5G NR Sidelink Multi-Hop Transmission in Public Safety and Factory Automation Scenarios

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Nadezhda Chukhno, Antonino Orsino, Johan Torsner, Antonio Iera, and Giuseppe Araniti

Abstract—**The deployment of D2D communications (also known as ProSe or sidelink transmissions) in cellular networks benefits from proximity, multi-hop, and spatial reuse gains. In this article, we first describe the main advancements of NR sidelink compared to LTE-A sidelink. Then, we run a simulation campaign to test D2D-based ProSe for public safety and factory automation scenarios with their mission-critical requirements and ultra-reliable low-latency communications, respectively. A preliminary study on NR sidelink usage for both considered use cases is performed, aiming to identify the main advantages and disadvantages thereof. Finally, important future directions for the NR sidelink development from a standardization perspective are highlighted.**

Index Terms—**3GPP NR, sidelink, device-to-device (D2D), multi-hop, public safety, factory automation**

I. Introduction

Third generation partnership project (3GPP) sidelink transmissions in Long-Term Evolution - Advanced (LTE-A) systems have already proven to play a crucial role in supporting public safety and vehicle-to-everything (V2X) services, among others, by featuring direct communications between two user devices (UEs) without any base station (BS) involvement. Fostered by the successful evolution in LTE-A, the 3GPP sidelink developments are going on in New Radio (NR) based systems, wherein sidelink transmissions become an essential component complementing the Uu communication between UE and BS. 5G wireless communication systems utilize NR sidelink for device-to-device (D2D) based proximity service (ProSe) communications [1] and can operate in both lower (up to 7.125 GHz) and higher (up to 52.6 GHz) frequency ranges. Focusing on providing low-latency, high-reliability, and high-throughput services, NR supports a number of new sidelink communication features not provided in LTE-A. These include, among others, support for unicast and groupcast in the radio layers (LTE only supported broadcast) and hybrid automatic repeat request (HARQ) operation at the MAC level.

On the application side, we observe that public safety organizations have already begun to shift from traditional land mobile radio to cellular communications systems, leveraging a new set of deployed devices to meet mission-critical requirements and target new public-safety broadband applications. Accordingly, 3GPP Rel-16 targets defining the common architecture for public safety and commercial ProSe services. In the case of public safety, maintaining ProSe discovery and communication is especially critical when the UE resides outside the coverage area of the cellular network, e.g., in the case of disaster management in remote areas. Hence, the support for both direct discovery (discovery is integrated into the initial sidelink connection establishment message) and unicast and groupcast communication (one-to-one and one-to-many communication) was introduced. Moreover, out-of-network-coverage discovery is already feasible in Rel-16.

Note that *public safety* service reliability can be achieved by using either multi-hop[1] D2D communications (e.g., in out-of-coverage scenarios) or through the flexible use of radio resources provided by the multi-connectivity and multi-radio access technologies (multi-RAT). Technologies such as mobile edge computing (MEC) and software-defined networks (SDN) can improve latency and security in public safety services [2]. Also, network function virtualization (NFV) and network slicing can manage various use cases with varying priorities in cellular networks [3]. In this article, we investigate the main *advantages and disadvantages of D2D ProSe transmissions.*

ProSe support can be also beneficial to commercial use cases and services. In the realm of *factory automation*, for example, it can provide new possibilities for discrete manufacturing and help producers accomplish efficient operations. Nowadays, as mentioned above, factory automation is based mainly on the wired connectivity, which bounds the degree of freedom for functionalities, especially for mobile terminals. Hence, robust wireless connectivity can improve the location flexibility of a large number of machines, such as sensors, actuators, programmable logic micro-controllers. Furthermore, as factory automation use cases usually (but not always) belong to the class of ultra-reliable low-latency communications (URLLC) and the existing technologies operating over the unlicensed spectrum are not capable of guaranteeing the required quality of service (QoS) in the considered scenario, NR sidelink has the potential to offer interesting opportunities.

Note that the NR sidelink can be easily deployed on the licensed spectrum. Suppose the mobile network operators (MNO) spectrum is to be used for the Industrial Internet of Things (IIoT). In that case, the NR sidelink may have an advantage over other D2D technologies (because the operator presumably uses NR cellular). Otherwise, in case the spectrum is unlicensed for industrial use, other D2D technologies can

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[1]Note that the NR sidelink (Rel-16 and Rel-17) does not support multi-hop (i.e., UE1-UE2-UE3) at radio layers.

