5G-ACIA White Paper

Using 5G sidelink in industrial factory applications

5G Alliance for Connected Industries and Automation

1 Executive Summary

The aim of this 5G-ACIA white paper is to identify and understand uses for 5G sidelink in industrial factory and process automation. It presents sidelink communication as standardized by 3GPP from LTE to 5G and addresses, examines, and considers existing use cases related to factory applications specified in TS 22.104. The benefits and challenges of 5G-based sidelink for industrial factory and process automation are identified.

About 5G-ACIA

The **5G Alliance for Connected Industries and Automation** (5G-ACIA) was established to serve as the main global forum for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects of 5G for the industrial domain. It embraces the entire ecosystem and all relevant stakeholders, which include but aren't limited to the operational technology industry (industrial automation companies, engineering companies, production system manufacturers, end users, etc.), the information and communication technology industry (chip manufacturers, network infrastructure vendors, mobile network operators, etc.), universities, government agencies, research facilities, and industry associations. 5G-ACIA's overarching goal is to promote the best possible use of industrial 5G while maximizing the usefulness of 5G technology and 5G networks in the industrial domain. This includes ensuring that ongoing 5G standardization and regulatory activities adequately consider relevant interests and requirements and that new developments in 5G are effectively communicated to and understood by manufacturers.

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2 Introduction

5G sidelink, in the form standardized by the Third Generation Partnership Project (3GPP) Release 16, is a feature of the 5G system that enables devices to communicate directly with one another without necessitating the need to route user data via the cellular infrastructure. Its use is growing in importance, especially in the commercial, public safety, and automotive (V2X) domains. 5G sidelink communication may be used in different constellations with respect to radio coverage such as in-coverage, partial coverage, or out-of-coverage.

The technology supports two main operating modes. In one, referred to as mode 1, a base station activates sidelink resources with configured grants for periodic traffic or dynamic grants for aperiodic traffic. In the other (mode 2), a mobile device (UE) autonomously uses sensing mechanisms to monitor control channel information from nearby UEs and select sidelink resources for transmitting it. 3GPP recently approved 5G Advanced study items for investigating the unlicensed use of 5G sidelink [4] and 5G sidelink positioning [5] for meeting the requirements of commercial, public safety, IIoT, and vehicle-to-everything (V2X) use cases.

Reliable, deterministic communication is vital for factory applications that use 5G. 3GPP's releases 16 and 17 already specified requirements for the most typical use cases, namely motion control and cooperative carrying mobile robots. Since then, it has added specifications for network-centric solutions with stringent reliability and latency to meet the needs of factory and other applications. The standard solutions now available from 3GPP are expected to meet the communication requirements of these use cases, provided that the 5G network is properly deployed and has good coverage.

Figure 1: Sidelink evolution timeline

LTE SL Rel-12	LTE SL Rel-14	5G SL Rel-16	5G SL Rel-17	5G SL Evo Rel-18
Introducing proximity based services for device to device communication	LTE V2X architecture	5G V2X Architecture	V2X Relay (L2 and L3)	Support of sidelink in unlicensed frequency bands
Discovery mechanism	gNB scheduled and autonomous resource selection	Support public safety services	V2X Remote UE to NW Relay	Supporting relative positioning/ranging for V2X/IIoT/commercial/public safety services
gNB scheduled and autonomous resource selection	Broadcast type traffic for cooperative awareness	Target KPI: 3 ms at 99.999%	Reliability enhancement for autonomous resource selection	V2X UE to UE Relay
Broadcast type traffic	gNB scheduled and autonomous resource selection	Unicast/GroupCast/Broadcast type traffic	Sidelink power saving features for vulnerable road users	Study of sidelink beamforming support for FR2
		Support of reliability enhancement such as L1 HARQ and CSI report		
		gNB scheduled and autonomous resource selection		

Source: 5G-ACIA / ZVEI e. V.

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Wireless communication via the 5G network is scheduled by gNB, by doing so the exact latency requirements are expected to be met based on proper deployment. Due to the various responsibility models and actors involved in 5G network deployment, chances exist that the intended service area does not always benefit from full 5G network coverage. 5G sidelink could be a tool to extend coverage to those areas.

