sliced to create any number of virtually distinct networks per application — even handling older serial protocols for legacy applications.

On the road to 5G

Over the coming five years, 4.9G/LTE is designed to evolve into 5G, which will be like a super-charged wireless Ethernet. In other words, 5G will be able to handle any of the applications currently being run over Ethernet in terms of reliability, security and capacity with far greater ability to scale, handle extreme low latency applications and generally support industrial automation.

Although the general availability of 5G for industrial applications is still some years off, 4.9G/LTE is fully capable of handling the communication needs of many terminal applications today. Because 5G is an evolution of 4G, the move from one to the other is being planned carefully and, in most cases, the two will operate side by side with 5G being used for the more extreme applications initially.

The advanced capabilities of 5G will enable applications that are currently not supported by technologies such as Wi-Fi. One example is unmanned aerial or drone inspections. Drones have proven themselves as a key technology in emergency situations where they can provide instant situational awareness. They are especially useful in terminal and yard operations where they can provide remote visual asset inspection, monitoring of dangerous goods and perimeter surveillance.

Most importantly, 5G will enhance automation of freely-ranging container handling equipment.

Next-generation terminal automation

Automated terminal operations have been underway for several decades with the first use of unmanned container handling machines occurring at the ECT Delta Terminal in Rotterdam in 1993. The automated rail-mounted gantry cranes (aRMGs) worked in tandem with automated guided vehicles (AGVs) to provide horizontal quay-to-yard container transfer. The next terminal to follow suit was the Hamburg HHLA Container Terminal Altenwerder in the early 2000s.

Today aRMGs and AGVs are still widely used in automated terminal operations. Although there have been early cases of automated straddle and shuttle carriers and automated rubber-tired gantry cranes (aRTG), the industry needs to move more aggressively in the direction of freely-moving container handling machines such as aRTGs, shuttle and straddle carriers, and a freely moving version of the AGV called the automated intelligent vehicle (AIV).

Untethering gantry cranes from their rail infrastructure, or AGVs from their complex beacon networks, requires robust and reliable wireless communications. This is where 5G and even 4.9G/LTE hold great promise.

Remotely controlling automated equipment requires very low latency communications because of the need for almost instantaneous response from the remote operator or central control software. Fortunately, 5G has a number of time-sensitive networking (TSN) features and supports industry protocols, such as Profinet. It also includes support for ultra-reliable low latency communications (URLLC). In one trial of the 5G Wireless for Verticals (WIVE) research project, Kalmar together with Nokia successfully demonstrated the ability of URLLC technology to advance container yard automation with reliable and low-latency messages, for example, in safety related messages.

Remote control of these free-moving machines also requires the capacity to carry video from on-board cameras. There can be 15+ cameras for an aRTG and six for an automated straddle carrier. 5G's extreme mobile broadband (eMB) feature supports the kind of bandwidth required by so many cameras.

Supplementing remote control by video, current research explores the use of audio and haptic feedback using 5G. The additional feedback helps to improve remote container handling. The remote operator can hear, for instance, the screech of metal on metal or feel the bumps and hesitations that might indicate a less than clean pickup. This not only speeds up container handling, it also helps to avoid damaging containers, which is a major objective in every terminal operation. This kind of audio, video and haptic feedback over 5G will be extremely quick, to the point of instantaneous, for remote control to be effective.

Additionally, the industry is testing the use of network-based RF localization for highly accurate positioning with little or no additional dedicated infrastructure, as is required, for instance, with beacon technologies used by AGVs. This represents another feature of 5G.

Kalmar, part of Cargotec, is doing ongoing research on terminal automation and energy-efficient cargo handling. Their research test bed includes a private 4.9G/LTE network from Nokia. "The digital automation platform with its connectivity and application layers makes it possible for us to test new service products and concepts. That gives us the opportunity to demonstrate to our customers how our new services work, which is particularly valuable," says Pekka Yli-Paunu, Director, Automation Research, Kalmar.

Enabling smarter terminal operations

As we look further into the future, Industry 4.0 applications will continue to digitally transform terminal operations. Along with automation and remote-control applications, there is also the possibility of predictive asset maintenance and end-to-end management of all operational processes based on real-time data and sophisticated workflow management.