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be utilized. However, in terms of power consumption, devices should only maintain the cellular interface active to save power [4].

In summary, as proven by several research works focused on direct links between UEs, deploying D2D communications in cellular networks benefits from proximity and spatial reuse gains. However, two main NR sidelink aspects **have not been sufficiently investigated and standardized yet**: (i) *multi-hop transmission (relaying)* and (ii) mobility. In this article, we focus on the first feature – multi-hop transmission – by considering a static scenario. More precisely, while other existing studies only investigate the special case of one relay node (two-hop) sidelink operation, we investigate the case of an arbitrary number of hops. Thus, our article aims to partially fill the mentioned research gap by elaborating on the concept of D2D ProSe communications while referring to public safety and factory automation sample use-cases. We first discuss the pros of NR sidelink, including the comparison with LTE ProSe communications. We then review the NR sidelink applicability for the public safety and factory automation applications and conduct a preliminary simulation study. Finally, we offer future directions for the NR sidelink development from a standardization perspective.

II. NR Sidelink in a Nutshell: Why NR Sidelink?

LTE sidelink (or D2D) was introduced for the first time as a part of 3GPP Release 12, aiming at covering public safety scenarios and supporting two operation modes. In mode 1, eNB[2] assists UEs and allocates dedicated transmission resources, whereas, in mode 2, UEs randomly select the radio resources from the pool that was previously sent by eNB. Both modes have the same pool of resources, wherein the transmission is scheduled during the so-called physical sidelink control channel (PSSCH) [5]. Later, in LTE sidelink Release 14, 3GPP added several enhancements to the mission-critical push-to-talk (MCPTT) standard and upgraded the functionalities of public safety applications by introducing mission-critical data (MCData) and mission-critical video (MCVideo) [6].

At radio level, in terms of backwards compatibility the following aspects define new and old specifications: LTE sidelink Rel-13 is compatible with LTE sidelink Rel-12; LTE sidelink Rel-14 is not compatible with earlier LTE sidelink; LTE SL Rel-15 is compatible with LTE sidelink Rel-14; NR sidelink is not compatible with any LTE sidelink; NR SL Rel-17 will be compatible with NR sidelink Rel-16. Here, a new model was introduced, where each set of services is mapped onto a single release of the specification (e.g., safety services are mapped onto Rel-14, whereas advanced driving services are mapped onto Rel-15). That is, each release is aimed at supporting a certain set of services [7].

NR sidelink (Rel-16) operates more efficiently and is designed so as to utilize both licensed and unlicensed frequency bands. More specifically, both LTE and NR sidelink support communications in the licensed spectrum as well as in unlicensed ITS spectrum (essentially the 5.9 GHz band). However, neither LTE nor NR sidelink support communications in different unlicensed spectra such as the 2.4 and 5 GHz bands. In view of this, various NR protocols facilitate the coordination and control of the sidelink transmissions within the network coverage, which ensures that the D2D communications effectively coexist with cellular data traffic in shared frequency bands.

The direct mode interface (PC5 or sidelink), which complements the cellular interface by introducing new flexibility to the NR technology, has been presented in Rel-16 [8]. PC5 or sidelink operates in in-, out-of-, and partial-coverage scenarios[3], leveraging NR frequency bands and supporting unicast, multicast, and broadcast communication, where members interact via groupcast transmissions. This option is useful in the transmitter-receiver close proximity scenarios and in the intermittent network coverage ones. Release 16 sidelink transmissions solely involve V2X scenarios though, the 3GPP is planning further sidelink-related features in Rel-17 that are expected to play a decisive role in expanding the applicability of 5G NR to a wide variety of new use cases in both industry and public services, such as public safety, factory automation, enhanced V2X, advanced relay, and extended reality (XR) interactive games, among others.

However, energy efficiency – a crucial feature for pedestrian/drone UEs in terrestrial/aerial V2X, wearable UEs in interactive games, or mobile UEs in public safety – is not the primary concern in the Rel-16 sidelink transmission design. In this regard, a high degree of energy efficiency at both the network and device sides must be ensured. In Release 16, the blind decoding of the PSCCH appears to be one of the significant causes of energy consumption in Modes 1 and 2. The transmission and reception procedures of PSCCH and PSSCH may be further advanced to save power at the UE side. Thus, within NR sidelink Rel-17, a work item on sidelink enhancements is targeting energy efficiency improvements.

