Warehouse automation and private wireless networks

White paper

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Introduction

Automation and digitalization initiatives are occurring across most asset-intensive industries, with supply chain and logistics being close to the top of the list that would benefit. The expansion of e-commerce, super-charged by the global pandemic, has put the spotlight on the industry. In 2016, DHL's survey suggest that 80 percent of warehouses were unautomated and only five percent fully automated.[1] Warehouse automation has grown since then and is expected to grow by close to 40 percent in 2021. Nonetheless, there remains much potential for the industry. Whether embracing full automation or some degree of semi-automation, there are foundational technologies that warehouse operators can view as table stakes for starting on their digital automation journey. Industrial private wireless networking is one of them.

Why automate?

There are many time-consuming and redundant tasks in manual warehouses that are good candidates for automation. For instance, order picking operations consume over 50 percent of the time taken in order fulfillment, with only 25 percent of that time spent in the picking operation adding any value. The rest of the time is spent searching (10%), writing (5%), and walking (60%), with an order picker able to average six miles per day.[2] Thus, there are significant incentives to reduce the non-value-added time, especially since labor shortages are driving wages up, and health and safety costs are also rising. Warehouse automation solutions include picking and sorting systems, conveyors, and storage and retrieval systems. Other systems capture data from goods using barcodes or RFID tags, analytics software optimizes many processes, and there are guidance systems for directing automated guided vehicles (AGVs) and autonomous mobile robots (AMRs).

Besides the obvious productivity gains, there are other factors at play in the rise of warehouse automation. The growth of e-commerce is an important industry trend, but it is having a mixed effect on warehouse operators. The biggest e-commerce retailers are creating their own automated logistics operations. Much publicized examples of fully automated operations are Amazon, with their Kiva and Pegasus robots, and Ocado Group, a food retailer in the UK, with its robotic grid. Both have created fully automated warehouses in-house. Promises of same-day delivery are especially creating the need for more warehouses in metro areas, where the cost of land is high and labor shortages are driving the need for automation.

The effect of ecommerce for third-party logistics providers (3PL) isn't the same, however. To the extent that logistics companies get involved in e-commerce supply chains, it is often at the edges of the distribution network where these e-commerce giants do not have enough business to warrant their own logistics operations. For many 3PL operators, e-commerce is actually a loss leader, which helps them to build volume, but does not contribute much to the bottom line.[3] It is a growing market, nonetheless, and for them to make money at it, some level of automation will be required, but they will need automation solutions that are highly flexible, scalable and reconfigurable. An example of this is in manual picking operations using multi-modal scanners and vision picking, or adopting AMRs (vs AGVs) to improve productivity and flexibility.

Despite e-commerce growth, B2B supply chains are the bread and butter of the logistics business. With the disruptions to the supply chain caused by the pandemic, the industry is recognizing the need to bring more automation and to digitalize more of their processes. The disruptions have led to a demand by suppliers and customers to bring more transparency to the supply chain. Planning, pricing and unmet

1 Robots in Logistics, March 2016. In the last five years this could have changed significantly.

2 Logistics IQ, "Warehouse automation market: Forecast to 2026," p. 16.

3 Dekhne e al, "Automation in logistics: Big opportunity, bigger uncertainty," McKinsey, April, 2019.

delivery commitments have all created costs that often can be traced back to a lack of end-to-end transparency. This is putting a new kind of pressure on the logistics industry to embrace digitalization.

MHI and Deloitte surveyed more than 1,000 supply chain and manufacturing leaders to learn how they are responding to the global pandemic.[4] This year's survey found that 49% of supply chain leaders have accelerated spending in digital technologies to make their operations more agile and responsive. Cloud computing, robotics, and inventory/network optimization tools saw the biggest jump in terms of supply chain investment. A key finding is that companies that embrace digital technologies and innovations can respond more quickly and effectively to the immediate challenges posed by disruption, recover faster than their peers, and create sustainable competitive advantages that enable them to thrive in the post-disruption world.

Nokia Bell Labs Consulting examined the value of enterprises implementing Industry 4.0 digital automation across three important metrics: safety, productivity and efficiency. In their analysis, they examined the addition of collaborative robots with humans in workspaces, high-definition mobile video sensing and AMRs in 5G smart manufacturing and warehouses. The analysis found that sigificant value can be realized across all three metrics when adopting these digital automation technologies (Figure 1).

Figure 1. Value of digital automation

	Safety	Productivity	Efficiency
Collaborative robots	↓25% Hazardous operations injuries	↑25% Manufacturing productivity ↑30% Factory output	↑15% Overall equipment effectiveness ↑25% Labor efficiency
Video sensors	↓22% Injuries	↓10% Equipment repair time ↓30% Unanticipated breakdowns	↑18% Overall equipment effectiveness ↓30% Defects and scrap
Automated guided vehicles	↓18% Transport accidents	↑30% Transportation capacity ↓40% Milk run time	↓21% Factory logistics cost ↓40% Late deliveries

Source: Bell Labs Consulting

Despite the generally positive outlook for warehouse automation, there are, nonetheless, speed bumps as well: investment in full automation is long-term and for logistics companies supply contracts are often short-term; the technologies are changing rapidly and often hard to source; and supply chain patterns continue to be in flux following the pandemic.[5] Land for warehouses is also in short supply, especially in the all-important metropolitan areas.

4 "Innovation-driven Resilience", The 2021 MHI Annual Industry Report.

5 Dekhne e al, "Automation in logistics: Big opportunity, bigger uncertainty," McKinsey, April, 2019.

These factors will impact the level of investment in automation that 3PL providers can deploy, whereas for businesses that handle their warehousing in-house, the specialization of the infrastructure and the longer investment horizon makes full-scale automation using modern automated storage and retrieval systems (AS/RS) much more promising. Nonetheless, the pandemic has accelerated digital adoption to the point that 3PL providers are looking for systems that realize the benefits of automation but also give them maximum flexibility and agility.

Developing a digital strategy

As companies look out at the digital landscape there are a rapidly growing number of technologies and solutions they need to learn about. Industry 4.0 digitalization and automation is being widely adopted in many industries from manufacturing and railways to aviation and ports. Many of the same technologies are used across industries such as autonomous vehicles and robots, remote-control of machinery, use of IoT sensors and data analytics to optimize processes and do everything from setting maintenance schedules to identifying safety issues.

A cursory survey of the literature on warehouse automation finds artificial intelligence and machine learning, augmented reality heads-up displays, warehouse-management systems with real-time inventory tracking matched to the ordering system, 3-D printers creating parts to order, smart storage systems that optimize where goods are stored based on ordering trends, and order-flow software. Where to start?