Juha Pankakosk, Executive Vice President, Technologies at Konecranes, has been testing the use of automation by adding sensors, actuators and video cameras joined by a private 4.9G/LTE network. Based on their research and experience, he observed that "the new mobile network technology has the potential to bring machine-to-machine communications, IoT security and machine learning to the next level."

Asset management is one of the key areas where machine learning is a game changer. Traditionally, asset maintenance is accomplished by one of two methods: time-based or condition-based. An example of time-based maintenance is the manufacturer's recommended maintenance schedule for the equipment. Condition-based maintenance monitors the equipment, applies analytics and uses the insights generated to determine the optimal maintenance schedule.

Industry 4.0 is changing asset management by introducing digital technologies that can monitor assets and optimize performance in real time. Machine and sensor data along with analytics can be used to create a virtual model or 'digital twin' of the machine. The digital twin can then be used to assess the equipment's performance in order to more precisely pinpoint when it is likely to fail, commonly referred to as predictive maintenance. Because the increasing need for reliable and flexible terminal operations calls for zero downtime, predictive maintenance is the best approach given the interdependence of the terminal and its many stakeholders.

Predictive maintenance based on software analytics is only the beginning of an entirely different way of managing operations as a whole. Digital twins or virtual models can be aggregated to create a picture of the entire terminal workflow. This introduces the possibility of workflow optimization, where analytics programs can suggest areas for workflow improvement and re-design processes that have terminal-wide and business-wide impacts. Risk assessment models can identify and measure the spillover effects of malfunctions and failures in specific assets, helping to prioritize capital spending and maintenance. This data can be mapped to parameters such as cost, quality and, ultimately, even stakeholder satisfaction.

Creating an aggregate digital twin of the terminal operations, in order to optimize the overall workflow requires a robust, mission-critical communications system, such as 4.9G/LTE, to connect mobile devices, sensors and actuators. It is possible to save between 7 and 10 percent in the overall efficiency of operations using workflow optimization alone.

Figure 4. Data points for the digital transformation of terminal operations.

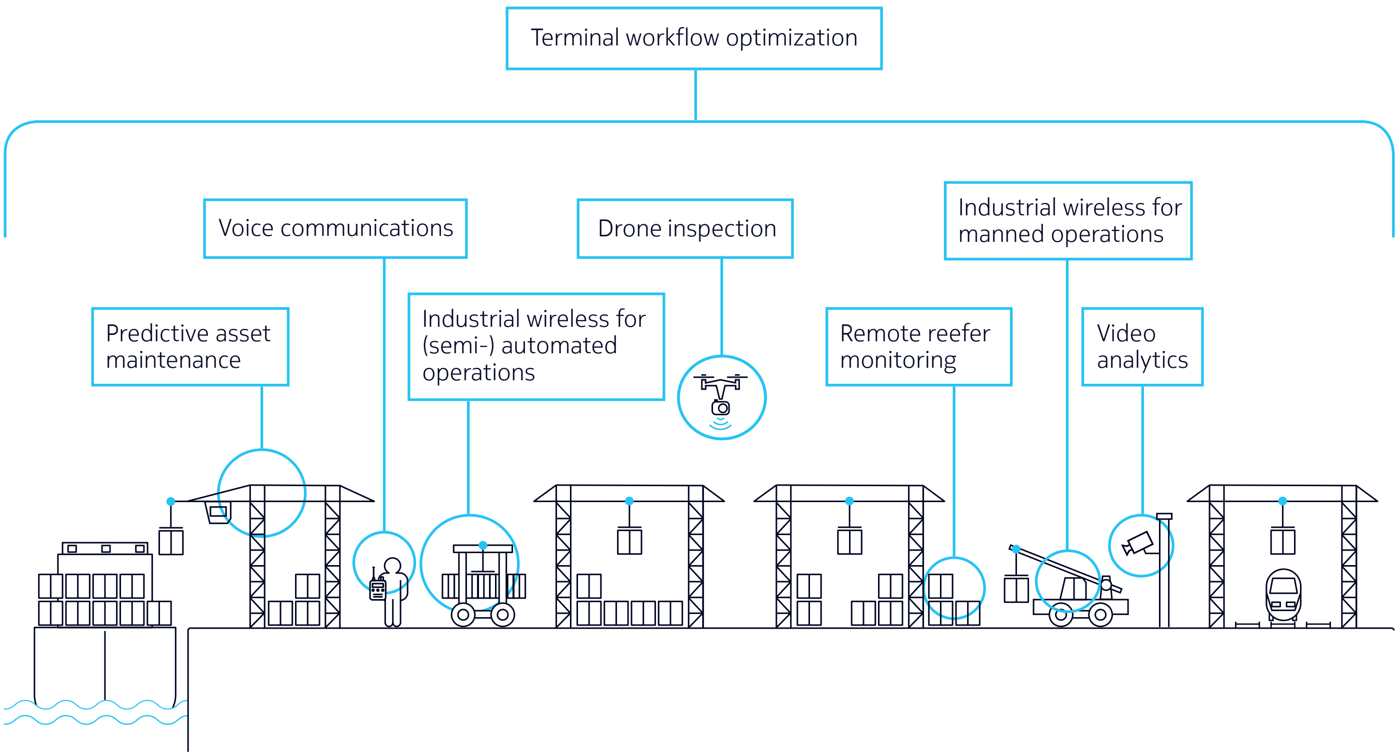
Wireless data for manned operations	To increase **TOS efficiency**	+30%
Workflow optimization	To increase **terminal TEU throughput**	+7-10%
Asset lifecycle optimization	To reduce **maintenance spent**	+10-15%
Remote reefer monitoring	To reduce manual work and damage of **perishable goods**	-90%
Worker fatigue and safety monitoring	Improve safety risk management and reduce **safety alarm rate**	-25%
Voice communications	To benefit from **one wireless network for all applications**	Convergence
Wireless remote control for (semi-) automated operations	Enable **next-generation of automated container handling equipment**	Future ready
Optical LAN for (semi-) automated operations	**Minimize maintenance efforts** by reducing active equipment	Simplification
Video analytics	To reduce **human review cost**	Automation
Drone inspection	To ease **asset inspections** and response to **emergency situations**	Aerial insight