To summarize, four new features are introduced in NR sidelink to meet the service requirements of the use cases that demand high reliability, low-latency, high-throughput transmissions, and high connection density. First, point-to-multi-point and point-to-point transmissions are supported in addition to broadcasting. Second, ultra-reliable and low-latency NR uplink communications are achieved thanks to grant-free transmission, a promising multiple access protocol. Finally, the channel sensing and resource allocation procedures are improved to facilitate collision mitigation among different sidelink transmissions initiated by various UEs.

LTE, LTE sidelink, and NR transmissions can also be used for public safety and factory automation scenarios. However, these are still less efficient in supporting mission-critical services. In the case of LTE, even though there are solutions, such as portable eNB on trucks, to address disaster and emergency situations, most of the time, the coverage and robustness of such solutions are somewhat limited and may not guarantee the requirements requested by modern applications. LTE sidelink has a public safety focus, but its main drawback is that

[2]E-UTRAN Node B, also known as Evolved Node B (abbreviated as eNodeB or eNB), is an LTE BS.

[3]The LTE sidelink could also operate in-coverage, partial-coverage and out-of-coverage.

it operates only in broadcast mode and only in unlicensed spectrum, thus meaning that there is no support for public safety bands in LTE. Moreover, LTE sidelink has very little support from chipset vendors, implying that there are no real UEs on the field so far. When touching NR, the initial focus of NR was eMBB (Rel-15), then IoT and URLLC (Rel-16 and Rel-17). This means that there is slight support for public safety features, but the technology is not mature yet since more work is expected to be done in the following Rel-18 and Rel-19.

III. NR Sidelink as a Tool to Support Public Safety and Factory Automation Use Cases

Several new use cases are still expected to be supported in Rel-17. These use cases are related to V2X and public safety. Then, the Rel-17 NR sidelink can also be used for industrial communication, such as sidelink between robots, machines, and industrial sensors (even though IIoT is out of the scope of Rel-17). To fully cover new and already existing use cases, we consider public safety and factory automation applications that differ in requirements.

A. Public Safety

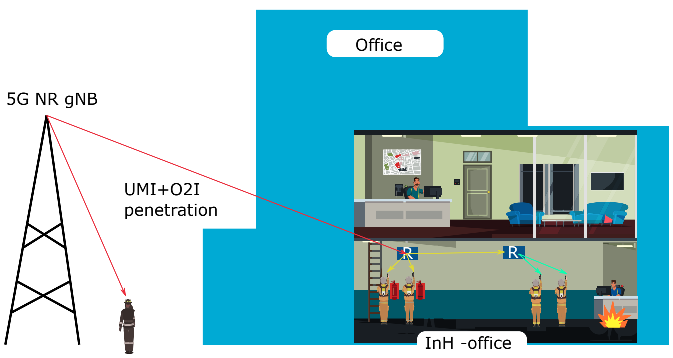

Fig. 1. Public safety use case illustration. "R" stand for a relay. "R" can transmit data via unicast and groupcast. In this work, we use only unicast. Note that broadcast is only used for LTE.

Public safety organizations are responsible for providing services that ensure the people's and properties' safety thanks to first responders, such as firefighters, emergency medical service staff, etc., equipped with devices exchanging time-sensitive and critical information via typically wireless communication links. To support the mission-critical requirements of public safety services, these organizations have begun to move from traditional land mobile radio to cellular communications systems with a new set of terminals.

Reliability in public safety services can be achieved via multi-hop relaying, which is considered to be one of the key technologies facilitating enhanced system performance in future 5G+ systems. For example, it allows establishing direct connections between devices in scenarios outside the coverage area, thus ensuring first responders with the connectivity they need, especially in hazardous situations. For instance, in [9], the fire brigade use case is already under consideration to enhance the indoor coverage.

