SIEMENS

Ingenuity for life

5G communication networks: Vertical industry requirements

Executive Summary

5G, the next generation of mobile and fixed communication, is on the horizon. It will play an important role in the future worldwide communication infrastructure. 5G will not only be an evolution of mobile broadband networks, it will bring new network and service capabilities.

This is well known in the growing 5G community. A large number of initiatives are collecting requirements from a broad range of industries and play a vital role these days. Especially industrial networks need to meet a variety of requirements, depending on the industry they will support. The white paper "5G in vertical industries" [2] summarizes requirements from the main vertical sectors in Europe, namely automotive, transportation, healthcare, energy, manufacturing, media and entertainment.

As a major player in most of the aforementioned verticals, Siemens offers comprehensive products, solutions and services based on powerful, integrated communication networks. These networks are vital to drive efficiency across the entire value chain, from the field level to the management level. Use cases include efficient communications in wind farms, end-to-end network solutions for manufacturing, road and rail, or reliable communications under the harshest conditions in the oil and gas industry.

Future application fields will depend on a communication infrastructure going beyond current 4G systems, which were optimized to provide mobile broadband data access. In addition to the never-ending "deliver more" requirements, i.e. higher peak data rate, more capacity and higher cost efficiency, novel requirements have to be met for the operation and maintenance of distributed industry-grade systems. Examples include network reliability, quality of service, response times (latency), battery lifetimes (years instead of days) and reduced power consumption in cellular networks.

Furthermore, it is anticipated that millions of devices will "talk" to each other, including machine to machine (M2M), or more general x-2-y use cases. The number of connected devices supported by future networks is therefore crucial.

These devices will do much more than simply connect to a network and transmit data. They will use their own embedded computing resources to combine and process both device-internal data as well as external data so as to provide users and other devices with value-adding information as opposed to merely raw data. Rather than just having a simple network interface, devices will offer a rich set of web services which can be accessed by users and other devices. As a simple example, a device might recommend a maintenance strategy or inform about its maintenance history, rather than just sending raw data like oil pressure and temperature. Such scenarios have to be supported by 5G and the requirements derived from such use cases have to be taken into consideration.

The design of future 5G networks has a direct and significant impact on Siemens' business. Siemens is therefore actively contributing to the development of 5G. An overview of the requirements which should be considered from a Siemens perspective is provided in the following table, including a comparison with current promises. They will be explained in more detail in the following sections.

Category	Requirement	Explicit 5G promises (according to [1], Figure 2)	Consolidated requirements from verticals - Siemens view
Industry-grade Service Quality	**Realtime capability – Latency**	5 ms (e2e)	1 ms (local) 5 ms (long distance)
	Realtime capability -–Jitter	-	1us (local)
	Bandwidth	Peak data 10 Gbps Mobile data volume 10 TB/s/km² Number of devices: 1 mio/km²	kbps ... 10Gbps
	Time period of information loss during failures	-	none (seamless failover)
	Availability/coverage	-	ubiquitous
	Range (distance between communication neighbors)	-	0,1 m ... 200 km
	Reliability (minimum uptime per year [%])	99,999%	99,9999%
	Mobility	500km/h	500km/h
	Outdoor terminal location accuracy	<1m	0,1 m
	Multi-tenant support	yes (Network Slices)	yes
Operation and maintenance	**Non-standard operating conditions**	Energy consumption reduced by factor 10	• Battery powered devices with >10years lifetime • Harsh environments (weather, vibrations, heat, dust, hazardous gases, etc.)
	Ease of use	-	• Communication services approach • Plug and play device (sensor, actuator, controller) integration
	SLA Tooling	-	Service Level Agreement (SLA) monitoring and management tools for provider and consumer
	Service deployment time (time between service request and service realization)	90 min	hours
	Private 5G infrastructures	-	yes
Non-technical	**Scalability: Number of devices per km²**	10^6	10^5
	Globally harmonized definition of Service Qualities	-	yes
	Technology availability	-	>20 years
	Globally simplified certification of ICT components	-	Yes
Assured Guarantees		-	mandatory

Table 1: 5G Promises vs. Vertical Requirements (summary)