Industrial-grade wireless as a platform

Although this may sound far off in the future, once installed a private 4.9G/LTE network can function as a kind of platform for future evolution. As an example of this, Steveco, a terminal operator in the HaminaKotka port in Kotka, Finland, worked with Nokia to build a private 4.9G/LTE network to support video cameras that were installed on ship-to-shore cranes. The application was designed simply to record the status of containers before and after handling. Thus, in the case of future insurance claims, it was easy to establish clear responsibility.

Steveco has since built other applications on top of the 4.9G/LTE network, because it was there. They have added perimeter surveillance and asset monitoring by video. All cargo handling equipment and personnel in the terminal and warehouses communicate over the 4.9G/LTE network. And they are considering future Industry 4.0 applications that they can launch off the LTE network.

Figure 5. Industrial-grade wireless as a platform for the digital transformation of terminal operations.



Conclusion

Digital transformation of all industries is coming very quickly. Terminal operations are no exception. As part of a vital link in today's industrial supply chains, it will become table stakes for future ports to have digital awareness and management of everything passing through them in real time. Automation and autonomous technologies will find new roles in terminal operations just as they are being employed in many other areas of the economy.

To achieve the fully digital terminal with the current mix of wired and wireless communications technologies will increase complexity, create more points of failure and additional operational costs associated with managing and securing the separate networks. At some point, the additional communications burden associated with supporting new applications may prove a barrier to further digital evolution.

Today, 4.9G/LTE industrial-grade wireless and, in the future, 5G can provide the communications platform for the full digital transformation of terminal operations. From low-powered sensors and RF-based location-based services (LBS) to high-capacity mobile video remote-controlled cranes and straddle shuttle carriers, it is possible to support the terminal from vessel to truck or train.

This single, highly secure network reduces complexity, speeds the deployment of new applications and can be the platform for employing sophisticated analytics to create an aggregate digital model of the entire operation for better risk management and workflow optimization.

Viewed on an application-by-application basis, there are already strong business cases for moving to 4.9G/LTE. Viewed systematically, the argument for adopting a private LTE networks as the terminal communications platform is even stronger and it will only strengthen over time.

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