Factories of the Future Enabled by 5G Technology

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Abstract
Fifth generation (5G) wireless systems are expected to be a key enabler for factories of the future. In fact, they are not only seen as an evolution of current mobile broadband networks, but also as an "ecosystem" able (i) to provide the unified communication platform needed to disrupt new business models and (ii) to overcome the shortcomings of current communication technologies. Along these lines, we can expect that the forthcoming 5G technology has the potential to enable a new family of multimedia services and applications in factory scenarios and, at the same time to unlock new business opportunities for manufacturing for the vast community of industries, SME, and academic bodies.

1. Challenges and opportunities of an un-wired industry

As is shown in Fig. 1, there are a number of critical machine-type communication (MTC) use cases such as intelligent transport systems, smart grid, and process and factory automation, that generally are classified according to mobility requirements, packet error rate and latency requirements [1]. However, the industrial automation use case is gaining momentum due to its wide range of applications with very tight to very loose delay requirements where the most stringent latency requirements reaching down to 1-5 ms. At the same time, also the reliability plays a fundamental role for this use case with packet error rate requirements that range from 10-9 to 10-7.

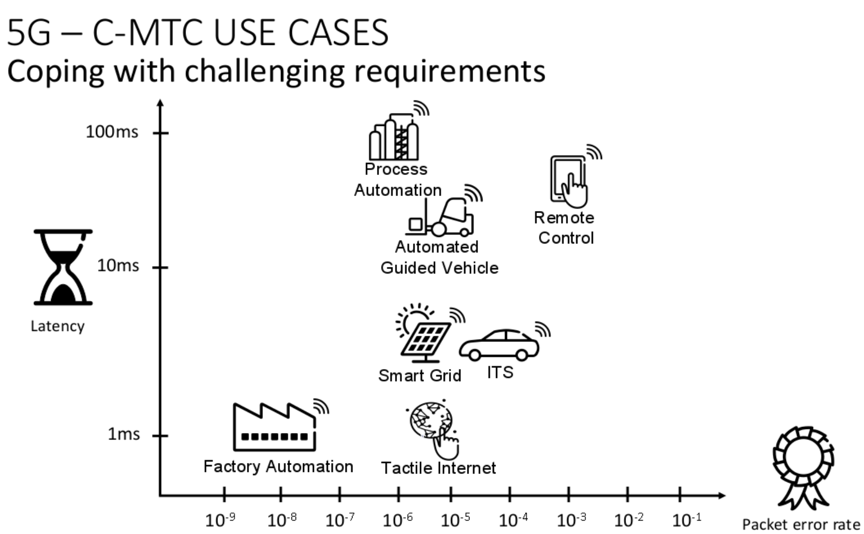

Figure 1: Typical 5G use cases.

In the last years, the Industry 4.0 initiative gained momentum for its purposes to increase the production efficiency, create new business opportunities, and enable ubiquitous high data rate wireless connectivity for the factories [2]. In doing this, the main scope will be to achieve an optimized utilization of resources such as machinery, energy, real-time process data and human expertise. In fact, production cycles have to be drastically shortened to cater for very small, but yet diverse production lots and fast changing customer requirements. However, the drawback of this solution is that short cycles bring new complexity and flexibility that is difficult to handle with current wired / wireless technologies. Therefore, new solutions in terms of communication technologies are needed to cope with such requirements and guarantee more reliable and low latency performance.

Nowadays, communication standards in factory environments are mostly "wired" rather than "wireless". The wired deployment prohibits flexible adjustments of the production lines and are more sensitive to problems due to brakes or fall outs. For this reason, they require constant maintenance and re-adjustments. In order to avoid such costly and time consuming processes, employing technologies of the 4^{th} and 5^{th} generations of wireless communications is envisioned to be a possible solution. In fact, it is expected that un-wired industrial communications will be the key enabling technology to reach the required flexibility and performance requirements [3].

Generally speaking, it is possible to divide the industrial automation use case in two sub-categories that include, on a wide spectrum, most of the applications and services typical of such scenario. On one side we have the ***process automation*** case. In this category, we include all those applications that that deal with monitoring and diagnostics of industrial elements and processes like heating, cooling, mixing, stirring, and pumping procedures. It is worth noticing that these actions are generally tolerant in terms of latency requirements (i.e., can be between 100 ms and several seconds) since measured values change relatively slowly. In addition, these types of applications often cover a quite large area that, in some case, can comprise multiple buildings and outdoor areas.

The second category that can be referred to the industrial domain use case is the so-called ***factory automation***. Here, typical applications are those ones involving real-time control and monitoring of machines in the scope to enable fast production and manufacturing. Due to the small area usually interested by these types of applications, mobility of objects / machines / users is limited or almost stationary. Hence, measurements and control commands need to be applied faster (less than 10 ms), and fail-safe transfer of sensor and actuator signals is important.

2. 5G for Factory Automation use cases

Latency targets of around 1ms for 5G are currently being proposed at ITU-R for the "IMT Vision of IMT for 2020 and beyond" (i.e. 5G); similar low latency requirements are also defined for a group of applications (including critical MTC use cases) denoted as the tactile Internet [4] that are to be addressed by 5G.