Digital transformation means something different to every company. It is important to understand the goals and to develop a long-term digital strategy to achieve them. It will be a rare warehouse operator that will jump into a full automation solution like Amazon or Ocado. Most will start with a single point solution, such as an inventory tracking system to help reduce the time for searching and provide transparency to upstream and downstream clients. But there is a danger in the point solution approach without having a long-term plan.

The end goal of digitalization is to have all the sub-systems within the warehouse talking to each other to provide a comprehensive view of their operations. Too often, providers of single point solutions will make choices regarding things like communications that are fine for that solution but will prove to be incompatible with future projects. In many companies, for instance, it’s not uncommon to find four or five different communications systems in place within a single operation. When it comes time to integrate those sub-systems, incompatibility, interference, and simply the operational costs associated with operating, administering and maintaining five systems all become barriers to realizing the value of end-to-end digital optimization.

Connectivity

Thinking strategically, a good place to start is with connectivity. Virtually all digital technologies require robust, reliable and predictable connectivity to connect tablets, sensors, robots, and personnel to cloud-based software systems that analyze and optimize the end-to-end workflow. Connectivity is a key part of the digital platform, which, along with the cloud setup, needs to be in place to support the various use cases and applications that will come later.

The activity in many warehouses and warehouse yards tends to be highly mobile. For 3PL operators, configurations often change with supplier contracts. This kind of agility and flexibility will require robust wireless coverage, supplemented by cabled networks for fixed infrastructure. Until recently, however, the choices of wireless technology from the IT industry have had limitations in performance, reliability and support for an end-to-end automated warehouse (Table 1).

For instance, workers have long relied on private radio, such as TETRA or P25, for voice communications, but these systems are unable to handle data or video. Sensor networks use narrowband protocols that support low-powered sensors over short distances, such as Bluetooth low-energy (BLE) for location tracking, medium distance mesh networks, such as Zigbee, or longer distances, with LPWAN technologies such as Sigfox for sensors. Beacon networks, such as iBeacon, also use BLE for guiding AGVs. Near-field communications (NFC) is often used for asset and product identification. None of these technologies, however, can transfer more than very small amounts of data.

Table 1. Data capacities of IoT communications technologies

	P25 / TETRA	Wi Fi 802.11 ac	WirelessHART	sigfox / LoRa	
Security	■		■	■	
Reliability	■		■		
High data-rate/ low latency		■			
Predictable performance	■		■		
Coverage				■	
LP-WAN			■	■	■
Mobile	■				
Voice	■		■		

*IDC, European Enterprise Communications Survey, 2019

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For higher bandwidth data applications, the principal wireless technology has been Wi-Fi, which virtually all warehouses use today for wireless scanners, for instance. Recently standardized Wi-Fi 6 provides an incremental performance improvement over Wi-Fi 5 and supports a growing range of devices with its proponents touting it as the connectivity solution for the warehouse.

All of these technologies, except TETRA, are designed for static, not mobile communications. Wi-Fi, for instance, only supports walking speed mobility and, so, does a poor job of supporting next-gen AGVs, autonomous forklifts and mobile robots, which will often lose connectivity when moving between Wi-Fi zones and have to reduce to walking speed — even then, they often have to be manually reconnected to the network.

Figure 2. Comparison of Wi-Fi and LTE/5G

Wi-Fi	LTE	5G
Capacity ~30-100 active connections per access point	**Capacity** - Up to 800 connections on a single small cell; tens of thousands on a macro antenna	**Capacity** - Up to x connections on a single small cell, 10k's on a macro antenna
Indoor coverage - Access point radius of ~10-20 meters	**Indoor coverage** - Access point radius of ~20-40 meters*	**Indoor coverage** - Access point radius ~15-30 meters*
QoS - Best effort; lack of prioritization	**QoS** - Dependable quality of service management with prioritization	**QoS** - Deterministic QoS management with prioritization
Performance - High peak rates; unstable performance/capacity	**Performance** - Predictable data rates; 3-5 x 9's 'carrier grade' reliability	**Performance** - Predictable data rates; 6 9's reliability @ 1ms TSC (R17-18)
Mobility - Loss of connection up to 15 secs on handover between APs	**Mobility** - Up to 350 km/h	**Mobility** - Up to 500 km/h (R15)
Latency - Fluctuating between 1 ms and 2 secs; reliability decreases with number of connections	**Latency** - Between 8-20ms; remains stable with increasing number of connections	**Latency** - Between 2-10 ms, remains stable with more connections
Security - High risk for hacker attacks and intrusion	**Security** - Security by design	**Security** - Zero trust design
Services - Co-existence with private radio, no IoT support; no handover to public network	**Services** - One network for PTT/PTV, broadband, video streaming, IoT; same technology as public 4G	**Services** - One network for PTT/PTV, broadband, video, IoT and TS machine control
Interference - Poor signal penetration	**Interference** - Up to 3 times greater signal penetration	**Interference** - Up to 2 times greater signal penetration
	Network slicing - Static QoS, radio + core only, limited slices/US, Evo to dynamic & E2E	**Network slicing** - Slicing and slicing automation evolution (R16-R18)
	Basic geo-positioning - ~ 30m accuracy	**Enhanced geo-positioning** - ~cm accuracy

*dependent on frequency selected, max output power authorized, type of radio solution used and total spectrum bandwidth

This need for occasional manual resets, highlights one of the principal concerns with Wi-Fi: its non-deterministic performance. In terms of latency, for instance, Wi-Fi can deliver <10 ms latencies, but you might also get 10–50 ms delays or even hundreds of milliseconds when the access point is congested, and this isn't predictable. This is because Wi-Fi is a "best-effort" protocol. It is hard to design warehouses and logistics operations around a communication technology that is unpredictable.

Wi-Fi can be engineered to overcome some of these deficiencies, but it is expensive. It takes a lot of radio engineering to understand how Wi-Fi signals will propagate in a typical warehouse facility. There are cases where the cost of the radio engineering study exceeded the cost of the Wi-Fi capex. And when the warehouse is retooled, shelving re-arranged or any significant changes to the metallic structures, it all must be redone.

A converged communications network

This was the state of things until recently. Over the last decade, industries have used LTE cellular as a more robust, single alternative to all of these diverse wireless technologies. It supports all the communications needs outlined above, and it is more secure and provides more reliable coverage and greater scalability (or density per sqm). The latest version is 4.9G/LTE and the the next generation, which is 5G is being finalized and can easily be added to existing pW networks..