Not enough attention has yet been paid to analyzing the performance of 5G sidelink communication in factory use cases. For example, low latency and high reliability requirements (specified in 3GPP TS 22.104 [3]) must be met to support industrial factory and process applications. These requirements can be even more stringent than those for V2X, which needs a latency of 3 ms and 99.999% reliability (see Table 5.3-1 of 3GPP TS 22.186 [6]). To address these shortfalls and appropriately enhance 5G sidelink for industrial factory applications, it will be necessary for 5G sidelink to support new QoS capabilities and time-sensitive communication, among other things, in future 3GPP releases.

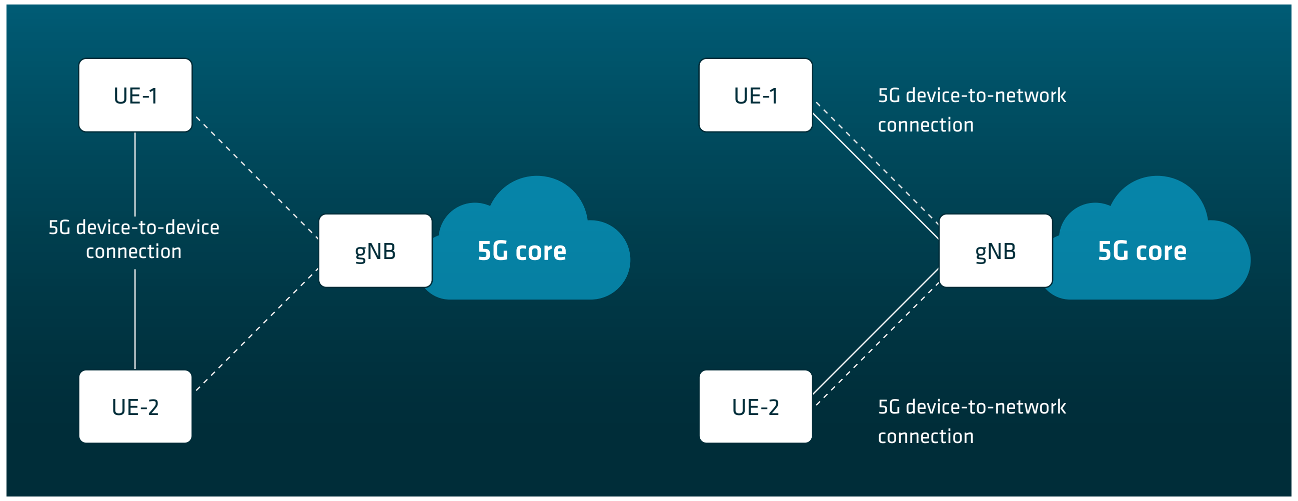
3 Potential Benefits and Challenges of Using 5G Sidelink in Factory Applications

This chapter discusses the potential benefits and challenges of using 5G sidelink communication in automated factories.

5G sidelink makes it possible to directly send user data between devices (via the NR-PC5 interface) instead of routing it via the base station (gNB), which requires it to pass through the NR-Uu interface twice (see Figure 2).

5G sidelink communication could possibly be used in Industrial IoT when devices are in proximity to one another. UEs

Figure 2: Device-to-device (left) and device-to-network communication (right)



Source: 5G-ACIA / ZVEI e. V.

of these kinds, such as mobile robots in the cooperative carrying use case, typically maintain a line of sight with little or no relative motion (see section 4.2). For user data transmission between devices, the single wireless hops of 5G sidelink communication (NR-PC5) could deliver benefits in the form of reduced latency because there is only one wireless hop instead of two via the network. The extent to which latency is reduced with 5G sidelink communication depends on the distance between UEs, among other factors.

In the use case of cooperative carrying mobile robots (see section 4.2 for details), multiple devices typically move as a group with limited or no relative mobility among them. The following can be expected in such a case:

- When using sidelink, the quality of communication between devices will be similar. But even if they maintain equal distances from one other as the group of UEs moves across the factory floor, radio conditions and especially interference will vary.
- Direct data communication requires no handovers.

Depending on the actual location of the devices and the corresponding 5G infrastructure elements, better-quality 5G wireless links may be available for sidelink. This is possible in situations in which 5G sidelink communication is between devices is close proximity to one another, as compared to communicating via the network with fairly distant gNBs.