Furthermore, public safety use case introduces potential new requirements [9], such as, among others, the following ones: (i) the 5G system shall support the relaying of MCPTT, MCVideo, and MCData services between remote UEs and a network using multi-hop relay UEs; (ii) the 5G system shall support service continuity when a remote UE moves into an area within the coverage of a different multi-hop relay UE; (iii) the 5G system shall allow the user to decide when to deploy additional multi-hop relay UEs to maintain a reliable communication path, etc. We emphasize that new public safety services with their mission-critical requirements call for cellular communication systems that support a D2D ProSe (see, e.g., Fig. 1).

B. Factory Automation

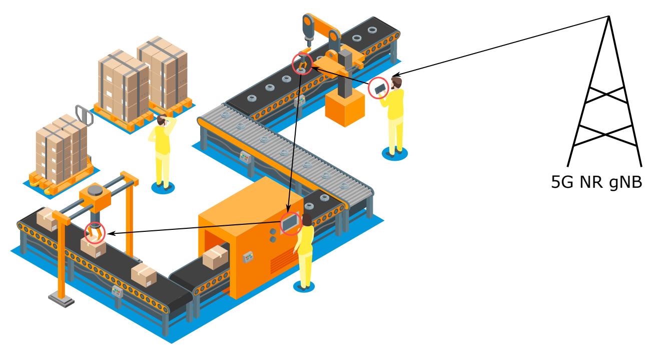

Fig. 2. Factory automation use case illustration.

The scenario that is expected to be investigated in Rel-18 is multi-hop sidelink for *factory automation scenarios* (see, e.g., Fig. 2). Here, complementary to deploying multiple gNBs[4], the factory owner may leverage UEs with multi-hop relay capabilities to relay messages between, e.g., remote UEs and gNBs [9].

IIoT scenarios, such as factory automation use cases, usually demand URLLC and include communication between automation devices, such as industrial robots, controllers, and sensors. Even though different technologies are designed to support industrial communication, e.g., IWLAN, WISA, WirelessHART, these standards do not satisfy flexibility and real-time-response requirements of control loops. Moreover, 3GPP defined the target packet error rate at 10^-6 (known as "six nines" reliability).

To this end, factory automation services can benefit from D2D ProSe since direct communication between industrial terminals helps reducing communication latency. Further, it results in reduced resource usage compared to the legacy centralized traffic stream through the BS or, equally, gNB.

C. Performance Indicators

In factory automation and public safety scenarios, strict requirements[5] on the following concepts have to be considered:

[4]Next Generation Node Bases (gNBs) is the NR term for a BS).
[5]Note that not all requirements have to be satisfied at the same time.

- **Latency**. NR sidelink mitigates the end-to-end latency determined as the time taken for devices to respond to each other over the wireless network and is crucial for remote controlling, URLLC applications, etc.
- **Power consumption**. The terminals that operate in D2D fashion experience a reduced energy consumption primarily due to the mutual proximity and reduced latency, since total energy consumption of transmissions in the network is calculated by multiplying power in watts by time.
- **Service continuity**. When a link is broken, the terminal should be able to select another link as soon as possible not to lose too many packets, which can be achieved, e.g., through multi-hop D2D communication.
- **Reliability**. D2D technology can improve reliability, expressed as the fraction of sent network layer data units that are successfully delivered to a given node within the time constraint required by the targeted service.
- **Service availability**. A further metric that can benefit from the deployment of multi-hop D2D (among other technologies, such as MEC, multi-RAT, integrated access and backhaul (IAB)) is the communication service availability. It is defined as the time interval during which the end-to-end communication service is delivered in compliance with an agreed QoS, divided by the total time interval the system is expected to provide the end-to-end service in a given area [10].
- **Energy efficiency**. Efficient energy use aims at a reduction in the consumed energy while providing the service; it is defined as the achieved network throughput divided by the consumed energy.
- **Network throughput**. Network (or aggregate) throughput is the total data transfer rate delivered to all devices in the network.

A more detailed description of public safety or factory automation related requirements from the communication and other perspectives, is available in 3GPP specifications [9], [10].

IV. Public Safety and Factory Automation Scenarios: Preliminary Study

To analyze the gains and downsides deriving from NR sidelink multi-hop relaying in the use cases described above, we developed a MATLAB simulation environment (considering transmission part only) dimensioned according to the parameters' values listed in Table I. We emphasize that the NR sidelink frequency of operation can be FR1 that contains frequencies from 410 MHz to 7.125 GHz and FR2 (mmWave) that covers the range between 24.25 GHz and 52.6 GHz [11]. This section compares the performance of the NR and LTE sidelink-enabled systems with NR and LTE. Note that LTE and NR benchmarks exploit sequential BS-UE transmissions scheduled one by one, whereas multi-hop transmissions are used only for NR sidelink use cases.