Both 4.9G/LTE and 5G support high bandwidth applications now served by Wi-Fi, but also support high-speed mobility and are more reliable and provide better coverage than Wi-Fi. This is especially important for high ceiling warehouses and outdoor, both environments where Wi-Fi coverage is difficult to engineer.

One of LTE's weaknesses when it was first introduced was lack of support for low-powered sensor communications. Recognizing the importance of IoT to industry, 3GPP, the organization that controls the standards for LTE and 5G developed low-powered modes for IoT. 4.9G/LTE uses LTE-Machine (LTE-M) and Narrowband IoT (NB-IoT), which allows it to act as an LPWAN network that supports narrow bandwidths and signaling procedures to support low-power battery operated sensors. In its final form, 5G will have even more robust support for IoT being able to manage massive number of sensors — up to one million sensors within a square kilometer — carrying very small amounts of data and supporting 10+ years of battery life for sensors.

Along with low-powered sensor networks, 4.9G/LTE and 5G also support private radio applications such as push-to-talk and push-to-video to replace Land Mobile Radio (LMR) communications, along with industrial control protocols such as SCADA networks and low-latency machine-to-machine communications, which are critical for automation.

4.9G/LTE and 5G, in contrast to best-effort Wi-Fi, are deterministic. Quality of service (QoS) can be specified for a given service and the protocol will reliably meet the performance parameters that have been set for a specific use case. We can see the importance of being able to predictably control performance if we look at the following use cases.

Remote controlled and autonomous vehicles

4.9G/LTE can provide sufficient bandwidth for streaming video, which is used when remotely controlling a gantry crane or forklift. The difference between LTE and 5G is how many cameras can stream video simultaneously under the same cell with 5G being able to handle up to 10x more camera streams. For safety and usability reasons, these streams must be guaranteed.

Latency is often the bigger issue with remote-control. For instance, excessive latency for remote-controlled processes increases cycle times slowing down operations compared to direct manual control. For remote control of machinery is acceptable. 4.9G/LTE can deliver latencies of <10 ms, whereas 5G is expected to be able to achieve <1 ms. These levels of latency make 4.9G/LTE suitable for some remote-control situations, whereas autonomous vehicles (V2X standard) are fine with LTE and Edge, at speed up to 150kph. highly precise machine-to-machine communications for advanced automation will need 5G.

Autonomous vehicles

Future with cloud-based PLC most autonomous vehicles today need to process sensor and video information on-board. However, with the arrival of 5G, with its < 1ms latencies, it will become possible to have much less expensive and lighter AMRs that rely on the cloud to process sensor and video information to direct their movements.

Even before we reach cloud-based autonomous processing, AMRs with on-board processing still need to connect to the cloud to get their pickup lists and to assure the central warehouse management system that they are operating safely and more advanced ones, can also share route information with other for increasing the routing efficiency. They need to be in constant contact and cannot afford to lose connectivity as the device moves from one coverage area to another coverage area.

These two use cases illustrate how critical it is that the wireless network be completely reliable for safety and performance reasons.

Private wireless solutions

A private wireless network based on 4.9G/LTE or 5G can be installed by any enterprise, just as they might install a Wi-Fi network. The small cell access points are similar in size to a Wi-Fi access point, although fewer of them are needed to provide coverage for an indoor or outdoor space. They can be backhauled by an Ethernet connection or in remote outdoor locations, by point-to-point microwave.

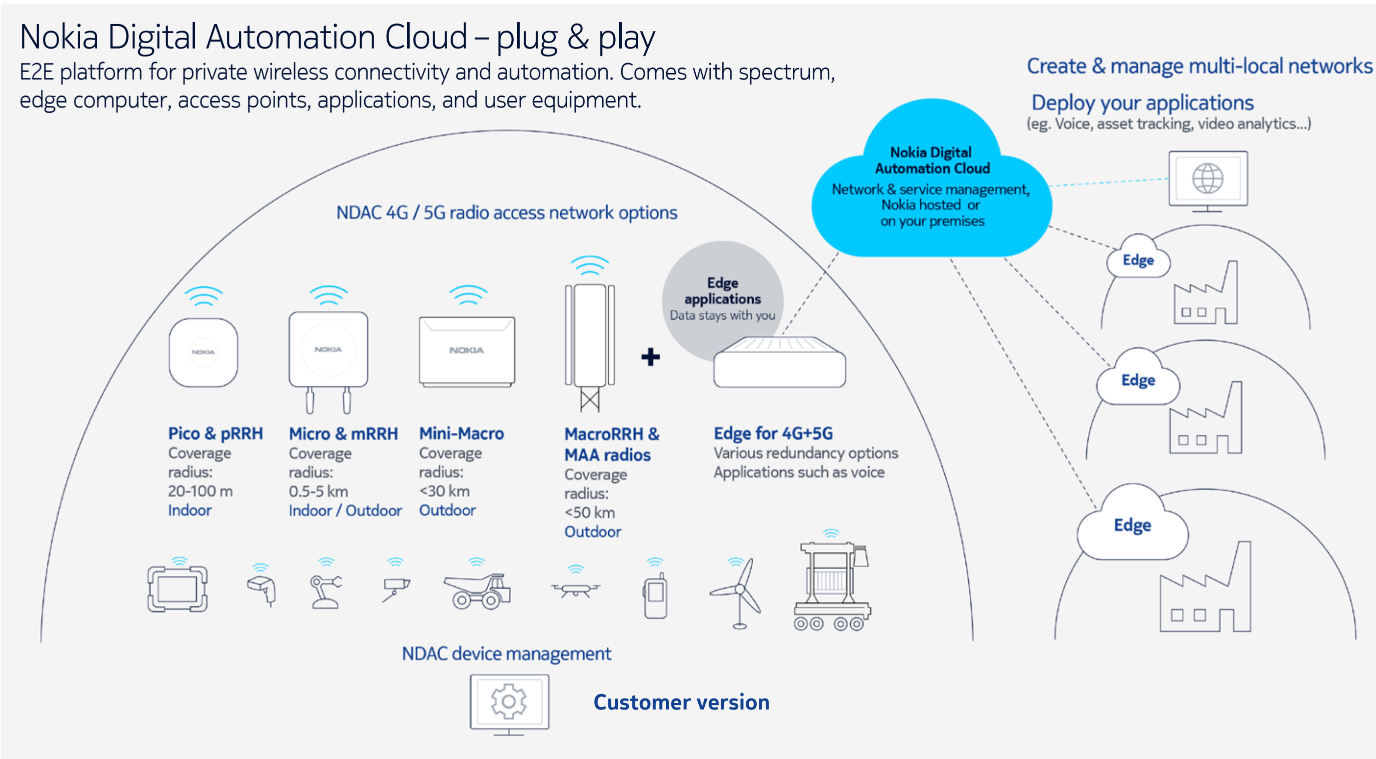
A private wireless network differs from Wi-Fi in that it has a core network, which in the enterprise version is similar in size to a mini-PC that can fit on a desktop. The core network provides functionality needed to manage and operate the entire network. The mobile gateway performs user data traffic processing and determines quality of service (QoS) for devices and applications. It assigns the IP address for the devices and performs the gateway function between the private wireless network, the internet and any other networks. It has a mobile management entity to provide cell coordination, control channels and generally manage the mobility of devices and the flow of traffic to the radio access points. It also manages subscriber service functions such as subscription management, operations and maintenance and priority settings.