For industrial solutions (such as IEEE frame replication P802.1CB [7]), 5G sidelink can increase reliability by providing an additional transmission path. There could then be both a device-to-network connection (NR-Uu) and a 5G sidelink connection (NR-PC5). This increases redundancy, for instance in the motion control use case, in which the failure of one communication path can be compensated for by switching to the other. However, this is not standardized in 3GPP and requires a solution involving dual-modem devices above the radio layers.

5G sidelink could extend coverage by relaying data communications to areas in which there is no or only partial RAN coverage.

5G sidelink ranging and positioning can make it possible to determine the distance between two UEs and calculate their relative positions independently of the available network coverage.

Apart from the potential benefits just discussed, sidelink also has certain limitations and challenges:

- Communication range over 5G sidelink (i. e. distance between UEs) for the targeted industrial applications is likely to be shorter compared to V2X communication range requirements (in TS 22.186 [6]), for URLLC communication due to output power and antenna size limitations compared to a gNB with higher transmit power and better receive sensitivity in device-to-network communication. Hence for longer communication range device to network connection maybe preferred.
- Device-to-network communication (using NR-Uu) currently supports more advanced features for improving coverage and/or reliability. These include massive MIMO, supplementary uplink, multi-TRP communication, slot or mini-slot based repetition, carrier aggregation, and dual connectivity with PDCP duplication.
- Sidelink's ability to manage interference is less than that of a gNB, making it more susceptible to collisions.
- 3GPP has not yet evaluated whether sidelink mode 1 or 2 would support the URLLC requirements for factory applications. The challenges here include:
  - For mode 1: how the gNB schedules resources to support URLLC, since the gNB is not aware of the sidelink channel condition and Sidelink HARQ feedback reporting to gNB is prone to delays.
  - For mode 2: how the device selects resources for low-latency transmission, due to the deterministic, periodic traffic involved. Because there are fewer candidate resources, applications with low latency requirements run the risk of packet collisions.

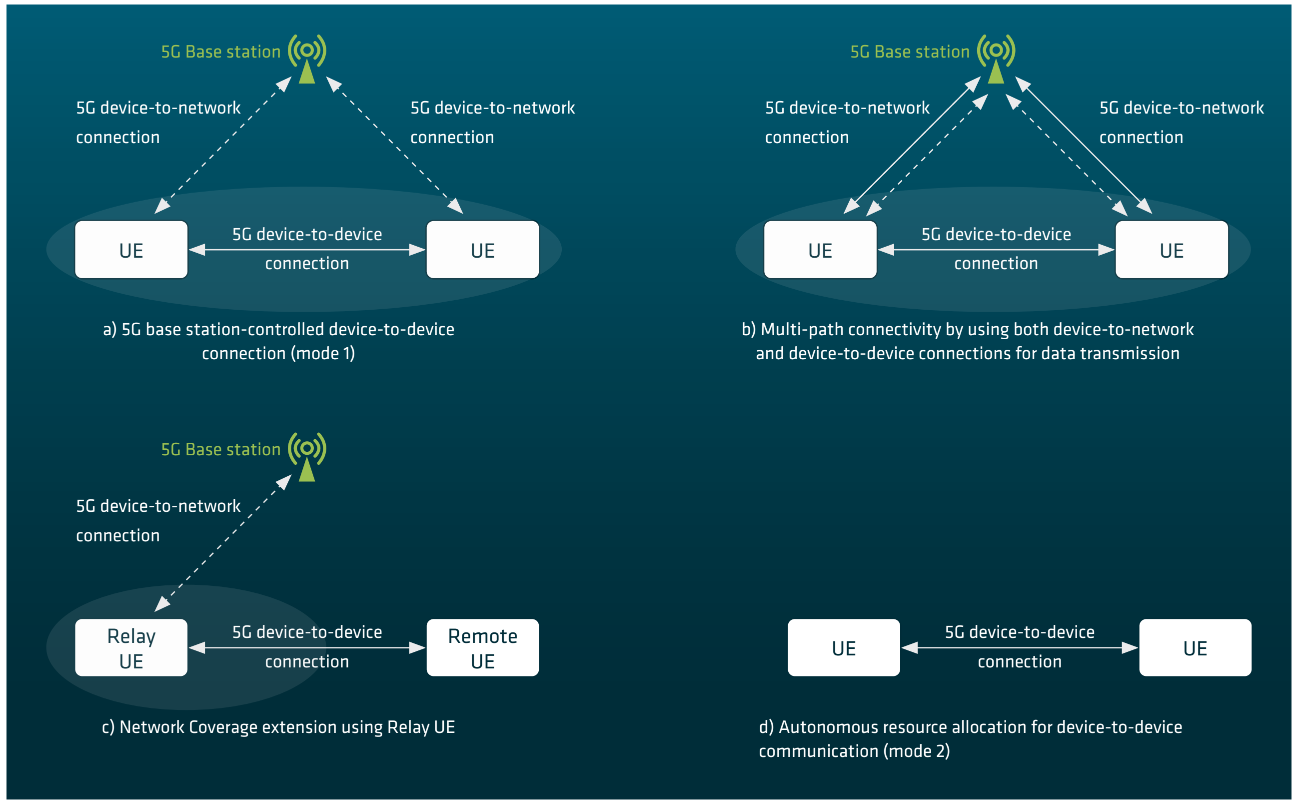
4 5G Sidelink in Industrial Factory Applications

