5G Opportunities in Warehousing

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As capabilities of fifth generation wireless technology (5G) improve, adoption will go beyond current urban cellular networks into industrial settings enabling the IoT landscape. 5G primarily delivers value by enhancing mobile broadband through ultra-reliable, low-latency signals and massive machine-type communications. With the concurrent development of 5G and industrial automation, replacing Wi-Fi and LTE services with 5G networks offers an opportunity to enhance scheduling, latency, jitters, and redundancy in demanding applications. Additionally, the equipment redesigns and upgrades to operate in 5G will pave the way for innovation in operational strategies previously constrained by network capabilities.

In this paper, we consider the warehouse operations and functions that are most likely to benefit from 5G adoption. The areas 5G will impact in warehousing are robotic operations, such as AGVs/AMRs; augmented reality devices for picking, training, and maintenance; inventory management through real time asset tracking; equipment battery life from network slicing; and data security. In general, the capacity and low-latency available through 5G will support continuous data transfer that is sufficient to support real-time analytics and decision-making. Knowing which functions will benefit most from 5G will provide strategic guidance for upgrading equipment and operations and aid in developing the factory of the future.

Keywords—5G, Warehousing, Inventory Management, Industry 4.0

I. Introduction

5G technology has the potential to drive transformation across all industries. New use cases, technologies, and even business models will emerge from this period of hyper-connection. Fast, intelligent internet connectivity enabled by 5G technology is expected to create approximately $3.6 trillion in economic output and 22.3 million jobs by 2035 in the global 5G value chain alone [1]. The first 5G enabled devices are on the market and 5G network deployment has begun. In the immediate future, most 5G innovations involve public consumers, where operational costs are justified through the ease of implementation into a very large market. As 5G is integrated into the consumer space, organizations throughout the supply chain need to learn, identify, and predict distinctive use cases to leverage the benefits of 5G. In this paper we review current 5G technical specifications, applications, and case studies for the purpose of highlighting the warehouse operations and functions that are most likely to benefit from 5G adoption. For each operation or function, we delve into its value, historical progression, and potential impact and transformation by 5G. The functions considered are limited to typical warehousing operations and specifically those with functional limitations under Wi-Fi.

II. Problem Description

To fully realize the benefits of 5G it is important to compare the differences and progression of cellular technology. The launch of 3G in 2001 enabled many new capabilities because 3G technology quadrupled the speed of the previous 2mbps, 2G technology. The next transition, from 3G to 4G in 2009, included Long Term Evolution, widely known as LTE. LTE technology enhanced existing infrastructure and networks, decreasing the cost of reaching customers and enabling a wider coverage area [2]. We are currently transitioning to 5G technology, enabling greater reliability, larger bandwidth, and lower latencies. Larger amounts of data can be processed almost instantaneously, with latency down to nearly one millisecond [3]. The ongoing shift from 4G to 5G opens countless possibilities in the world of robots, artificial intelligence, virtual reality, and other applications currently limited by data transfer speeds.

The emergence of 5G is happening at the same time as advancements in industrial automation, resulting in the general acceleration of industry 4.0 operations [4]. Specific to warehousing operations, leveraging 5G will primarily affect operations supported by automation such as material movements, asset tracking, order picking, and security. In general, 5G will enable artificial intelligence (AI) to control and act with a timely response based on real-time data and satisfy the demands of stringent latency and reliability service requirements [4]. For example, with 5G, automated guided vehicles will leverage real-time data transfer speeds necessary for sophisticated real-time decisions such as rerouting to avoid congestion; vision systems combined with 5G low latency and accuracy will enhance order picking to locate parts regardless of their location; private network opportunities with 5G will provide increased security and individualized reliability and performance; real time inventory management and asset tracking will lead to quicker response times and better decision making; finally, battery life and power consumption will be optimized through 5G enabled network slicing and efficiency. These applications and use cases will enhance warehouse operations, increase efficiency and reliability, and prepare the way for 5G to fully usher in the potential of industry 4.0.

