Indoor Measurements of 5G Sidelink for Broadband Public Safety Applications

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***Abstract*—This paper presents indoor measurements of 5G sidelink coverage using on-board units originally designed for vehicle-to-everything communication. The objective is to evaluate the suitability and challenges of sidelink communication for broadband communication in the context of public safety organizations. The experiments focus on the packet loss rate during indoor data transmission under realistic deployment conditions. A direct sidelink connection between two on-board units is compared to a relay-assisted setup. The results show that the use of a relay is necessary to achieve good coverage in realistic scenarios, especially when communication over multiple stories is required.**

***Index Terms*—5G sidelink, broadband communication, public safety organizations, indoor measurement.**

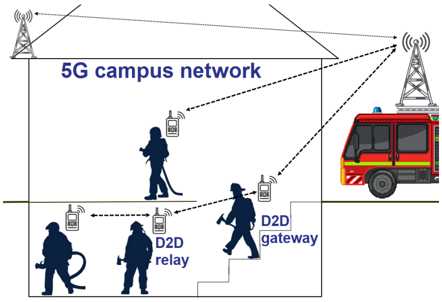

Fig. 1. Use case of 5G broadband communication for public safety applications with campus network and device-to-device communication.

I. INTRODUCTION

Reliable broadband communication is a critical requirement for public safety organizations, particularly in mission-critical scenarios where the conventional network infrastructure is unavailable or unreliable. The 5G sidelink interface (PC5) enables direct device-to-device (D2D) communication, offering low-latency, high-reliability connectivity independent of the cellular network, even in challenging propagation environments.

Although sidelink has primarily been deployed in vehicular systems via cellular vehicle-to-everything (C-V2X), its properties also make it well suited for public safety applications. First responders frequently operate in indoor or coverage-limited environments such as multi-story buildings, basements, or disaster zones, where maintaining continuous communication is essential for operational efficiency and safety.

The Third Generation Partnership Project (3GPP) has continuously advanced C-V2X standards. LTE-V2X, introduced in Release 14 and enhanced in Release 15, was the first standardized LTE-based implementation. Release 16 extended these capabilities with 5G New Radio (NR) V2X, enabling advanced sidelink communication for both vehicular and mission-critical applications. C-V2X defines two communication interfaces: PC5 at 5.9 GHz for direct D2D communication, and Uu for vehicle-to-network (V2N) connectivity. C-V2X offers functionalities comparable to those of IEEE 802.11p-based systems, such as DSRC in North America and ITS-G5 in Europe, which rely on periodic broadcast messages - basic safety messages (BSMs) or cooperative awareness messages (CAMs) - to convey vehicle position, speed, heading, and acceleration. While effective for traffic safety, these broadcast mechanisms are insufficient for applications requiring continuous, high-throughput, and low-latency data. Public safety tasks, including live video streaming, sensor data transfer, and mission-critical control, demand robust broadband connectivity even when the network infrastructure is unavailable.

The evolution of sidelink communication is described, for example, in [1], [2], with a focus on automotive applications and C-V2X. 5G sidelink communication in a more general manner, including public safety applications, is described in [3]. The authors in [4] also focus on safety applications and mission-critical communication with 5G. Another important issue within such safety applications is positioning with focus on first responders, which is addressed in [3], [5]. An important aspect for sidelink communication is the applied resource allocation method. In mode 4 in C-V2X as well as in mode 2 in NR-V2X, resource allocation is a sensing-based semi-persistent scheduling (SPS) algorithm. Details can be found in [6] and [7].

In this paper, we evaluate the performance and challenges of commercially available C-V2X hardware for broadband public safety applications. A typical use case is depicted in Fig. 1. The focus is on indoor scenarios in which a 5G campus network provides connectivity to first responders in that area. In addition, sidelink communication is applied in combination with D2D gateways and relays. Controlled indoor measurement campaigns were conducted to evaluate performance under realistic conditions, with a particular emphasis on relay-assisted transmission and its influence on link reliability and throughput.

The hardware we used for the investigations presented in this paper is based on the C-V2X standard and sidelink transmission mode. In detail, we used the Cohda Wireless MK6 on-board units (OBUs), which are based on the Qualcomm SA515 C-V2X chipset. In a previous project, a similar evaluation was conducted for the communication between cars and bicycles. For this, we used a previous version of these OBUs without relaying [8]. The authors in [9] also examine sidelink C-V2X communication based on measurements. However, they use software-defined radio modules and a machine learning approach for coding and modulation.