Generally, Factory Automation is used for discrete manufacturing where products are assembled, tested, or packed in many discrete steps (automotive, general consumer electronic, good production). For factory automation, the in-time deliveries of messages and high reliability (robustness) are very important to avoid interruptions in the manufacturing process. Typically, every manufacturing step involves many sensors and actuators controlled by one controller (e.g. Programmable Logical Controller) and many of these connections used to be wired which makes them often stressed by repeated movement and other harsh conditions. For this reason, nowadays sensor and actuator nodes with relaxed requirements are usually connected using wireless technology to improve the productivity and increase the availability compared to wired sensors/actuators at difficult locations.

However, the existing wireless solutions in industrial automation do not offer sufficient performance with respect to real-time and reliability requirements. The major challenge for wireless communication systems are high requirements regarding latency, synchronism, and reliability for closed-loop control applications in factory automation.

Low latency and high reliability wireless communication technologies will bridge the gap and can become a key factor for the wide-spread penetration of wireless in industrial communication systems. It is evident, indeed, that legacy 3GPP Long Term Evolution (LTE) solutions and the emerging 5G New Radio (NR) will represent the key enablers to meet such stringent requirements and provide ubiquitous, ultra-reliable, and low-latency connectivity "anywhere" and "anytime". Along these lines, even if LTE is already enough to handle challenging requirements for many factory automation use cases, new types of applications and services are expected to take place driven by the recent enhancements in the context of forthcoming 5G wireless systems.

Table 1: Class definition for Factory Automation in terms of latency and reliability requirement

Factory Use Case	Uplink Latency [ms]	Uplink Reliability	Round Trip Latency [ms]	Round Trip Reliability
Factory automation	1	10^{-9}	2	10^{-9}
Machine monitoring	1	10^{-6}	2	10^{-6}
Printing machine	1	10^{-4}	2	10^{-4}
Packing machine	5	10^{-4}	10	10^{-4}
Process automation	10	10^{-4}	20	10^{-4}

** We note that in some factory use cases the latency (either in uplink or downlink) can be < 1 ms.*

As an example, Table 1 visualizes different levels of requirements for different factory automation applications. The service requirements are usually categorized in 5 classes with respect to the latency and reliability. It is worth noticing that, while the last two one can be accomplished already with legacy cellular systems (e.g., LTE), the first three classes require the new NR solutions to be in place.

3. 5G key to industry transformation

It is expected that 5G wireless technology will represent a key factor to address all the potential challenges and issues within the factory automation use case [5]. In fact, the radio technology that is going to be used should be scalable for the stringent requirements of latency and reliability. However, in doing so it is essential to introduce a minimal complexity in the radio access design and to understand what are the practical limits of the applications and services of the factory automation scenario.

Similar to LTE, NR will use an air interface based on orthogonal frequency-division multiplexing (OFDM) thus avoiding the inter-symbol interference (if certain conditions are fulfilled). Further, to enable low latency and high reliable transmissions new enhancements to the existing wireless systems should be considered. These enhancements span from physical to higher layers and take into account innovative solutions given by the exploitation of new features that are not present in current LTE systems.

For instance, in order to provide high data rate and low latency on the physical layer, NR is expected to use ultra-high frequencies in a range of 3 GHz up to 100 GHz. However, this may lead to serious challenges when considering the high propagation losses due to the short nature of such millimeter waves (mmWave) wavelength. Hence, a redesign of the physical channels is needed in order to allow an early channel estimation and to take into account signal blockage phenomena. Regarding the other layers of the protocol stack, due to the usage of mmWave frequencies, the numerology should also be revised compared to what is used for LTE. Novel solutions in this sense are represented by the reduction of the transmission time interval (TTI) in a range of 500μs-60μs, and the adoption of a wide range of carrier frequencies and bandwidths.

Further, the enabling of new factory use cases by the 5G technology is strictly related also to the network architecture. The general idea is to exploit multi-connectivity and a tight integration between LTE and NR. This new concept, named LTE-NR dual connectivity (LTE-NR DC), is able to guarantee an increased connectivity robustness, enhanced coverage, and very low delays.

Finally, another technology able to cope with the stringent requirements that the industrial use cases may require is cloud computing. In fact, the enhancements that this technology is having towards 5G provide a way to exploit virtualization and consolidate computing resources, with minimal upfront investment, thereby enabling the worldwide availability of services and information. If we consider that in most of the factory processes a large amount of data has to be delivered (e.g., from multiple teams in remote locations) to a remote host and then analyzed, cloud computing is expected to enable the communication of such complex (and large) data and to perform large scale, complex computing operations.

4. Conclusion

A new industrial revolution is about to take off. In fact, the recent advances achieved by the current mobile and cellular systems posed the basis for new factory services and applications that require new modifications and solutions to meet challenging latency and reliability requirements. Related to this, the scale of information that will be exchanged across machines, robots, engineering and production intelligence, and the workforce (blue and white collar workers) will grow several orders of magnitude. In this scenario, 5G NR is expected to be the key technology to overcome the challenges and issues related to the industrial domain. As a matter of fact, 5G NR is coming and will bring with it a new radio interface capable of providing enhanced capabilities, e.g., sub-millisecond radio transmission, a failure rate down to 10-9, and a minimal additional complexity to the network infrastructure and architecture. However, the standardization is still ongoing and new features / novelties will be discussed with the aim to bring current factories to always more "digital" entities.

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