III. Related Research and Results

A. Research and Results for Autonomous Mobile Robots

Technology has driven vast changes to the supply chain; however, specifically within warehousing, autonomous mobile robots are revamping material handling activities. An autonomous mobile robot (AMR) is equipped with numerous sensors and software integrations, enabling the robot to interpret, understand, and move through an environment; navigate around fixed and variable debris; support and enhance human capabilities; and perform tasks such as picking, sorting, and other material handling tasks without human intervention. Autonomous mobile robots improve the efficiency and productivity of a process, either working alongside humans or autonomously enabling labor reallocation.

The predecessor to an AMR, the autonomous guided vehicle (AGV), performs similar functions, but lacks autonomous movement and requires infrastructure investments. The first known AGV was introduced by Barret Electronics in 1953 [5]. In the years that followed, AGVs were integrated into warehousing activities utilizing optical and color sensors along with magnetic strips as guidance technologies. Transistors, microcomputers, radio signal guidance, and programmable controllers were integrated into AGVs as the technology progressed [6]. In 1987, the first AMR patent was granted, launching developments in sensor-based navigation, speech guided AMRs, and neural network and algorithm integrations [6, 7]. Managing and guiding AGVs and AMRs through wireless networks and open-source software systems became an industry standard in the 2010s. Current developments focus on advanced applications, machine learning, and reaching higher levels of autonomy [6].

Current AMR control is primarily performed locally on the AMR with intermittent data transfer occurring in discrete chunks at predefined moments, such as initialization and destination points. Advancements in AMR control algorithms, for example those with machine learning, will require a transition from discrete to continuous data transfer, with sufficient speeds to support real-time decisions and actions. Current networks are insufficient in this sense, but the 5G technology can provide the necessary data transfer speeds. Therefore, it is helpful to review current wireless technologies, their limitations considering AMR operations, and how 5G can overcome some of those limitations.

The most common technology for wireless connectivity to mobile robotic systems is based on the IEEE 802.11x set of standards, commonly known as Wi-Fi. These networks transmit at publicly available frequencies within 2.4 or 5 GHz space and are sliced into channels 20 or 40 MHz [8]. These channels are essentially the pipes that data passes through and the width of these channels significantly impacts system throughput. With Wi-Fi, most of the channels overlap, creating interference, and reducing the effective available bandwidth. The presence of radio noise, common in manufacturing and production environments, further degrades the performance of Wi-Fi [8]. Mobile robots that move in and out of the Wi-Fi coverage could experience severe impairments. A simple conceptual solution to address this problem is enabling robots to receive more channels; however, the increased cost and complexity of this option have rendered it impractical. LTE resolves some issues presented by Wi-Fi but lacks the bandwidth necessary to operate robots without latency issues [9]. With 5G technology, the higher bandwidth sufficiently supports the deployment of AMR fleets that can operate free of latency issues [9]. In discussions with AMR manufacturers and system integrators, the general gauge is that warehouses without 5G technology will quickly become irrelevant. A 5G enabled warehouse will offer the coverage, bandwidth, and latency needed to support time critical applications that require very high capacity and low latency such as that of AMRs.

B. Research and Results for Battery Life

Energy storage plays a critical role in high-tech manufacturing where an uninterruptible power source of constant frequency is essential. It is reported that $80 billion is lost by U.S. industry each year because of short power interruptions [10]. 5G technology and network slicing will enable longer lasting and more efficient battery life. This advancement will improve manufacturing processes and support transitioning to a renewable world.

Network slicing is an essential factor in 5G adoption because of recent advancements in computing and network function virtualization technologies. In network slicing, a physical network is divided into several logical networks, where applications can harness a specific slice and experience tailored and enhanced services. Following the first IBM operating system design that supported time sharing and virtual memory, the concept of network slicing and virtualization emerged. In the 1970s and early 1980s, network virtualization was widely adopted in data centers. Overlay networks, an early form of network slicing, were proposed in the late 1980s. In the early 2000s, a programmable network was proposed in which resource control frameworks were provided to a node operating system [11]. Growth in network slicing technology and approaches continued throughout the 2000s; in June 2021, Deutsche Telekom, Ericsson, and Samsung Electronics announced the world's first implementation of 5G Network Slicing with a commercial 5G device in a gaming application [12]. As time progresses, network slicing will continue to evolve and move into the manufacturing space.