II. MEASUREMENT SETUP

The setup for the measurement campaign described in this paper consists of multiple parts:

- A GNSS repeater to have a stable time synchronization in the cellar.
- Three Cohda Wireless OBUs.
- Three computers for handling data packets and for controlling the OBUs
- A vehicle which transports the receiving OBU.

A. GNSS Repeater

GPS and GNSS work perfectly in outdoor scenarios under normal conditions. However, the measurements were taken on the ground floor and in the basement of a large and solid building. It is impossible to detect the GNSS signal in the basement with standard equipment. One solution could be the use of an external antenna. However, a wired solution would not be suitable for a driving vehicle. Therefore, a self-built GNSS repeater was used.

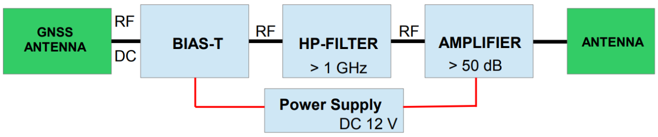

Fig. 2. Schematic of the GNSS repeater.

The repeater consists of a receiving antenna with integrated filters, additional filtering, amplifiers, and a transmit antenna. Its schematic is depicted in Fig. 2. The required voltage is provided by a bias-T. Since the vehicle also drives around a corner at a distance of approximately 55 meters, a high RF output level is preferable. Nevertheless, to avoid RF feedback through the receiving antenna, the gain had to be adjusted carefully.

B. Hardware

In this work, three Cohda Wireless MK6 OBUs were used. Each OBU is equipped with a Quectel AG550Q modem, utilizing the Qualcomm SA515 chipset that supports 3GPP Rel. 15 C-V2X sidelink on band B47. The first OBU is configured as a transmitter. The second OBU is configured as a repeater node. This operation requires an external computer because the built-in relay function of C-V2X is not available until Release 17 [1], [2]. The third OBU is configured as a receiver. For operation in the C-V2X sidelink mode, the OBUs require a valid GNSS signal. This is necessary in 3GPP Release 15 to achieve time synchronization because the protocol uses fixed time slots. In future releases, other techniques are specified to synchronize the radio units.

The operating frequency in the ITS band is 5.9 GHz. The OBUs are using the MobileMark MGWG-303 external antennas. The MGWG-303 has two V2X antennas with 5 dBi gain and a GNSS antenna integrated. The antennas are connected to the C-V2X and GNSS ports displayed in Fig. 3. The MK6 OBU can transmit with a maximum power of 21.5 dBm (C-V2X Class 3). The receiver sensitivity is -99 dBm at 3 Mbps.

Fig. 3. Cohda Wireless OBU MK6 with connections.

The transmitter and repeater nodes were not moved during the measurements. Their position will be explained later in Sec. II-D. The receiver node is a vehicle that would be controlled by firefighters in an emergency scenario. Therefore, the receiving OBU is mounted on a vehicle as shown in Fig. 4.

Fig. 4. Equipped vehicle for measurements in cellar.

The vehicle is developed in the research project ”5GCamp-BOS” and will be equipped with different sensors and actuators, e.g. camera, radar, temperature sensor, two-way speech communication. In this paper, the focus is on data transmission, so that the vehicle is equipped with an OBU and a computer only. Each wheel of the vehicle has a motor with an encoder included. This ensures a constant velocity and uniform movement during the measurement.

C. Software

The data transmission using sidelink communication is implemented with a UDP bridge between the Ethernet interface and the sidelink modem. Thus, the OBU sends each UDP packet arriving on the Ethernet interface via the Quectel modem. The bridge can also be configured in the receiving path to forward all sidelink communication to the Ethernet interface. By using UDP on the Ethernet side, it is ensured that the packet loss is not improved by Ethernet protocols.

The payload of the UDP packets consists of three parts:

- A 23-byte header, which is used for the evaluation of the packet loss. It contains information on the source, destination, and repeater, as well as a unique identifier and packet length.
- Data of variable length. For the conducted measurements, the data are random bytes.
- A CRC32 checksum to verify the integrity of the received packets (4 bytes).

During measurements, the PCs connected to the OBUs handle packet generation and processing. Additionally, the transmitter, repeater, and receiver save all packets they process for later evaluation.

During the evaluation, the CRC32 checksum is evaluated first to measure the packet error rate. The next step is to find the number of lost packets. For that purpose, the unique packet identifier is used. Three packet loss rates are calculated: the loss between the transmitter and receiver, the loss between the transmitter and repeater, and the loss between the repeater and receiver.