SIEMENS
Ingenuity for life

Relevance of 5G technology and 5G-based public networks for industry

Communication is a major element of most industrial solutions already today. In many cases, these solutions pose very stringent requirements on the underlying communication infrastructure. Dedicated and/or domain-specific technologies have been developed to meet these requirements. However, the use of dedicated communication technologies leads to increased efforts and costs for construction, operation and maintenance along the complete lifecycle. For the growing number of industrial use cases that are distributed over a wide area (e.g. smart grids) or cross-domain, the costs of deploying and integrating dedicated communication infrastructures become outright prohibitive. Consequently, there is a clear tendency to use standard technologies, enriched with industry-specific features if necessary. This approach not only leverages the existing, public communication infrastructure, it also enables interoperability across domains. In this context 5G is expected to provide an important common technical basis, similar to the Ethernet's impact on the industrial world.

Today's public networks are very often not equipped to serve the more stringent industrial requirements, either due to lack of a sound technical basis or due to a missing positive business case for all involved players. 5G is expected to provide the technical means, flexibility and cost efficiency to significantly improve this situation. 5G will provide a new architecture for a seamless end-to-end connectivity. It is not only about radio access/mobile networks but about seamless connectivity. It will bring new network and service capabilities. The expected time line is a market introduction around 2020, with deployment peak in 2040. It is the vision of 5G to provide the means for the tactile internet, for massive and ultra-low-latency machine type communication (MTC) and also for enhanced mobile broadband (eMBB).

If future generations of general-purpose communication technology take industrial requirements sufficiently well into account, it will be increasingly possible to build industrial systems with off-the-shelf communication technology, without relying on dedicated industry-specific standards. This will result in lower cost and improve interoperability with the outside world even further. This is expected to apply in particular to 5G technologies. Ideally, such off-the-shelf communication technologies will become available for industry-grade applications with no or little adaptations.

This does not mean that industrial applications will no longer need dedicated communication solutions. Industrial applications are often faced with harsh conditions, requiring special protection against dust, humidity, extreme temperatures and the like. Furthermore, the need will remain to implement application-specific protocols on top of the basic communication protocols. However, if the right choices are made today, industry-grade communication gear and general-purpose communication gear will increasingly share the same core, with significant technical and economic benefits.

For many new application fields, such as smart grid, connected mobility, remote maintenance, smart logistics, or Industry 4.0, this is crucial because systems and solutions in this context are typically distributed over a wide area. They will not have the luxury of dedicated communication infrastructures, and rather depend on the public communication network. Furthermore, the growing interlinking of different industrial domains will have to rely on the public network.

1. Requirements from industry perspective in detail

As described in the section before, the realization of service guarantees has to be taken into account to make the wide area network/public network infrastructure available also for industrial purposes. More specifically, table 2 provides an overview on the specific requirements for selected vertical domains as well as a comparison of these requirements with the current 5G vision. These requirements can be sorted by some categories as follows:

Requirements to support industry-grade service quality

- **Real-time capability – latency, jitter:** In industrial applications, data are often exchanged as part of a control loop, where transmitted data (e.g. a command signal or a critical sensor value) need to trigger a defined response (e.g. closing a valve) within a defined time interval. In order to achieve this, the transmission of the data has to be done within strict latency and jitter (= latency variation) bounds. Depending on the application the latency guarantees can go down to milliseconds (ms) range and the jitter guarantees to microseconds (μs) range. The shutdown of a machine by means of a remote emergency switch usually needs to be triggered in a matter of milliseconds. For motion control applications (e.g. controlling the motion of a machine tool) the requirements are even stronger (<100 μs), whereas for less demanding applications, "real-time" may be a matter of seconds or even minutes.

- **Bandwidth (minimum bandwidth to be guaranteed):** Industrial applications are less about the maximum bandwidth and more about the guaranteed bandwidth. The amount of bandwidth which has to be guaranteed is relatively small in most cases compared to the typical broadband applications addressed in the telco/multimedia arena. However, the demand on bandwidth may also grow for industrial applications in future (e.g. streaming of data in multiple sensor environments or video supervision).