The scalability of 5G systems is a key capability for industrial settings. Networks sliced on a case-by-case basis easily allow the scaling up or down of a specific service. Additionally, each slice is customizable to the necessary specifications of an application. In terms of manufacturing, a great example is that an operator can customize the network for a low power machine application. This specific network, sliced for the low power application, can lead to the reduction of battery drainage, lengthening the life of the battery and time between recharges.

5G technology shows promise in enhancing the battery life of equipment in industrial settings. Because 5G transfers data faster than LTE or Wi-Fi it requires less power to transmit the same amount of data [3]. In terms of efficiency and power the "time to rest" is an important measurement as it describes how quickly a task can be completed allowing the equipment to retreat to its low power, resting state. The high speeds that 5G brings will reduce the time to rest for most industrial equipment and lead to a longer battery life.

In addition, 5G New Radio (NR), a radio access technology standard for 5G, improves efficiency and offers battery saving avenues. 5GNR will reduce transmission power by adopting small cells instead of large cells which have been shown to provide a clearer signal with less power [13]. 5GNR will also enable Bandwidth Part Switching (BWP) in which a device is configured with many varying bandwidth parts and can switch during activity based on the demands of the task [14]. BWP switching has been shown to improve power consumption efficiency up to 45% [15]. Lastly, 5GNR supports a connected discontinuous reception (DRX) mode enabling a device to periodically sleep and wake up. A DRX cycle can be configured based on demands and usage data and can lead to more time in the sleep mode [16]. This time in sleep mode will lead to a reduction in power consumption and can enable greater performance and reallocation of bandwidth in a sliced network.

All in all, 5G power saving techniques aim to maximize time in sleep mode, maintain a small active bandwidth, minimize unnecessary communication, and tailor network slices for specific machine demands. In turn, power saving increases equipment uptime and life spans, improving overall efficiency and decreasing life-cycle operating costs.

C. Research and Results for Virtual Reality & Augmented Reality

5G's low latency and large bandwidth support virtual reality and augmented as a reality in the warehouse of the future. Virtual Reality (VR) is a technology that immerses a user into a computer-generated virtual world by replacing the real world with a virtual world. Augmented Reality (AR) is a technology that "augments" an environment by overlaying computer-generated information into the real world so that the user can complete the task in an easier or more efficient manner.

The basic idea of augmented reality was first demonstrated by Ivan Sutherland in 1968 [17] as a headset that was so heavy it had to be hung from the ceiling. In 1992, Tom Caudell and David Mizell proposed a head-mounted display for construction workers that superimposed the position of cables through the eyewear and projected them onto multipurpose, reusable boards [18]. Caudell and Mizell coined the term "augmented reality". The open source ARtoolKit, released in 1999, further facilitated the spread and growth of augmented reality technology. In the late 2000s augmented reality emerged to the public through video games such as the Eye of Judgement (2007) and the Nintendo 3Ds (2011) [19]. According to an estimate by Goldman Sachs, AR and VR are expected to grow into a $95 billion market by 2025 [20].

The most important and challenging aspect of integrating augmented reality into industrial processes is reducing latency. For the most part, sensor latency levels are imperceptible to humans. However, delays that occur from non-sensor specific data transfers such as haptic responses, loading information from the cloud, and rendering, have a significant negative impact on results [19]. Like latency, bandwidth also limits applications such as 3D reconstruction, pre-processing information, and sending information to be displayed. These activities are currently feasible but experience large delays and low bandwidth. This also impacts the transmission of direct data streams and responses from individuals. The 5G network will provide a mobile data transmission rate 10-100 times faster than current 4G/LTE networks. Additionally, the 5G network will enable a latency below 1 millisecond, again 10 to 100 times better than the current network [3]. Because the feasibility of incorporating augmented reality into everyday interactions is dependent on low latency and high bandwidth, these common activities will benefit the most from 5G technology.

Two use cases in warehousing that will benefit from 5G technology are training and picking. Augmented reality training has already been shown to result in higher levels of trainee engagement, efficiency, and risk reduction. In terms of bin picking, a research study by Smart Factory Lab of the Poznan University of Technology demonstrated the effectiveness of AR technology for identifying materials in a production system [21]. However, the process was slower than that of the traditional technique. 5G technology has the capabilities to improve the speed of these processes and will lead to a higher adoption rate of augmented reality technologies in manufacturing processes.