D. Environment

The measurements are conducted in a cellar on the campus of the Hochschule Niederrhein in Krefeld, Germany. The transmitting OBU is located on the ground floor near the entrance of the building. This represents a typical position for a gateway node to an external cellular network or a campus network. In the reconstructed scenario, an autonomous vehicle is sent into a dangerous building to investigate the situation. When the limit of the sidelink coverage is reached, a repeater should be used to extend the coverage.

In the described scenario, the vehicle is driving in a corridor in the cellar of the building with a repeater located in the staircase. A schematic of the hardware used is shown in Fig. 5. The path along which the vehicle drove is shown in Fig. 6. The ”S” marks the starting point and the numbers represent different checkpoints on the path. The checkpoints are as follows:

- CP1 - start of the corridor
- CP2 - location of the GNSS repeater
- CP3 - emergency fire door in the middle of the corridor
- CP4 - end of the corridor
- CP5 - no line of sight available
- CP6 - end of path

The measurements were carried out inside a multi-story office building made of reinforced concrete walls and glass facades. Thus, the expectation is that a repeater is necessary to achieve sufficient sidelink coverage. This work evaluates two radio paths: First, a direct link between the transmitter near the entrance and the vehicle in the cellar. Second, a relay link with a repeater between the transmitter and the receiver.

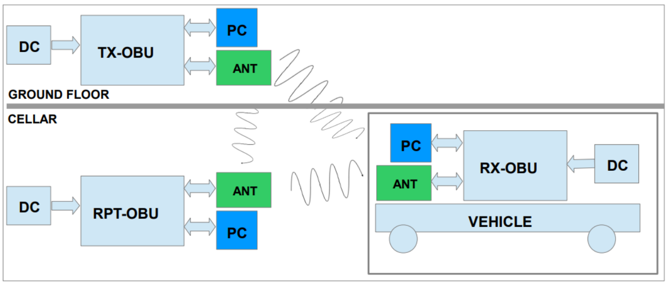

Fig. 5. Schematic of the measurement setup. Transmitter, repeater and receiver OBU with power supply, antenna and PC.

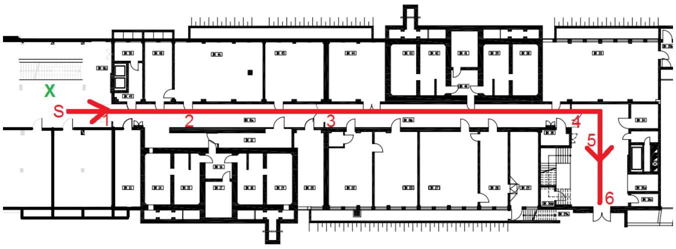

Fig. 6. Map of the cellar with marked driving path (red line) and numbered checkpoints (1-6); the green cross marks the position of the repeater.

E. Measurement Parameters

The measurements are carried out with different parameters for UDP packets. The standard C-V2X sidelink parameters are applied in the measurements. Each packet has a duration of 1 ms, with time slots synchronized via GNSS. In event mode, the transmitter can use a time slot each 5 ms. The modulation is automatically adjusted by the OBU to fit the current situation according to the configured modulation-coding scheme (MCS) table. For example, during fast movement of the radio, a more robust modulation is used. Because of the fixed time slots of 1 ms, a lower MCS leads to a smaller packet size.

To investigate the influence of different transmission modes, the UDP packet length and rate are varied. The values of the packet rate are 10, 50 and 100 packets per second. The highest packet rate of 100 packets per second is chosen to use the maximal theoretical packet rate during event mode with two transmitters. In addition, the packet size is configured to contain 512 or 2048 bytes of data. Table I displays the detailed parameters for each measurement.

TABLE I
MEASUREMENT PARAMETERS.

measurement	packet rate	packet size	event mode
M1	50/s	2075 bytes	on
M2	10/s	2075 bytes	on
M3	100/s	2075 bytes	on
M4	50/s	539 bytes	on
M5	50/s	2075 bytes	off

III. MEASUREMENT RESULTS AND DISCUSSION

The results of all measurements are presented in the following section. In particular, the packet loss rates of the original and repeated packets at the receiver are of interest. During the evaluation of the packet error rate, it was discovered that all received packets are without errors. Thus, the sidelink modem only forwards correct packets, so that the following evaluations focus on lost packets (packet loss rate). Furthermore, the number of sidelink packets is not equal to the number of UDP packets. This can be seen by analyzing the RF signals, as will be discussed later.