5G sidelink as defined in Release 16 includes in-coverage, partial coverage, and out-of-coverage modes. So the possible scenarios for deploying 5G sidelink in factory environments include the following:

a) A 5G base station-controlled device-to-device connection (mode 1) in which data is transmitted via 5G sidelink and the base station schedules resources for sidelink transmission/retransmission.
b) Multipath connectivity, in which device-to-network and device-to-device data transmission takes place concurrently for greater reliability. This could be taken advantage of for IEEE 802.1CB frame replication [7]. It is not yet supported by the 5G sidelink standard in 3GPP, however.
d) Network relay for coverage extension, in which 5G sidelink connectivity between devices helps the base station reach UEs that are outside the area covered by the network.
d) Autonomous resource allocation mode (mode 2): 5G sidelink devices communicate without the support of a base station, and sidelink resources are autonomously selected from a (pre-) configured resource pool by a transmitter UE (e. g., using a sensing mechanism).

While 5G sidelink communication is technically possible in all deployment scenarios, the choice of selecting the 5G sidelink deployment in a factory environment is up to the factory network operator. The network operator is required to understand when sidelink might be a suitable solution, i. e., whether 5G sidelink can achieve the performance requirements of the use case and whether the particular deployment fits with the conditions of that use case. The factor affecting the 5G sidelink deployment may include whether 5G sidelink meets the QoS requirements in relation to latency and reliability (which requires further evaluation) and potentially spectrum availability for 5G sidelink.

Figure 3: Various technically feasible 5G device-to-device deployment options



Source: 5G-ACIA / ZVEI e. V.

5 Use Cases That Could Benefit from 5G Sidelink in Factory Automation

The following use cases, described in 3GPP TS 22.104 [3], were investigated in connection with deploying 5G sidelink for factory automation.