D. Research and Results for Inventory management

Inventory management involves controlling and optimizing inventory levels through various stages of ordering, storage, and fulfillment. Inventory policies affect every aspect of the supply chain. Poor inventory management can lead to huge losses and failures, while proper management of inventory throughout the supply chain enables an organization to thrive. The visibility of inventory throughout the supply chain is a critical part of this control.

Long before the industrial age, keeping track of inventory consisted of manual counting. Artifacts have been discovered, detailing the counting of livestock and other agrarian items [22]. With the industrial age, Herman Hollerith developed the first modern American computing machine that led to designs aimed specifically at inventory management applications [23]. Barcodes, the primary inventory management tool today, was developed in the late 1940's by Norman Woodland to aid in inventory tracking in a grocery store [24]. In the 1970s developers, inventors, companies, academic institutions, and government laboratories were actively working on RFID, and notable advances were realized at research laboratories and academic institutions [25]. The 1980s became the decade for full implementation of RFID technology. The greatest interests in the United States were for transportation, personnel access, and, to a lesser extent, animals [25]. Today, RFID technology is more efficient and accurate than the bar code system and is increasingly integrated in many industries [26].

RFID is becoming increasingly accepted for inventory management and typical for smart warehouses. RFID in inventory management consists of a scanner that sends radio waves to communicate with an RFID tag, either active or passive. Active tags broadcast a signal for real-time tracking and passive tags are powered by the reader, responding with a signal when in range. Traditional passive RFID tags present many challenges: lack onboard power supply, limited onboard computing power, respond with limited information e.g., electronic product code (EPC), and require a short range with the reader relatively close (2m-10m). A more sophisticated active sensor, however, has the potential to operate as a beacon & receiver and record data. An ideal ecosystem will make use of both passive and active tags, equipped with the underlying technologies that can optimize the tag's operational value.

With enhanced cloud computing and RFID tracking, 5G will drastically change communication throughout the supply chain, enabling large scale smart logistics. Smart logistics is the integration of technology to achieve advanced supply chain monitoring and tracking. Larger computing capabilities and greater machine-to-machine communication, empowered by 5G, will enable cloud computing for supply chain inventory management. Devices will be able to receive and exchange data faster and more reliably. Experimental studies on supply chain information sharing models that utilize cloud computing and the internet of things demonstrate improvements in the overall operational efficiency of supply chain management and realize supply chain information sharing and business collaboration [27].

The benefits of increased efficiency, time, and cost savings achieved through improved cloud computing will be exemplified through RFID tags and digital twins. RFID has promising advantages: simultaneous identification of multiple objects, a battery-free design, and flexible sizing suitable for large scale deployment [28]. With increased bandwidth and latency, RFID tags not only enable the automating of tracking and recording, but also open the potential for real-time tracking and decision-making. RFID active tags with real-time tracking enables the creation of digital twins. This combined with the speed and volume of 5G opens options to leverage the digital twins for real-time decisions. Digital twins are virtual replicas of physical assets, processes or systems that log changes in real time so that companies can quickly respond to events such as delays, shortages, or hazards [29]. The consumer benefits of digital twins include an agile environment, end to end transparency, intelligent optimization, and holistic decision making. From the asset tracking perspective, the 5G network will increase the usage and data capabilities of RFID tracking and enable real time data transfer, enhancing logistics decision making.

E. Research and Results for Data Security

5G technology is leading a plethora of digital transformation initiatives with the potential to revolutionize the warehousing and supply chain industry. However, new technologies also present new potential threats. As Industry 4.0 emerges, mission-critical or industry-specific data, essential for real-time decision making, could be exposed through the various connected devices and applications. The next generation of technology will not be confined to data behind screens and centralized on servers, but will exist amongst sensors, robots, and autonomous processes. This digital transformation will introduce new risks and vulnerabilities through these connected entities. Concurrent with 5G is edge computing: a form of cloud computing that pushes processing out to the edge devices instead of a central processing and storage infrastructure. While this will reduce latency and network issues, it will increase the security risks as the edge devices are more susceptible to physical attacks [30]. Instead of hacking a central unit that can be well protected, a malicious entity has many options to choose to attack. Data will not only be exposed through edge computing but will also become increasingly exposed through the integration of artificial intelligence and machine learning technologies into manufacturing. 5G increases the feasibility of artificial intelligence solutions, presenting an opportunity for novel attacks such as distorting models or changing input data. Risks such as these are unprecedented and are being heavily researched [30].