TABLE I
Simulation parameters factory automation scenario

Scenarios	**Factory Automation**	**Public Safety**
Area	100 m x 70 m	500 m x 1000 m
NR carrier frequency	28 GHz (FR 2)	700 MHz (FR 1)
LTE carrier frequency	2.1 GHz	2.1 GHz
Total NR bandwidth	100 MHz	100 MHz
Total LTE bandwidth	100 MHz	100 MHz
Height of AP	3 m [12]	10 m (UMi) [12]
NR subcarrier spacing	120 kHz	60 kHz
LTE subcarrier spacing	15 kHz	15 kHz
NR transmitter processing delay	0.0357 ms	0.0179 ms
LTE transmitter processing delay	1 ms	1 ms
NR transmitter processing delay	0.0357 ms	0.017 ms
LTE transmitter processing delay	1 ms	1 ms
NR frame alignment time	0.0179 ms	0.0089 ms
LTE frame alignment time	0.5 ms	0.5 ms
NR transmission time	0.0357 ms	0.0179 ms
LTE transmission time	1 ms	1 ms
NR receiver processing delay	0.0536 ms	0.0268 ms
LTE receiver processing delay	1.5 ms	1.5 ms
NR one way latency	0.1429 ms	0.0715 ms
LTE one way latency	4 ms	4 ms
NR HARD RTT	0.2143 ms	0.1074 ms
LTE HARD RTT	8 ms	8 ms
Height of UE	1.5 m [12]	1.5 m [12]
Number of BSs	2 BSs	1 BS
Number of UEs	10 UEs	6 UEs
SNR threshold	-9.478 dB	-9.478 dB
Transmit power	20 dBm [13] for both BS and UE	46 dBm [BS]/ 23 dBm [UE] [14]
Fading margin	4 dB	4 dB
Interference margin	3 dB	3 dB
Path loss model	Heavy industry [13]	UMI+O2I penetration loss (low-loss model) [12] / InH - office
Antenna array	32x4 URA	16x4 URA
Packet size	10-300 byte	10-300 byte

A. Factory Automation Scenario

For the factory automation use case, we use 5G FR2 that has been allocated to 5G in the mmWave region. We deploy a private network with two BSs within the factory that is separated from the global network. Nodes (10 UEs) are uniformly distributed in an area of 100 m x 70 m. From the application point of view, this scenario corresponds to URLLC IIoT. In our performance evaluation, we use a bandwidth of 20 MHz and 100 MHz per single LTE and NR carrier, respectively. Then, to fairly compare the performance of NR and LTE, we use LTE carrier aggregation to 100 MHz. The path loss model is adopted from the heavy industry [13], and the received rate is computed using the Shannon Theorem.

We consider the following traffic model: the number of users in the cell (or area of interest) is constant, and each user is assigned a finite payload to receive. When a UE receives the packet, it can transmit the data to the other UEs in the network by establishing multi-hop communication. We assume that multi-hop communication can be established as follows:

- **Case 1:** multi-hop communication is established as a chain of sequential unicast transmissions (see Fig. 3(a)).

For instance, the following chain of transmissions can be determined: BS/AP $\rightarrow$ relay 1 $\rightarrow$ relay 2 $\rightarrow$ relay 3 $\rightarrow$ relay 4 $\rightarrow$ relay 5, etc. Here, each next relay is selected based on the best channel quality (e.g., SNR, RSSI) between the last relay and the devices that have not received the data. We note that thanks to the better channel conditions between hops, the latency can be reduced. However, relaying may also add a delay (compared to multimedia broadcast multicast services, MBMS) due to the hops when one considers HARQ, etc.

- **Case 2:** multi-hop communications with concurrent unicast transmissions can be established. For example, both orange links marked as 3 in Fig. 3(b), are concurrent links, and transmissions 2 and 3 coming from the first relay are performed one after the other. Here, similarly to case 1, each next relay is selected based on the best channel quality, but at the same time, several relays (that already received packet) can forward data to those who are still waiting to be served.