5.1 Motion Control

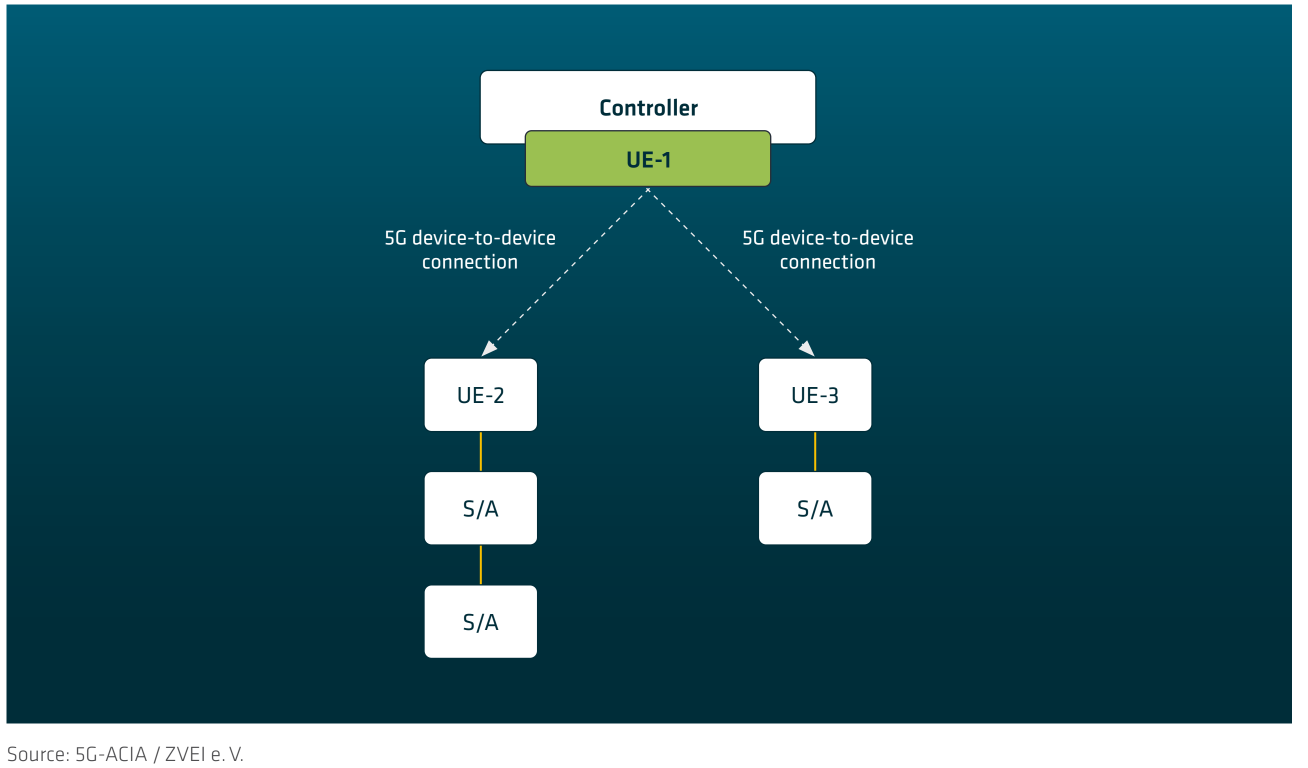
A motion control system controls moving and/or rotating parts of machines in a well-defined manner, for example in printing presses, machine tools, or packaging machines. In these scenarios, it may not be feasible to use a wired connection to a gateway device (containing one or more field devices) in the rotating part of a robot arm.

5G sidelink connectivity between a motion controller connected to a UE and one or more actuators may reduce communication latency or resource consumption compared to a device-to-network connection, assuming that the same level of radio link reliability is achievable in both cases.

5.2 Controller-to-Controller

Communication between industrial controllers is already used today for various use cases, including control-to-control communication between motion (control) subsystems. Examples include large printing presses for which it is not possible or desirable for a single motion controller to operate all of the actuators, individual machines that collaborate to achieve a particular result (e. g., machines in an assembly line), and an individual machine that contributes to a joint task by controlling and coordinating the transfer of workpieces from one machine to another. The requirements are described in A.2.2.2 of 3GPP TS 22.104 [3].

Figure 4: An example 5G sidelink deployment for a controller connected to UEs



Source: 5G-ACIA / ZVEI e. V.

5G sidelink connectivity between controllers linked to a UE can reduce communication latency and resource consumption compared to a device-to-network connection, provided that the controllers are located close to one other. The same level of radio link reliability can be achieved with 5G sidelink communication and a device-to-network connection. A device-to-network or fiber-optic connection is preferable when the controllers are further apart.