- **Time period of information loss during failures:** Many industrial applications are mission critical. In some of these applications, the need to ensure continued operation implies that in case of an equipment failure it must be guaranteed that all data in transit are preserved.

- **Availability/coverage:** Many industrial applications are realized in rural areas. For these a suitable connectivity has to be assured which in many cases will have to rely on mobile access techniques, since establishing wireline connectivity is much too expensive.

- **Range:** The distance between neighboring communication nodes can be very different in industrial systems depending on the domain and on the specific application. It varies over many orders of magnitude. From a technical point of view, this requirement is of major relevance to make 5G-RAN technologies applicable to private networks for industrial purposes.

- **Reliability:** Assuming that the required 5G-based communication services have been set up or contracted, their uninterrupted operation needs to be assured for a specific portion of the time throughout the year.

- **Mobility:** In many industrial use cases the devices which have to be connected are not static but are moving with some maximum speed. Even in such cases, the communication services must remain available with the requested service quality.

- **Outdoor terminal location accuracy:** The rough or even exact location of a connected device can be important information for industrial applications/systems. Ideally such information can be provided by the 5G infrastructure with the required accuracy and without further proprietary adaptations.

- **Multi-tenant support:** As it is already very common in telecommunication and enterprise environments, industrial environments increasingly need to handle different stakeholders using the same physical infrastructure to run their services, e.g. for automation, video supervision, remote services, office applications, etc.. This has to be supported while still assuring the communication service quality level avoiding conflicts between the stakeholders' interests**.**

Operation and maintenance requirements

- **Non-standard operating conditions:** The absence of low-voltage power supply can be an issue in the field, creating the need for battery- or energy-harvester-powered ultra low-power area networks with a corresponding low bandwidth. Harsh environments, including wind and weather, vibrations, heat, dust or even hazardous gases may also be a challenge for communication equipment.

- **Ease of use:** Communication networks should be able to be planned, set up, operated and maintained without in-depth knowledge of communication technologies and with a minimal time effort. The communication network should provide so-called "Communication Services" with clearly defined quality levels, which simply can be used without taking care how these communication services are realized.

- **SLA Tooling - Monitoring and Management for 5G service providers and industrial consumers:** Since the fulfilment of service guarantees (industry-grade quality of service) is of utmost importance for mission and business critical industrial solutions, there need to be means for a proper monitoring and management of the Service Level Agreements (SLAs) from both perspectives: the service provider has to be sure that he provides the agreed service quality, the industrial user has to monitor that he really gets the service according to the SLA. 5G needs to provide the technical basis for such tooling.

  Moreover, for identifying and reacting on fault situations as fast as possible, mechanisms need to be provided for diagnosis, fault localization and restoration responsibilities and procedures.

- **Service deployment time:** Today, end-to-end services traversing many network domains, covering large distances or asking for specific quality properties need a long time (in the order of weeks to months) to be setup by the service provider. The reasons for this are suboptimal processes, technical inflexibilities, required manual interventions, missing suitable interfaces, etc. For remote services on demand and many other services this is not acceptable. Significantly reduced lead times are needed.

- **Operation of private 5G network infrastructures:** Leveraging the full potential of 5G can only be achieved if from the very beginning the set-up and operation of 5G infrastructures can be done also in a local and closed environment without the involvement of a 3rd party network provider and without sharing the infrastructure with other (potentially less controlled) users/applications. As a prerequisite specific parts of the spectrum needs to be available for such specific infrastructures.

  The need to keep the operation of local/closed 5G networks in the responsibility of the industrial operator are mainly due to system criticality: the dependence on 3rd parties is minimized, the transparency in the level of compliance with required quality levels is intrinsically given, and responsibilities and liabilities are much easier to determine. All this leads to a significantly reduced risk for the industrial operator. In addition, maintenance strategies of the industrial solutions will be very different to the ones applied by a 3rd party network service operator.

Non-technical requirements

- **Scalability (huge number of small devices):** “Sensors and actuators everywhere” implies that more and more physical devices are connected to the network and produce continuous streams of data.