For the *factory automation scenario*, we consider two main metrics that are critical for the use case: *latency* and *network (aggregated) throughput* (see Fig. 4). Note that latency is calculated as the time required for the data packet dissemination to all the terminals in the network, whereas throughput can be described as the total data rate delivered to all UEs and is calculated as the product of the packet size times the number of UEs divided by latency.

One may notice that in our simulation settings, NR sidelink improves the system parameters compared to other systems in terms of end-to-end transmission delay and network throughput thanks to the gains obtained from reuse, relay, and proximity. We recall that latency in the case of the URLLC scenario has to be minimized, whereas network throughput (or, equally, the sum of data rates) benefits from the reduced

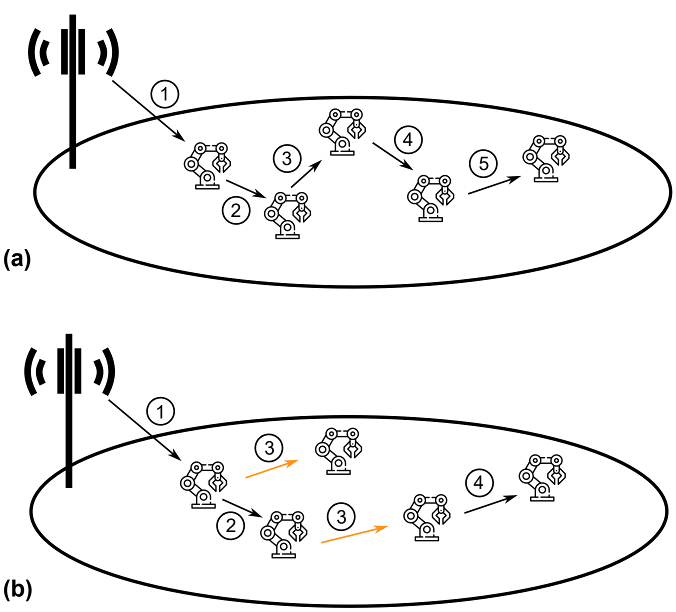

Fig. 3. Multi-hop establishment illustration: (a) chain, (b) concurrent transmissions.

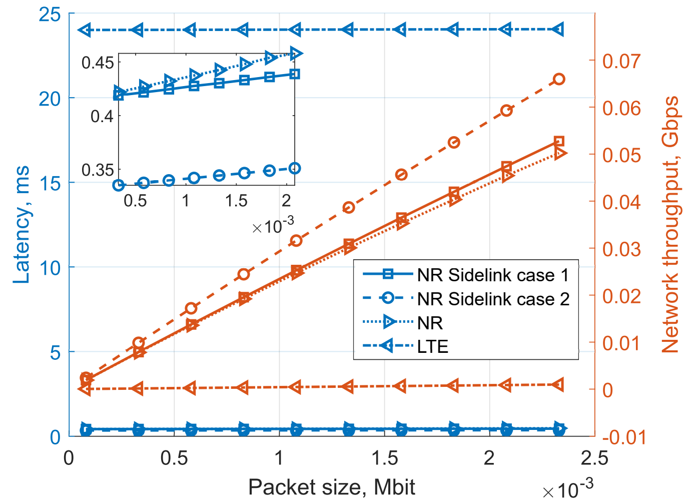

Fig. 4. Factory automation: latency as a function of packet size (blue); network throughput as a function of packet size (red).

end-to-end latency. Recall that the sum of data rates varies with the channel variations. Then, an increase in packet size may lead to a rise in latency to some extend. Note that the superior behavior of the NR sidelink comes from more flexible scheduling and scalable numerology. Also, sidelink can provide better energy efficiency and latency since transmissions generally occur over short distances, leading to the fact that the modulation and coding scheme selected during a sidelink transmission is generally high.

Most importantly, one may observe that the relay selection mechanism plays an important role in improving the system performance. More precisely, the possibility of utilizing concurrent transmissions and the sophisticated selection of the next-hop relay according to the channel quality between devices (case 2) reveals the best performance. Hence, we can deduce that designing the algorithms that are able to take fast and intelligent decisions on the relay discovery and selection is of particular interest.