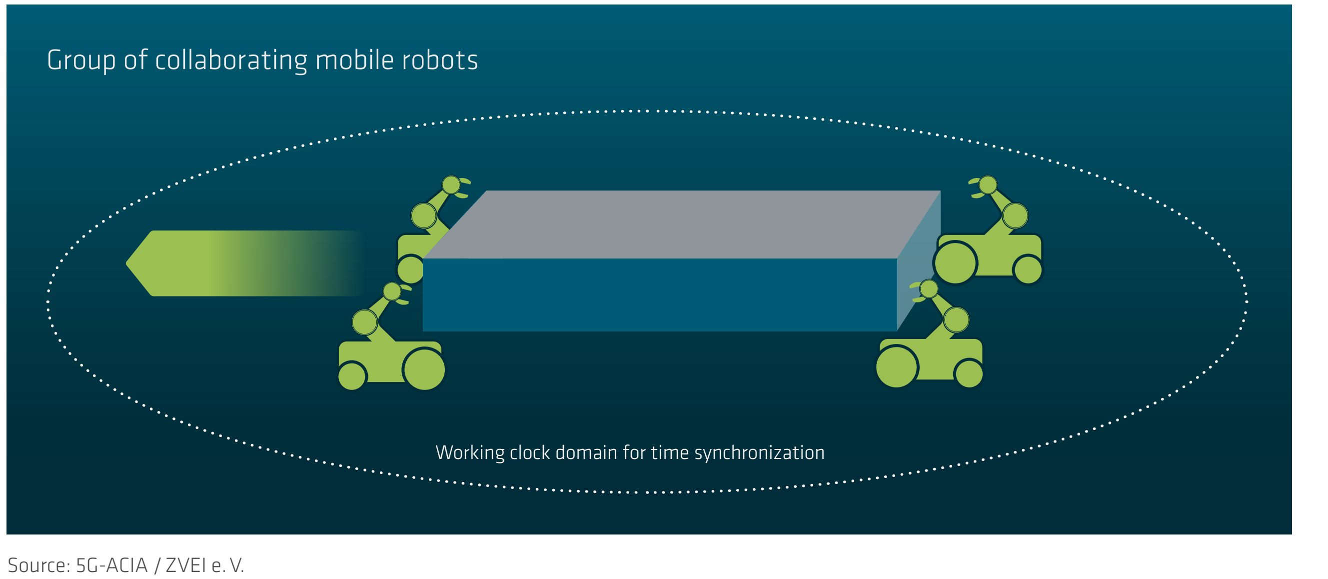
5.3 Carrying Mobile Robots

In a smart factory, a group of mobile robots or AGVs can collaborate as a team to carry large, heavy, fragile workpieces across the factory floor (see Figure 4). The control application achieves this cooperation by controlling their drives and motions. 5G sidelink is suited for maintaining stable wireless connections among collaborating mobile robots or AGVs that are fairly close together.

Mobile robots/AGVs integrate a 5G UE for 5G sidelink communication. The automation application on the collaborating mobile robots/AGVs establishes 5G sidelink communication. When the mobile robots are gathered around the workpiece, they form a collaborating group using basic information on things like group formation, a 5G radio configuration, and a working clock domain for time synchronization and deterministic communication. The simplest implementation of this use case for lifting and moving heavy but fragile workpieces is two AGVs in virtual coupling mode with the required KPIs of synchronicity and periodic deterministic communication.

The mobile robots/AGVs form part of a nonpublic standalone or integrated 5G network, for example as a private slice. High communication service availability and ultra-low latency (URLLC communication) are prerequisites for the mobile robots/AGVs to communicate with one another. Control commands and feedback are exchanged with periodic deterministic communication and time-sensitive networking. This happens over the 5G sidelink connection. IEEE 802.1AS may be applied for clock distribution and time synchronization over the 5G sidelink path. It is essential for all of the mobile robots/AGVs to receive application information at the same time, or more precisely within a specified time interval. The mobile robots/AGVs can exchange required information such as status information, control feedback, and control commands, as well as localization information via multicast or unicast. The control application's specific requirements in terms of the communication KPIs also depend on the work-

Figure 5: Mobile robots carrying a large workpiece together



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piece's structure and properties; for example, it could be more elastic or fragile than usual. Resource allocation for 5G sidelink communication has to be efficient and avoid interfering with the ongoing periodic deterministic communication among the mobile robots. Localization information, which can be either absolute or relative, can be exchanged together with the communication data.

The transmission range within which the mobile robots need to maintain stringent industrial 5G sidelink communication depends on the size of the workpiece. For large workpieces, a range up to 50 meters may be sufficient. Smaller workpieces can be cooperatively carried with shorter transmission ranges such as 10 or 25 meters. For larger workpieces, communication ranges of 100 meters could be implemented with the aid of an intermediate mobile robot/AGV acting as a relay. (Intermediate mobile robots/AGVs are probably required in any case.)