- **Globally harmonized understanding of QoS-related SLAs:** Distributed industrial solutions do not stop at national or service provider borders. Therefore a common understanding and definition of industry-grade QoS is required across national borders and between providers. This is the only way to provide service guarantees beyond connectivity in an end-to-end fashion. To assure that such end-to-end services can be set-up in a timely manner, fundamental industrial service/SLA profiles should be available, globally accepted and offered. This way long lasting negotiation periods with several network service operators can be avoided.

- **Technology availability (long-term availability of technology and the related infrastructure):** The lifetimes of industrial solutions are typically in the range of several decades. In order to ensure continuity, any underlying communication solution has to be available throughout the whole lifetime. Therefore an availability of 5G technology (components, spare parts, and infrastructure) over at least 20 years has to be assured. In this context also backward compatibility is of major importance. Moreover, today's 2G/3G/4G deployments and assigned spectra which are in use for vertical purposes already today should remain available for a similar time frame.
- **Globally simplified certification for use of 5G technology:** Industrial solutions are designed for international use. In many cases specific certifications have to be applied before this is legally possible. This will also include the certification of 5G-based communication solutions, especially concerning components carrying wireless interfaces. Region/nation specific certification procedures which are not accepted by other countries other are very cumbersome and expensive. Thus the 5G development should already foresee the means and the technical capabilities to successfully pass such certification processes. Moreover, a certification obtained in one country should be accepted by other countries in order to avoid multiple cost-intensive certification processes prior to deploying a system globally.

Assured Guarantees

In most cases the requirements of industrial solutions are much more stringent than those of consumer-related data, voice, video applications or enterprise services: service guarantees have to be given for several communication aspects, like bandwidth, latency, jitter, outage time in case of a failure, etc. It is not about the pure maximum performance of one or another of these parameters mentioned – it is about guaranteed values 24/7 for all parameters!

Moreover, using 3rd party wide area networks typically means that many other users/applications (i.e. tenants), which are virtually separated from each other, are utilizing the infrastructure. For an appropriate industrial use of the infrastructure these tenants must not adversely influence each other. The service guarantees mentioned above have to be given for each tenant accordingly.

SIEMENS

Ingenuity for life

Category	Requirement	Explicit 5G promises (according to [1], Figure 2)	Siemens demand	Smart City	Smart Mobility	Smart Manufacturing		Smart Energy			Smart Building
						Process	Discrete	Low Voltage	Medium Voltage	High Voltage	
Industry-grade Service Quality	Realtime capability – Latency	5 ms (e2e)	1 ms (local) 5 ms (long distance)	-	1ms (local) 10 ms (long distance)	20ms (local) 1s (long distance)	1ms (local) 20ms (long distance)	-	25ms	5ms (long distance)	100ms
	Realtime capability -– Jitter	-	1us (local)	-	-	20ms	1us	-	25ms	1ms	-
	Bandwidth	Peak data 10 Gbps Mobile data volume 10 $TB/s/km^2$ Number of devices: 1 mio/km^2	kbps ... 10Gbps	kbps (sensors) ... Mbps (video supervision) ... 10 Gbps (data centers)	10 Mbps ... 1 Gbps	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)	1 kbps per subscriber	5 Mbps per secondary substation	1Gbps along power lines	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)
	Time period of information loss during failures	-	none (seamless failover)	1s	100 ms	100 ms	none (seamless failover)	minutes	25ms	none (seamless failover)	100 ms
	Availability/ coverage	-	Ubiquitous	City-level	Ubiquitous	Industrial Plant Areas	Industrial Plant Areas	Ubiquitous	Ubiquitous	Ubiquitous	City-level
	Range (distance between communication neighbors)	-	0,1 m ... 200 km	10 km	1 km (cars) ... 10 km (trains)	0,1m ... 10 km	0,1 m ... 100 m	10 km	20 km	200 km	100m
	Reliability (minimum uptime per year [%])	99,999%	100%	99,9%	100%	100%	100%	98%	99,9%	100%	99,9%
	Mobility	500km/h	500km/h	100km/h	500km/h	50km/h	50km/h	5km/h	-	-	5km/h
	Outdoor terminal location accuracy	<1m	0,1 m	1 m	0,1 m	0,1 m	0,1 m	10 m	10 m	-	0,1 m
	Multi-tenant support	yes (Network Slices)	yes								
Operation and maintenance	Non-standard operating conditions	Energy consumption reduced by factor 10	• Battery powered devices with >10years lifetime • Harsh environments (weather, vibrations, heat, dust, hazardous gases, etc.)								
	Ease of use	-	• Communication Services approach • Plug and Play Device (Sensor, Actuator, Controller) integration								
	SLA Tooling	-	Service Level Agreement (SLA) monitoring and management tools for provider and consumer								
	Service deployment time (time between service request and service realization)	90 min	hours								
	private 5G infrastructures	-	yes	-	yes	yes	yes	-	optional	yes	optional
Non-technical	Scalability: Number of devices per km^2	10^6	10^5	10^5	10^4	10^5 (high density of devices)	10^5 (high density of devices)	10^4	10^3	10^3	10^5
	Globally harmonized definition of Service Qualities	-	yes	-	yes	yes (for long distance)	yes (for long distance)	-	yes	yes	-
	Technology availability	-	>20 years								
	Globally simplified certification of ICT components	-	Yes								
Assured Guarantees		-	Mandatory	Relaxed	Mandatory	Mandatory	Mandatory	Relaxed	Mandatory	Mandatory	Relaxed