There is also the optional possibility of employing an edge cloud server, which is often deployed as close as possible to the radio network. It can host some of the core services and do preliminary data processing from sensors or video. Edge servers are key to delivering low latency services locally for machine automation.

Using an industrial edge server such as the Nokia MX Industrial Edge, a third-party service provider, such as the Nokia or a mobile operator, can provide core network functions remotely using the on-premises edge cloud to deliver local processing thereby ensuring data sovereignty for the enterprise.

4.9G is the latest release of LTE wireless standard that is already being extensively used in many asset-intensive industry use cases. 4.9G/LTE features and performance will support approximately 85 percent of existing use cases, including some that automate warehouses. For the remaining use cases that require even better performance than 4.9G, there is 5G. The Nokia Digital Automation Cloud is a private wireless network solution that has been design to meet enterprise requirements (figure 3). It is a plug and play private wireless network that supports both 4.9G and 5G for OT applications and use cases.

Figure 3. Nokia Digital Automation Cloud private wireless 4.9G, 5G network solution



4.9G/LTE has a well-established ecosystem of device providers, as well as LTE modems that can be fitted to many kinds of industrial machinery. The 5G ecosystem is only beginning to develop as device manufacturers gear up to support it. Some of the most important industrial features of the 5G standard are also not yet through the standardization process. Devices that support some of these standards will not be available for several years.

Radio spectrum

Most of the technologies we have looked at such as Wi-Fi and the LPWAN technologies for IoT sensor communications use unlicensed spectrum. There are options to use unlicensed spectrum for 4.9G/LTE and 5G private wireless networks, which we will discuss below, but there are a growing number of countries that have released either 4.9G/LTE and/or 5G spectrum that can be acquired for industrial use. For example, in Germany, the Federal Network Agency, Bundesnetzagentur, has released 5G spectrum in the 3.7–3.8 Ghz range that can be licensed by companies for their own private networks. Another option is to use spectrum from a third-party provider of 4.9G/LTE or 5G private services. These providers come in two flavors.

The first is mobile operators, who have shifted their approach to industrial verticals and are realizing the tremendous opportunity presented by Industry 4.0. Holding the licenses to this spectrum, mobile operators can tailor a specific solution for a warehouse, often combing both unlicensed and licensed versions to achieve mission-critical (5x9s) coverage for the interior of the facility as well as its perimeter with all warehouse operational and IP data remaining on the premises.

Mobile operators have the added advantage that they can provide wide area network (WAN) coverage at either the local or national level to support long distance trucking or robot and drone deliveries over the last mile. This allows digitalization of the full logistics operation, end to end, using a single communications platform. Besides providing the private wireless network to the warehouse operator, the mobile operators can also offer additional value-added services such as network and device management and security services

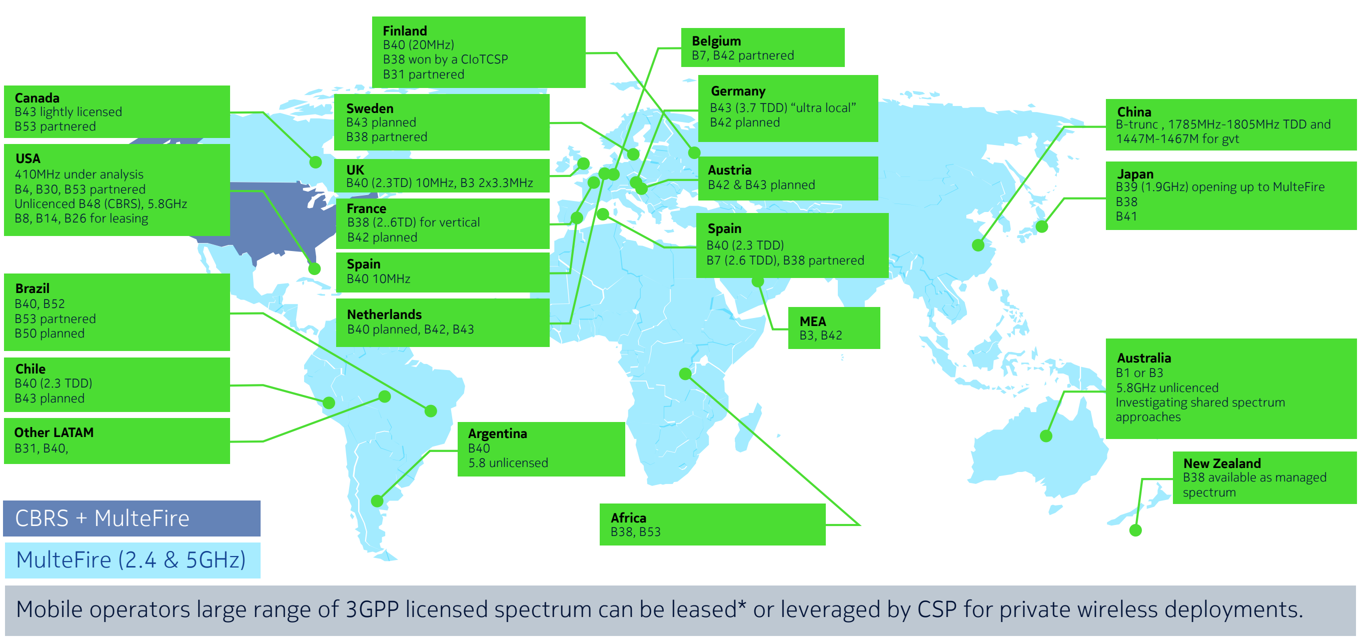
Mobile operators are also planning to offer network slicing with 5G. The standards are still being developed but the concept is to use the mobile operator's licensed spectrum and provide a dedicated "slice" of network resources (radio, transport, core) to deliver a service to an industrial user with a service level agreement (SLA) for a range of performance metrics.