5.4 Relative Positioning in Smart Factories

Positioning is a high-value capability in connected industries and automation; it can be employed for AGVs, AMRs, forklifts, and tracking of valuable assets. A wide range of sensor-based vehicle localization solutions such as laser scanner-based localization for route tracing and automatic pallet handling requires relative positioning with sub-centimeter accuracy. In open outdoor areas (like a factory's yard), AGVs with LiDAR positioning don't deliver good positioning results. To achieve optimal localization there is therefore a need for satellite positioning with a GNSS and/or 5G positioning. In narrow passages inside a factory, 5G positioning may not provide sufficient accuracy due to reflections and GNSS positioning isn't available; in these cases, LiDAR positioning combined with medium-accuracy 5G positioning enables good results. The best solution depends on the use case and situation. Hybrid positioning approaches can be deployed to achieve the required reliability and accuracy in different use cases and situations, combining cellular, UWB, GNSS-RTK, cameras, LiDAR, IMUs, etc.

It is typical for a UE to feed information from sensors/RAT independent positioning back to the 5G system. A location management function (LMF) in the 3GPP system can combine the information and provide final processed output to the application. This 5G system configuration as the "central point" for localization isn't optimal, however. Applications themselves should constitute the central point for using and/or combining different available localization technologies depending on the specific situation. Applications themselves have a better view of what is needed in a particular situation. Applications in the AGVs should be able to select absolute or relative positioning methods depending on network conditions to ensure accurate results for the location and scenario concerned. For example, applications in an AGV can use network-based absolute positioning while navigating inside the factory hall but switch to 5G sidelink-based relative positioning to achieve better accuracy at loading/unloading stations. Relative positioning between two UEs within 10 meters of each other must provide sub-dm accuracy in order to prevent AGVs from colliding. Relative positioning needs to be supported up to a distance of 50 meters, while more accurate localization is required when UEs are closer together as discussed above.

6 General Considerations of Spectrum Use for 5G Sidelink Deployment

5G sidelink spectrum and frequencies can be used in smart factories in configurations including in-coverage, out-of-coverage on the premises, and out-of-coverage off the premises. Depending on the country, the factory operator may be able to license spectrum to operate a standalone private network within a certain geographical area. The frequency for 5G sidelink can be set within the coverage of gNB on factory premises by configuring 5G sidelink and NR Uu (for device-to-network connections) in the same or a different frequency spectrum. In situations that involve out-of-coverage of gNB but still within the factory premises, the factory operator can configure the fallback (preliminary) configuration as a licensed spectrum (geolicensed spectrum) where the limits of the geolicensing spectrum model apply. In situations where 5G sidelink is out-of-coverage, typically outside the factory premises where the geolicensing spectrum isn't applicable, 5G sidelink can revert to the PLMN frequency depending on the subscription agreement between the factory operator and the PLMN operator.

7 Requirements for Using 5G Sidelink in Factory Applications

Chapter 4 identified Several use cases, where 5G sidelink might be used. In order to be able to use 5G sidelink in industrial factory applications, if so, decided by the factory network operator according to their preferences, The following requirements need to be achieved.

Ultrareliable, low-latency communication is the main requirement for many factory use cases. Communication is deterministic and can be periodic with fixed transmission intervals. For example, the motion control use case requires a latency of between one and two milliseconds and cooperatively carrying mobile robots need a latency of at least 1.7 and no more than 5 ms milliseconds. The availability for these use cases ranges from 99.9999% to 99.999999%. More information on the performance requirements of these 5G sidelink use cases can be found in 3GPP TS 22.104 [3].

Support for time synchronization and time-sensitive communication supports the exchange of periodic/aperiodic deterministic messages, for which a group of UEs must be synchronized with a common working clock. 3GPP TS 22.104 [3] addresses the corresponding 3GPP stage 1 requirements for connecting devices both directly and indirectly via a network. The time synchronicity budget of 5G communication via a direct device connection over 5G sidelink should not exceed 900 nanoseconds.

Resources must be efficiently allocated for 5G sidelink communication. Signaling traffic should be minimal and not interfere with ongoing deterministic communication. The validity of the allocated resources should support periodic traffic.