Table 2: 5G Promises vs. Vertical Requirements (details)

2. Recommendations from an industrial point of view

Foster cooperation between vertical and 5G industries

Wide area networks are becoming increasingly relevant for industrial applications. Thus a mutual understanding of vertical and 5G industries on communication requirements is mandatory.

- Currently there are too many initiatives contributing to the requirements clarification for 5G. Vertical industries need to be actively engaged in the requirements process in an **efficient manner**.
- It needs to be clearly understood by 5G industries that **service guarantees are of major relevance in many industrial scenarios** and that deterministic behavior, reliability and quality of service aspects have to be addressed to be able to serve industrial applications in future.
- The cooperation will facilitate **the emergence of the new business models** as well as the alignment and deployment of roadmaps within different sectors.
- Advanced **trials and test beds** (e.g. pilot roads for autonomous driving, smart city trials) should be sponsored or otherwise encouraged by policy makers in order to accelerate innovation in 5G applications.

Review the regulatory environment to encourage 5G innovation

The upcoming revision of the telecom regulatory framework is of utmost importance. The industry's expectations are the following:

1. **Net neutrality** is an important pre-condition for equal access rights to public communication infrastructures. It is an important driving force behind the continued expansion of network capacity, because it defeats business models based on the shortage of network capacity, and leaves network expansion as the only way to ensure the satisfaction of all customers.
2. **Net neutrality rules** should allow for **innovative specialized services** required by industrial applications while allowing for an **internet access quality and safety that are expected by all consumers**. Safety-relevant or real-time critical communication services asking for a guaranteed quality of service need to be possible and made available in a transparent way without requestor-based price/service access differentiation. This is of utmost importance for many industrial applications: e.g. the connection to an emergency switch to stop an escalator from injuring a human being should be always available even if in parallel video streaming tries to utilize all the network resources.
3. An **investment-friendly environment** for 5G deployment and use needs to be fostered. The increased number of network nodes and in-

creased performance of 5G will require major investments in wireless and fixed parts of networks.

4. 5G will not happen without further spectrum allocation – a scarce resource. The **allocation of spectrum should be harmonized and** carefully handled to contribute to a better exploitation. An internationally **harmonized spectrum policy** as well as an investment friendly allocation of spectrum should be promoted.
5. The industrial quality of service requirements of industrial infrastructures might need the **exclusive licensing** of spectrum as the default licensing regime. This will also guarantee predictability and offer safeguards for this long term investment. These portions of spectrum for industrial purposes should be harmonized on an international level as well.

References:

[1] 5G Vision, The 5G Infrastructure Public Private Partnership: the next generation of communication networks and services.

[2] White paper "5G Empowering Vertical Industries" by 5G PPP, the collaborative research programme organized under the European Commission's Horizon 2020 programme