The final approach is to work with a third-party private network services provider that can manage the issue of spectrum, developing a mix of licensed and unlicensed services to suit the applications involved and the locations of the warehouses. This approach of providing connectivity as a service is attractive to third-party logistics (3PL) operators, who may prefer, when developing an automation solution for a customer, to not be stuck with the unrealized capital investment if the customer switches to a different logistics company at the end of the contract. Third-party private network service providers, such as Nokia DAC solution can provide not only the private wireless network, set up edge clouds, source end devices but also provide professional services to support warehouse digital automation use cases.

Unlicensed/Shared radio spectrum

Warehouse operators have several options to access spectrum for their own private use beyond licensed spectrum. One is based on a variation of LTE that uses unlicensed 5 Ghz spectrum. This unlicensed spectrum band is also used by WLAN (Wi-Fi) or UWB (ultra-wide band) networks, but there are standards and procedures that are defined (e.g., listen-before-talk) that ensure fair usage. Figure 4 provides the latest status of available spectrum for enterprises across the world with specific bands identified in certain countries.   MulteFire unlicensed spectrum is available nearly everywhere and CBRS shared spectrum is available for enterprises in the United States (figure 4).

Figure 4. Private wireless spectrum options (LTE)



*depending on country's spectrum regulation

The industry has developed standards-based unlicensed spectrum solutions such as MulteFire that provide LTE networking. The MulteFire Alliance (MFA), of which Nokia is one of the founding members, sets the standards for the protocol and works with device vendors to develop chipsets and devices that communicate over MulteFire. The MFA together with 3GPP is also developing a 5G NR-U (New Radio-Unlicensed) version to which companies can seamlessly migrate.

Another option in the United States is using recently released shared spectrum that the federal government has allocated for industrial use. Citizens Band Radio Service (CBRS) spectrum in the 3.5 GHz range is available to industries and businesses for both indoor and outdoor applications. A Spectrum Access System (SAS) facilitates frequency sharing across three different tiers of users. Nokia is also a sponsor member of the CBRS OnGo Alliance providing private wireless networking solutions operating in this band.

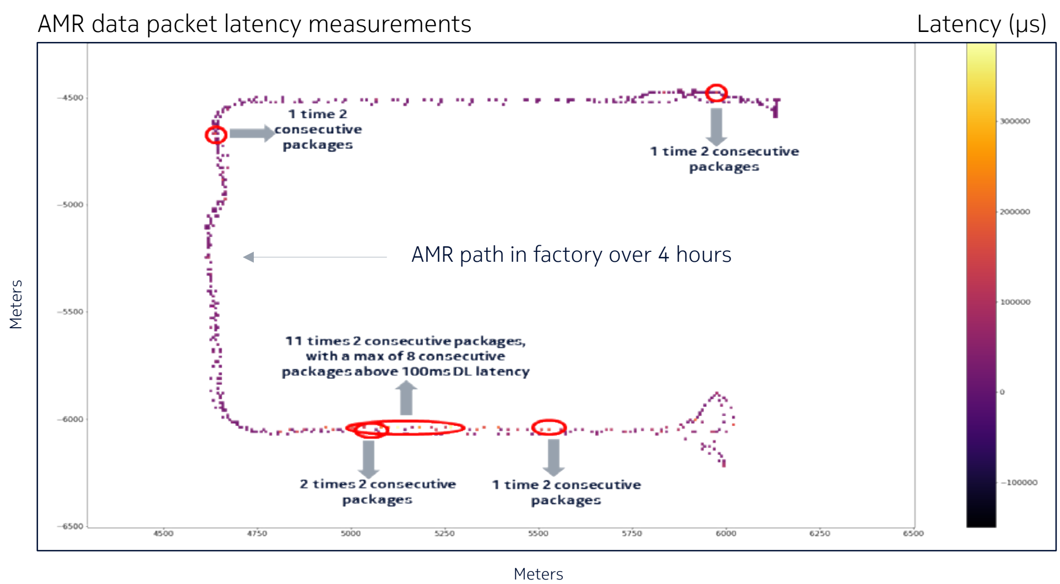
All versions of LTE and 5G, licensed and unlicensed, can be used for automated systems, AGVs, robots and IoT. They can also be used for asset management with precision indoor positioning, GPS/cellular outdoor campus positioning and global tracking and condition monitoring. They can support low-powered sensor networks, as well as high bandwidth video and augmented reality (AR), with 5G able to support greater densities per area of both low- and high-bandwidth devices.

Performance assessment

In the Nokia factory in Oulu, Finland, the use of 4.9G/LTE started in as early as 2015 to solve the problem of communicating with AMRs in the warehouse and the factory. They had previously used a Wi-Fi network but were struggling with loss of connectivity and the time required to re-set AMRs that had lost connectivity. The new solution saw a 98 percent reduction in system maintenance work. It went from requiring daily interventions to once a month maintenance. The efficiency of the material feed operation increased by 30 percent.

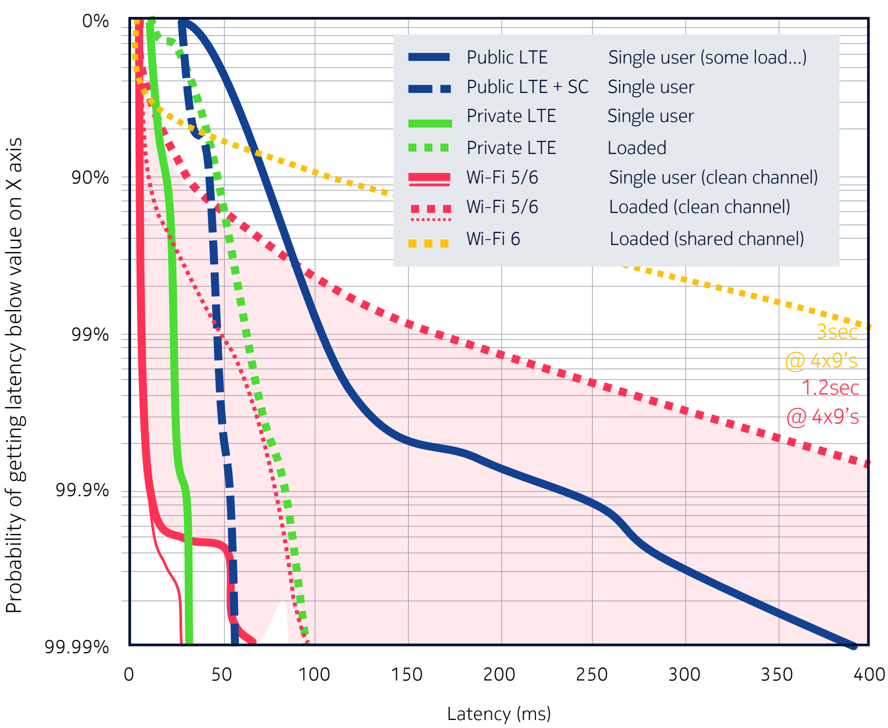
Nokia did an assessment of how well AIVs performed on the private wireless network vs. Wi-Fi. Over a four-hour period, the total delay time only exceeded 100 ms on 21 out of 344,537 packets sent or 0.004 percent of all packets sent (figure 5).