Since most factories will deploy private networks, 5G sidelink communication needs to be supported by both standalone nonpublic networks (SNPNs) and public-network-integrated NPNs (PNI-NPNs). In order to comply with regulatory requirements in different countries, it will presumably be necessary for 5G sidelink communication to be under gNB control in PNI-NPN.

It will be necessary to evaluate the achievable limits in terms of low latency and high reliability in connection with the use of 5G sidelink communication in factories, something that has not yet been done, while taking into account the distances between 5G sidelink devices (e.g., 10 meters, 25 meters, 50 meters etc.) and how resources are allocated and scheduled (mode 1 or 2).

8 Conclusions

In this white paper we have investigated the following use cases: motion controller, controller-to-controller, cooperative carrying robots, and relative positioning. 5G sidelink communication for close-proximity applications is attractive for factory deployment and may yield significant benefits. However, challenges and limitations have also been identified in connection with the availability, reliability, and range of 5G sidelink.

The principal requirements – based on those of the use cases described in this white paper – are ultrareliable, low-latency communication, precise clock synchronization, periodic deterministic time-sensitive communication, and support for 5G sidelink communication in nonpublic networks.

The 5G sidelink standardization efforts up to and including Release 17 mainly focused on meeting the latency and reliability requirements of public safety and automotive use cases, which are less demanding than factory use cases. URLLC requirements are not supported by current 5G NR sidelink specifications.

This white paper also concludes that 5G sidelink communication is supported better when implemented in private networks (SNPN, PNI-NPN). Factory network operators can deploy it according to their own preferences.

Feasibility studies of 5G sidelink factory applications for future 3GPP releases will need to evaluate performance (for example, the upper limit of low latency and the achievable reliability across defined distances), possibly by considering 5G URLLC features to understand the potential benefits of 5G sidelink-URLLC and time-sensitive communication.

9 Key Terms and Acronyms

3GPP
The 3rd Generation Partnership Project (3GPP) is an umbrella term for a consortium embracing a number of standards organizations worldwide that are collaborating to develop globally accepted specifications for mobile telecommunications. As its name implies, it was originally created to establish specifications for the third generation (3G) of mobile communication systems. It has continued working on subsequent generations, including the fifth generation (5G), which is considered in this white paper.

3GPP
The 3rd Generation Partnership Project.

3GPP Stage 1
Provides overall service description from the user's standpoint.

5G
Fifth Generation.

5G-ACIA
The 5G Alliance for Connected Industries and Automation is the globally leading organization for shaping and promoting Industrial 5G.

5GS
5G System.

5G Sidelink
Direct UE-to-UE communication via NR-PC5 interface.

AGV
Automated guided vehicle.

AMR
Autonomous mobile robot.

CAG
Closed Access Group.

Device-to-network connection
The device to network connection defines the connection between base station and user equipment (UE) via NR-Uu interface.

gNodeB (gNB)
Refers to the 5th generation base station.

GNSS
Global navigation satellite system.

IIoT
Industrial Internet of Things.

IMU
Inertial measurement unit.

LMF
Location management function.

LIDAR
Light detection and ranging.

MIMO
Multiple-in, multiple-out.

Mode 1
The gNB schedules radio resources for 5G sidelink communication between two UEs.

Mode 2
The radio resources used for 5G sidelink communication are autonomously selected based on sensing-based resource selection algorithm, i. e., estimating which radio resources are in use by other UEs by decoding sidelink control channel information of other UEs, and the occupied radio resources by nearby transmitting devices.

NPN
Non-public network.

NR-PC5
Refers to the interface where the User Equipment (UE), i. e., mobile handset, directly communicates with another UE.

NR-Uu
Refers to a radio interface in which the user equipment (UE) communicates with gNB.

PNI-NPN
Public network integrated nonpublic network.

PLMN
Public land mobile network.

RAT
Radio access technology.

RAN
Radio access network.

RTK
Real time kinematic.

SNPN
Standalone nonpublic network.

TSN
Time-sensitive networking.

UE
User equipment.

URLLC
Ultra-reliable low-latency communications.

User equipment (UE)
Allows a user access to network services. For the purpose of 3GPP specifications, the interface between the UE and the network is the radio interface as described in 3GPP TS 21.905 [8].

UWB
Ultra-wide band.

V2X
Vehicle to everything.

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