Further, we emphasize that the cooperation with several relays may introduce sufficient macro-diversity and system reliability in conditions of a high probability of line-of-sight paths being blocked. Hence, without sidelink features (or IAB, among other technologies), the system would experience difficulties guaranteeing reliable communication in factory automation setups. Then, this problem worsens for the dynamic scenario.

B. Public Safety: Fire Brigade Scenario

To investigate the impact of NR sidelink on system performance considering the public safety use case, we consider uniformly distributed points with coordinates (x, y) within an area of 500 m x 1000 m. Then, we deploy uniformly 6 UEs in a radius of 20 m with (x, y) as a center. The BS is located at the center of 500 m x 1000 m rectangular. The Head of the team is assumed to be out of the building and is controlling the rescue operation. One of the UEs is the first relay device from outdoor to indoor environments (the one with the best channel). We use the urban micro (UMi) 3GPP path loss model

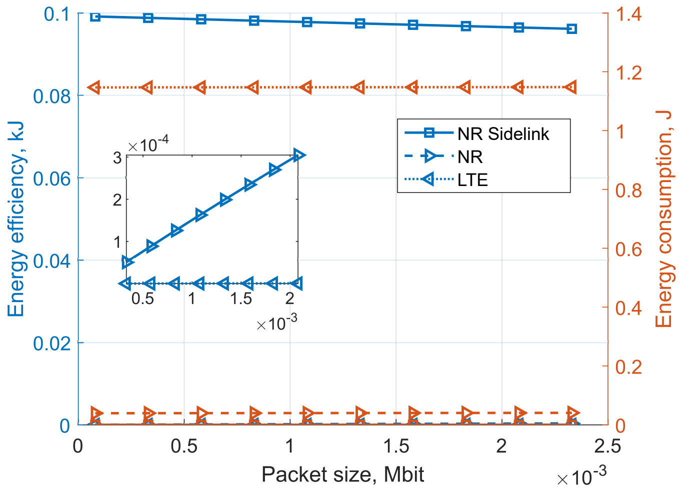

Fig. 5. Public safety (packet size ranges from 10 to 300 byte): energy efficiency as a function of packet size (blue); power consumption as a function of packet size (red).

for the link between the relay device and the BS as well as consider outdoor-to-indoor (O2I) penetration loss. The path loss incorporating O2I building penetration loss is modeled as described in [12]. Then, for indoor multi-hop relaying, we use the indoor 3GPP model (InH - office).

Regarding the way of forwarding the data to each device from the relay, there are two possible approaches: (i) relay UE forwards the data to each device independently, and (ii) relay UE forwards the data to one device, and then this device forward the data to another device and so on (i.e., a chain of transmissions). In our simulation, we exploit the second option, wherein gNB is connected to the first relay device, and the relay device forwards this information to the rescue team (according to the multi-hop case 2). To simulate antenna arrays, we use MATLAB Antenna Toolbox. We consider FR1 envisaged to carry much of the traditional cellular mobile communications traffic.

Differently from the previous use case, public safety focuses on wider coverage and power saving for battery-based UEs. As one may learn, Fig. 5, presents the results for the *fire brigade scenario* in terms of *energy efficiency* and *power consumption* as a function of the packet size. We estimate the total power consumption in the system by multiplying transmit power in watts by the time required for the packet delivery, whereas efficient energy use is defined as a division of network throughput by the consumed energy. That is, the energy efficiency is defined as the obtained network throughput divided by the used energy in bit/s/J, which assesses how effectively energy is utilized to get the network throughput.

We highlight that both transmit power and transmission delay impact on energy use. Then, the energy consumption can be reduced by lowering the transmit power. Hence, in our setup, the transmit power from the gNB and between relays are set to 46 dBm and 23 dBm, respectively. However, there is a trade-off between lower transmit power (less energy consumption) and delay (which also causes energy consumption).

From the obtained results, one may infer that NR sidelink brings its advantage in terms of proximity and relaying, affecting propagation properties as we deal with mixed outdoor-indoor environments. NR ProSe allows for high reliability, high bit rates, low power consumption, and low latencies. Note that reliability in public safety services can be satisfied by using different tools, such as multi-hop relaying, multi-connectivity, multi-RAT, etc. Relaying has many advantages, including the possibility to ensure extended coverage and reliability in the case of network failure. However, several challenges need to be addressed to provide a robust solution. For example, the security of D2D communications has to be guaranteed. Then, the question is when to do relaying, on what parameters the source node decides to relay via nearby nodes. Finally, latency constraints: relaying may also add a delay (compared to multimedia broadcast multicast services, MBMS) due to the hops. We discuss the future sidelink directions that have to be investigated in the next section.