Figure 5. Benchmark of AIV communications over four hours



In separate testing done by Nokia Bell Labs and Aalborg University, they compared the performance of a loaded Wi-Fi network against a loaded LTE network. A single user on a Wi-Fi network can often see performances better than LTE. But as soon as an access point is loaded with many users, Wi-Fi performance degrades quickly. Even with Wi-Fi 6 in a clean channel, with a reasonable loading the Wi-Fi 6 latencies are on par with 4.9G/LTE, but as soon as the channel is shared (very often the case in an industrial sites with many Wi-Fi networks) or when there are more than 20 devices connected per access point, the latencies goes above that of 4.9G/LTE.

Figure 6. Latency measures for Wi-Fi vs. public and private LTE

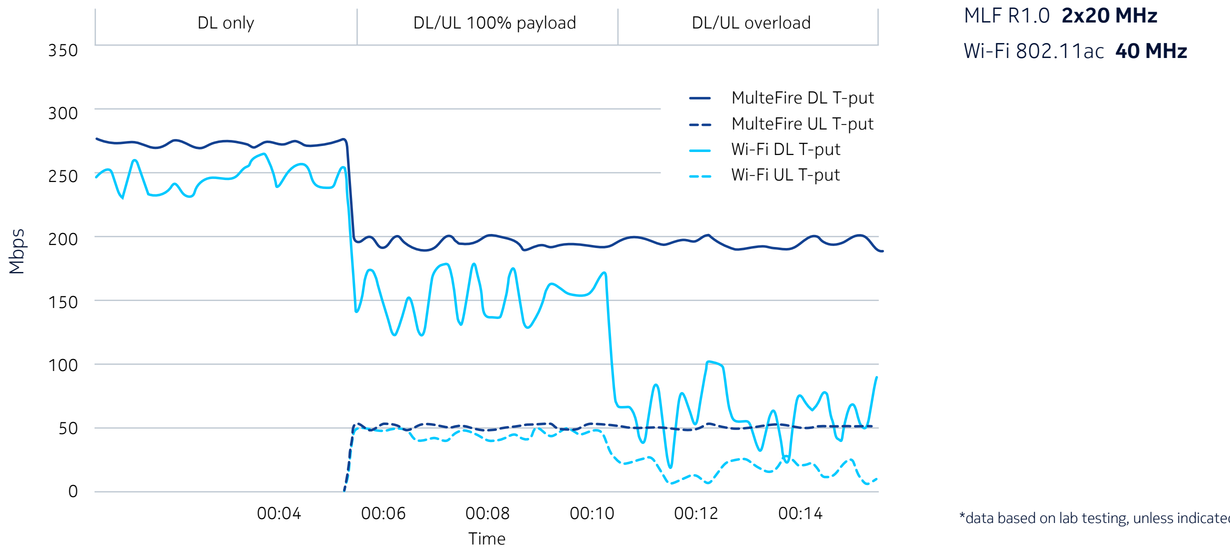


Wi-Fi's poor performance when loaded is primarily related to the scheduler used in Wi-Fi. The 4.9G/LTE scheduler prioritizes resources in frequency and time domain every millisecond to maximize radio efficiency. There are mechanisms that constantly monitor each device's radio condition and adapt the encoding and number of resources used, for instance, allocating less "noisy" sub-frequency blocks to enhance the chance of getting the data through the first time but also improving the encoding rate to get more data through.

A Wi-Fi network scheduler design is not as robust as a LTE or 5G radio network. Wi-Fi uses a "listen-before-talk" design where WiFi devices that want to connect to the access point continue to signal to it requesting access to a channel. Upon granting the request the device will transmit/recieve data until it is finished and only then will release the channel to other devices.

This makes latency on a Wi-Fi network unpredictable, even on a lightly congested acess point. Throughput on a Wi-Fi network also impacted when the access point was loaded. Performance measurements were taken comparing the performance of a 4.9G network versus a Wi-Fi 5 (802.11ac) network under three loading conditions: in the downlink only, when both the downlink and uplink were fully loaded and when both the downlink and uplink were overloaded (figure 7). 40 MHz in the same 5 GHz band was provided to both 4.9G and WiFi networks. IThe results show that in both the downlink and uplink, the throughput performance of the 4.9G/LTE network was more consistent and better than a WiFi network under different loading conditions.

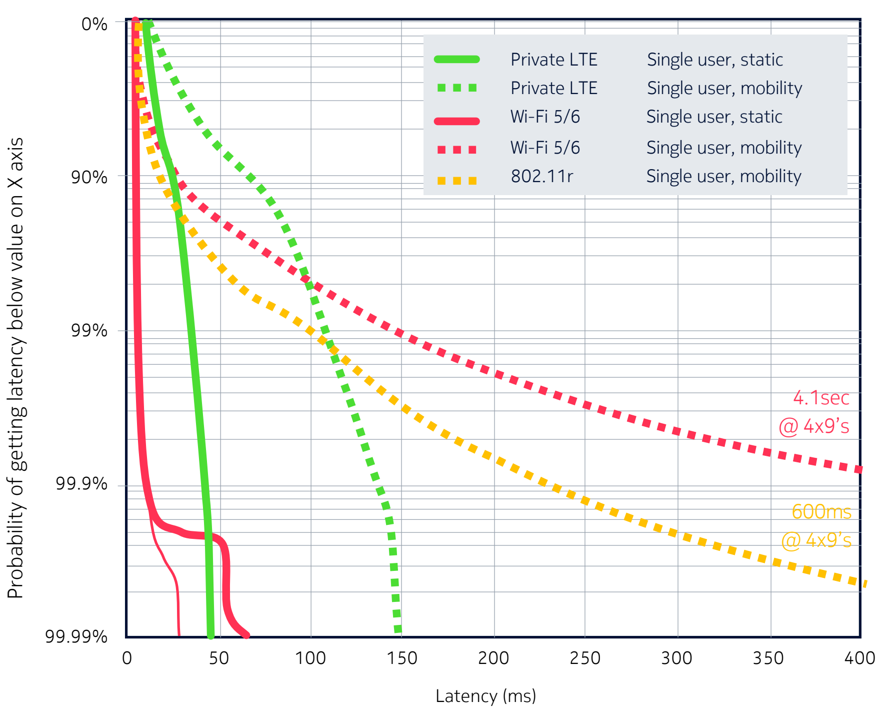
Figure 7. Comparison of throughput stability under load of 4.9G/LTE vs. Wi-Fi



*data based on lab testing, unless indicated

Bell Labs and Aalborg University also tested mobility of devices and how latency increased more on the Wi-Fi network when multiple devices were mobile at the same time. Latency delays reached over four seconds before going beyond our measurement parameters at maximum load (figure 8).