While it is important to understand and develop solutions to these risks, regulated standards are being created to prevent security challenges in the future of 5G. The Third Generation Partnership Project (3GPP) is a collaboration of seven telecommunication standard development organizations that manages the standards for ongoing mobile communication systems [31]. The 3GPP-approved 5G architecture provides user data integrity protection to prevent tampering of user data. Current standards also enable 256-bit key transmission, which is a safe encryption method [32]. In the future, cryptographic algorithms, developed and enabled by 5G, will be incorporated into standards [32]. Another new feature introduced in the latest standard is integrity protection of the user plane [33]. Integrity protection refers to mechanisms that protect the logic and/or data of particular software. In systems, user traffic is transmitted by what is known as the user plane [34]. Researchers have shown that attackers can exploit a lack of user plane integrity to maliciously redirect traffic [35]. This integrity protection feature has the potential to reduce attacks and protect user privacy. As the 5G timeline progresses, more standards will be established. These standards will enhance the security 5G offers and continue to offset the risks posed by all the possibilities 5G brings.

IV. Future Work

5G has great potential to revolutionize warehousing and many important questions remain to investigate. In broad terms, the interoperability between wired and wireless communication systems along with the cost-effectiveness of the necessary infrastructure needed to bring 5G to warehousing need to be researched further.

More specifically to the areas discussed in this paper, AMRs are a major area of opportunity in warehousing processes. Further research on integrating AMRs with 5G networks requires investigating the responses of AMRs with debris and obstructions in the warehouse, and global controls for real time routing. 5G possibilities for increased battery life have only been expressed in theory. Long term studies need to be conducted in a 5G network to quantify and convey battery savings in an industrial setting. Virtual and augmented reality have been proven to enhance warehousing capabilities. However, minimal research has been carried out with this technology in 5G networks. Therefore, future research should be conducted in 5G networks to realize, confirm, and educate the industry on the potential enhancements 5G can bring to virtual and augmented reality. Within inventory management, 5G has promising advantages, especially regarding RFID tracking and real-time decision making. Further research into managing processes and data interactions between an increasing number of tags, sensors, and machines will be important to realize the benefits. Finally, with an increase in sensors, IoT devices, and networks, there are increased security risks. Future research could examine early detection strategies for both insider and outsider threats and the secure integration and deployment of services at both device and network levels.

V. Conclusions

Research indicates that 5G has the potential to revolutionize warehousing because it creates an environment where it is feasible for data and analytics to function in real-time in conjunction with the operations of the warehouse. 5G will not only advance warehousing operations by enabling greater efficiency and productivity, but also will allow for real-time decision making and an increased responsiveness to customer needs. Warehouses and other facilities will benefit from higher speed networks because of 5G technology. 5G's unprecedented low latencies and high coverage will bring warehousing processes closer than ever, as well as pave the way for new capabilities and technologies that are limited in implementation.

In this paper we reviewed the warehouse operations and functions that are most likely to benefit from 5G adoption. With the increased coverage and bandwidth and lower latency that 5G brings, AMRs, virtual and augmented reality technology, and improved inventory management applications will have the necessary specifications needed to improve speed, enhance time-critical processes, and enable the adoption of industry 4.0 technologies. 5G also has promising advantages from a technology perspective. New battery saving techniques will increase equipment lifespan allowing for a more efficient and productive warehouse environment. Increased security measures and standards will enhance the security 5G offers and counteract some of the biggest risks associated with adopting 5G technology.

The infrastructure investments required for the transition to 5G go beyond the wireless network system itself; hardware and software systems must also be upgraded to function in the environment. Therefore, the contribution of this paper is a categorization of both equipment and function that will yield the greatest benefit from 5G and offer a starting position for facilities considering technology upgrades. To maximize this new technology, a benefit driven framework that capitalizes on the highest value-adding function is a valuable resource.

Further research should be carried out from both a technical and application perspective. Research into necessary infrastructure, allocating bandwidth, and managing processes and data interactions between an increasing number of sources will be important. When considering 5G deployment, requirements and processes will be use-case dependent. It is an exciting time for industry and for warehouses that can leverage and adopt the improvements 5G has to offer.

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