V. Future Directions of Sidelink

Sidelink technology was standardized for the first time during LTE 3GPP Release 12. However, due to the uncertainty on whether such a technology would have been of interest to the major mobile operators, the use cases that sidelink was supposed to handle were only confined to public safety and V2X. Besides, only a simple set of features ended up in the LTE specification, most of which actually needed to be pre-configured in the UE sim card. Note that pre-configuration is for out-of-coverage operation only, whereas the usual SIB/RRC mechanisms are used for operation in coverage.

However, with the multitude of use cases that 5G NR is expected to support, the sidelink technology again gained momentum among industry and mobile operators and is now considered one of the killer technology to guarantee low delay, extended coverage, and improved energy efficiency to the UEs. Most importantly, the use cases that sidelink is expected to handle are not only confined to public safety and V2X (i.e., as for LTE), but they span from unlicensed applications, IIoT, up to Unmanned Aerial Vehicles (UAVs). This is also becoming evident in view of the coming 3GPP Release 18, where vertical technologies and applications are interacting with each other in order to provide the connection to "anything", "everywhere", and "anytime" (one of the basis of 5G technologies).

Sidelink Relaying. One of the main goals of sidelink relaying is the coverage area extension of both sidelink communication and cellular network. Moreover, energy efficiency and enhanced QoS support are additional essential features. As defined in [15], there are two types of relaying that can be studied: (i) UE-to-UE and (ii) network-to-UE. The former aims to extend the coverage of the cell through a relay, thereby providing the service for UEs located at the edge or out of the coverage of the cell. The latter means that not only a single-hop relay (supported by Rel-17) can be performed. In this case, multiple relays (multi-hop relaying is currently not supported) can extend the sidelink coverage, but more work needs to be done.

The main aspects that have to be studied regarding relaying are relay (re-)selection, relay discovery, UE authorization, QoS provisioning, among others, which is becoming more complex in the case of multi-hop relaying.

Sidelink Positioning. One of the missing functionalities in Rel-17 is sidelink positioning, i.e., to satisfy the strict requirements for absolute positioning. Here, a study on positioning in Rel-17 can be considered as an initial point, and it is expected that sidelink positioning will be one of the main work items in Rel-18.

With the growing complexity of indoor and outdoor environments, the radio propagation between transmitting and receiving devices becomes increasingly complex, especially with dynamic blockers. Although the LoS paths between each pair of target and anchor nodes typically exist in the considered industrial/public safety scenarios, different environmental objects can block the LoS paths, turning them into challenging NLoS scenarios. Thus, novel positioning, tracking, and mapping frameworks employing both the multipath components and the relay paths from intelligent surfaces are seen to form an intriguing open research space to synthesize the location and environmental awareness towards an intelligent positioning and mapping system.

Sidelink and Artificial Intelligence. Artificial intelligence (AI) and machine learning (ML) can improve sidelink further communication. For instance, ML algorithms can perform resource allocation with the quality of the radio channel, road traffic conditions, among other input algorithm parameters. This, in turn, will reduce the overall latency and the throughput for future sidelink communications.

In conclusion, sidelink as a technology is continually evolving, and it is now evident that it will be one of the pillars not only in the further development of the 5G system but will also be at the center of the close to come 6G technology that will be the first standardization in 3GPP (hopefully) during 2023.

VI. Conclusions

In this article, we provided an overview of the main functionalities and features of NR sidelink compared to the LTE-A. NR sidelink is believed to become an essential technology to ensure both mission-critical and ultra-reliable low-latency communications. Then, we elaborated on NR sidelink as a solution for public safety and factory automation, outlining their principal requirements and use case flow. Throughout the simulation study, we raised the possibility of using NR sidelink communication for public safety and factory automation scenarios, demonstrating noticeable end-to-end latency and energy efficiency performance improvement compared to LTE, LTE sidelink, and NR transmissions. We concluded by highlighting the future directions of sidelink development.

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