Figure 8. Comparison of LTE and Wi-Fi latencies for mobile devices.



In summary, private industrial wireless networks that can provide a single connectivity platform for end-to-end automation are now a viable alternative to the mix of wireless technologies required heretofore. Companies like Nokia have provided early demonstrations of the power of these technologies. With the availability of unlicensed, shared and licensed spectrum, as well as devices and chipsets, private wireless networks using 4.9G/LTE and 5G can now be used to support a long list of use cases in the automated warehouse.

Warehouse automation use cases

There are several ways in which industrial-strength wireless based on LTE or 5G can support operations in the warehouse. The following summarizes the typical automation use cases, quickly highlighting the key trends in each of these areas and how they can benefit from the use of LTE/5G wireless solutions.

1. **Conveyor and sortation systems**
   Conventional systems are being replaced by modular conveyors (MDR), which allow independent operation for individual segments. MDRs are critical for enabling increasing goods-to-person workstations, robotic piece picking and bag order fulfillment. Easily reconfigured, MDRs increase flexibility and scalability, which calls for wireless as opposed to cabled connectivity. Private wireless can support data capture and analysis for improved maintenance practices including sensors that generate data and predictive recommendations to minimize system downtime. The same sensors that monitor the condition of equipment can alert a warehouse management system (WMS) to reallocate material flow from an overactive area to one that still has capacity, or simply slow down conveyors during lighter periods to reduce wear and tear.

2. **Overhead systems**
   Especially good for omni-channel fulfillment, overhead systems are a very flexible system for order fulfillment for either stores or direct-to-consumer delivery. Pouches are tagged with RFID and the RFID readers can be linked to the LTE/5G network. This allows for more reading points, and it speeds reconfiguration. Data from the readers can be processed in the edge cloud that supports the wireless network by software analytics that manage the efficient loading, buffering, transport and sortation of pouches.

3. **AS/RS**
   These are dense, automated systems for storing and retrieving both palletized and non-palletized goods in a small footprint and at varying speeds. One example of a non-palletized AS/RS is the “grid” developed by Ocado using robotic shuttles to lift and sort crates, either storing them or retrieving and transporting them to picker stations. The shuttles move horizontally over the AS/RS stacks, reaching down into them much like mini-overhead gantries. Moving at close to 9 mph (13 ft/s), the LTE wireless network can keep the 1,000+ shuttles connected to central software that manages their movements and coordinates the entire workflow. This contrasts with the Amazon AS/RS system, where the maximum speed of the robots is 5 mph on a modified Wi-Fi network.

4. **Automated data collection (ADC)**
   Also known as automated identification and data capture (AIDC), these systems use a variety of ways to identify items from bar codes and optical character recognition (OCR) to RFID and BLE tags. The data collected on handled goods is used by warehouse automation software to optimize warehouse processes and provide visibility of goods across the distribution center, as well as upstream to manufacturers and downstream to retailers and their customers. There is a trend towards optical scanners that not only capture the product ID, but the condition of the product and handling process issues. Handheld and wearable wireless devices are increasingly using consumer operating systems such as Android for more intuitive human interfaces; thus, it is natural for them to connect to LTE and 5G

networks, much like their consumer counterparts. They can also be used with 3D capture and imaging software and augmented reality to help with packing — the analytics software helping to calculate the best way to use the space and protect the most fragile goods.

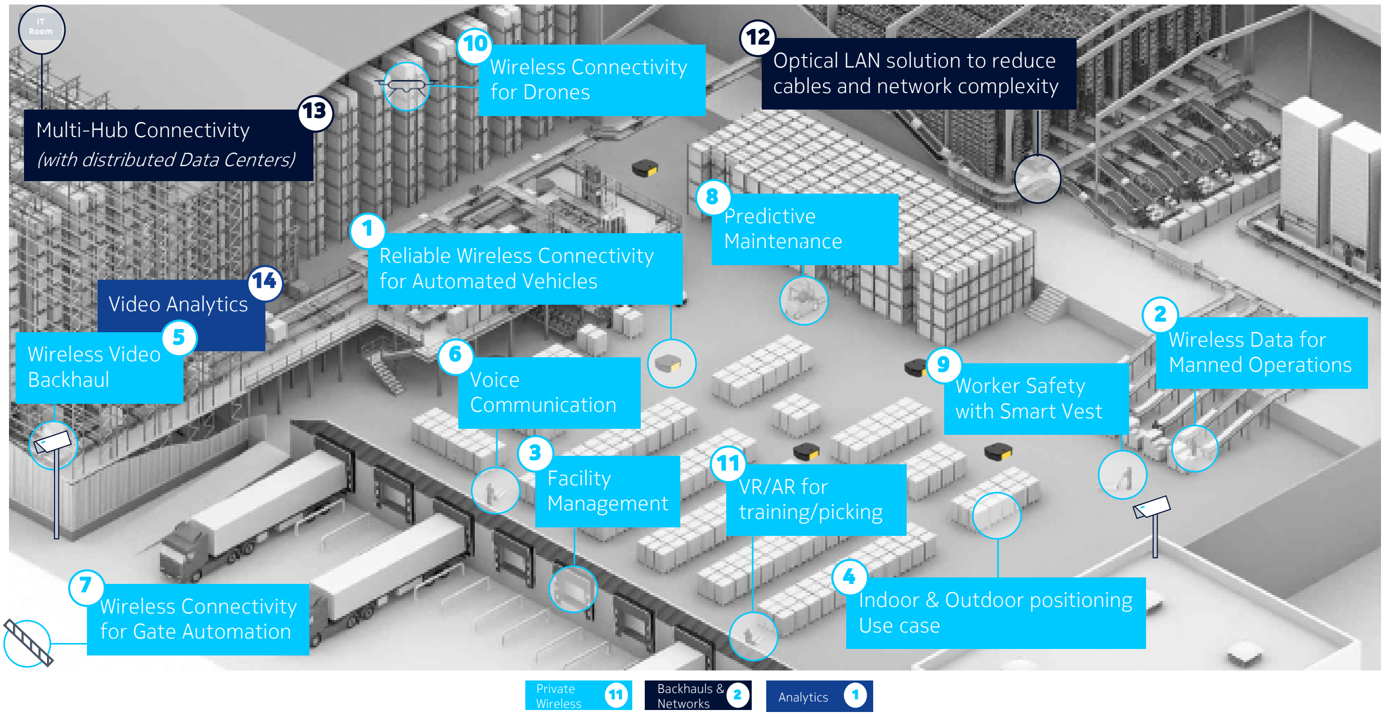
5. **Autonomous mobile robots (AMR)**
   The challenges for many warehouses are dealing with small, multiple SKU orders and shorter delivery times. To pursue automation, 3PLs especially require highly flexible and configurable systems. Although AGVs are heavily used in most automated warehouses today, in order to promote agility and reconfigurability, the industry is moving to AMRs, replacing AGVs over time. AMRs can be used, for instance, to create a highly flexible AS/RS system such as Amazon's Kiva AMRs.

   AMRs used in automated warehouses will require robust wireless connectivity as they self-navigate using a variety of technologies (e.g. LiDAR, SLAM, HD cameras) through the facility. Through data exchanges with other AMRs and the central warehouse management Fleet Management software, they dynamically adjust their routes in real-time to avoid other AMRs and, based on predictive analytics, they can adjust routes in real time to optimize batches and pick paths. Some AGV vendors are adding dynamic routing and 3-D sensors to become more like AMRs, which also require more robust wireless connectivity. LTE and 5G wireless will support much higher speeds for AMRs than Wi-Fi, as discussed above.

6. **Picking** — The industry largely relies on handheld scanners and voice-directed systems for manual picking operations today. There is a multi-modal trend, however, to combine voice and data systems to support voice-directed work, the use of voice commands, barcode or RFID scanning as well as mini-tablet-like information screen. As with AMRs, warehouse management software can use algorithms to constantly assess orders and adjust pick paths to optimize batches. Both LTE and 5G support push-to-talk and push-to-video communications, as well as the higher bandwidth requirements for these new multi-modal terminals. If manual pickers are using UTVs to move at speed around the warehouse or yard, Wi-Fi will be unable to support these devices and traditional private radio will not be able to support the data. LTE/5G wireless will enable multimedia as well as mobility.

   At the cutting edge, companies like DHL are trialing augmented reality goggles for "vision picking" that will require the higher bandwidths provided by LTE and 5G. On the horizon, robotic picking is getting faster and more accurate. It is expected that in some industries such as pharmaceuticals, grocery, and health and beauty, where SKUs are considered more pickable, robotic pickers will be adopted more quickly. Since many of these applications will be goods-to-robot scenarios, cabled communications are possible, however, wireless allows for rapid reconfiguration and scaling.

Nokia solutions addressing USE CASES in Warehouses and Hubs Operations



Other warehouse use cases

Once added to any facility, industrial wireless based on LTE and 5G can be used for a variety of other tasks not necessarily directly related to warehouse automation. We summarize these below.

1. **Worker health and safety** — beyond arming workers with multi-modal scanners, headsets and vision-picking goggles, there is the entire area of smart personal protective equipment (PPE) that can be used to increase worker safety, alerting them to approaching vehicles, environmental hazards and other dangers, or monitoring their vital signs such as heart rate and body temperature to proactively warn them of health issues.
2. **VR/AR training** — Beside helping workers to pick items, AR and virtual reality (VR) technologies can be used to train workers to operate more efficiently.
3. **Indoor and outdoor positioning** — 5G radio-frequency (RF) positioning promises to achieve sub-meter positioning using multi-meter (MM) waves, although it requires dense radio coverage, so is one of those applications that makes most sense if 5G is already being used for another use case.
4. **Drone and video surveillance** — both LTE and 5G support drone control and can backhaul video from the drone and stream audio to the drone for directing people verbally during an event.
5. **Video analytics** — besides the video analytics used in optical scanning, CCTV and drone video can be backhauled using wireless and analyzed in the 5G edge cloud to identify everything from security intrusions to traffic congestion and obstacles for AMRs.

6. **Predictive maintenance** — warehouse automation involves a lot of mechanical infrastructure that will need regular maintenance. Data from sensors on the equipment can be logged and analyzed in the 5G edge cloud to move from scheduled maintenance to condition-based and, finally, predictive maintenance for assets.

We see the adoption of warehouse automation going through several evolutionary stages as different technologies come into play. The use of private wireless technologies will allow warehouse operators to move to more flexible systems utilizing different robot suppliers, control the movements of robots more precisely and coordinate their movements collaboratively, meaning robot speeds can be increased with safety. Finally, combining private wireless connectivity and edge computing will allow for simpler robot designs where intelligence is moved to the edge cloud making for lighter, less expensive units that require less maintenance.

Summary

Spurred by the growth of e-commerce and pandemic-related supply chain issues, the digitalization and automation of the warehouse has accelerated and is expected to grow by 40 percent in 2021. We see that e-commerce and multi-modal retail will be more likely to develop fully automated solutions, while third-party logistics companies will likely move more carefully and prioritize flexibility and scalability in their solutions.

Whichever approach warehouse operators take to automation, they need to think carefully about their long-term goals and develop an implementation strategy that doesn't paint them into a corner. Taking a platform approach to communications and cloud will be a better approach then implementing a series of disconnected point solutions that will require extensive integration work in the future.

Across all industries, there is a lot of excitement around 5G because it promises to provide a truly flexible platform for Industry 4.0 automation. We have seen that much can already be done with 4.9G/LTE, the latest version of the previous generation, and it can be seamlessly evolved to 5G when the time comes. Both technologies have the capability to support everything from low-powered sensor communications to mission-critical voice, data, video and AR/VR applications. They are engineered to be more reliable, secure and provide superior coverage, and they support mobile applications.

Warehouse operators wishing to deploy these technologies can purchase their own private wireless networks using solutions that in most cases have a better total-cost-of-ownership than comparable Wi-Fi networks alone and, certainly, better than deploying four or five network technologies, as we have discussed. They can also turn to mobile operators and third-party private wireless providers, such as the Nokia Digital Automation Cloud, for private-wireless-as-a-service. In the case of Nokia DAC, this also includes integrated cloud services and devices and applications already pre-engineered for the warehouse automation market.

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

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