A. Packet Loss Rate

The packet loss rate is calculated across the entire path in the cellar corridor as marked in Fig. 6. The results for all five measurements are shown in Fig. 7. As can be seen, the loss rate on the path is very different for each measurement. However, all measurements have in common that the loss rate of the original packets from the transmitter is 100 % after a few meters in the corridor. The loss between the transmitter and the repeater (not shown in Fig. 7) is approximately 3 % for the first four measurements using the event mode. In the fifth measurement without event mode, the loss rate between transmitter and repeater is approximately 30 %. Thus, the packets that are already lost between transmitter and repeater are not forwarded to the receiver and are not considered within the packet loss rate in M5 of Fig. 7.

The measurements show that a transmission without repeater is impossible in the given scenario. Using the repeater, the packet loss rate in the cellar corridor is rather constant. This means that the RF coverage in the corridor is sufficient for the transmission and the packet loss is caused by other effects like limitation of the data rate. After checkpoint four, the loss rate increases because no line of sight is available.

The measurements also reveal some problems for the use of broadband in public safety scenarios. In measurements with higher data rates, the packet loss rate is higher than expected. Moreover, in the third measurement the loss rate exceeds 80 %. In addition, the repeater and transmitter seem to disturb each other. Before the first checkpoint, the receiver is in reach of the transmitter. At this position, the packet loss rate is very high for both the original and the repeated packets. But only for the higher data rates used in M1, M3, and M5. Using a slower packet rate or a small payload size, the loss rate is close to zero, even in the case where the repeater and the transmitter are both in reach. Thus, scenarios with low data rate requirements are possible. For example, transmission of speech or sensor data.

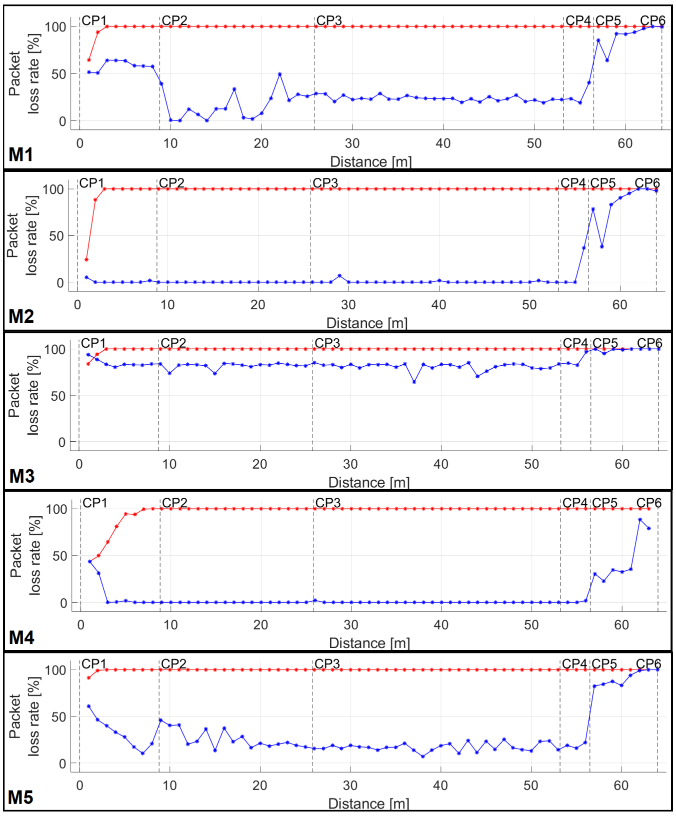

Fig. 7. Packet loss rate at the mobile receiver during measurements with different configurations as mentioned in II-E; red: loss of original packets; blue: loss of repeated packets.

B. Analysis of Sidelink Signal

In the event mode, the OBU is theoretically able to transmit 200 packets per second via the sidelink interface. One time slot of 1 ms is available each 5 ms. However, when transmitting UDP packets, it is important to keep in mind that one UDP packet might result in multiple sidelink packets. Figure 8 shows the captured RF signal from an OBU transmitting ten UDP packets of 2048 data bytes (2075 bytes total) per second. Thus, there should only be two detected transmissions in the 200 ms snippet. However, there are four transmissions detected for each antenna.

This effect is critical when one approaches the theoretical maximum packet rate. This is shown in Fig. 9. There, an OBU is sending 100 packets of 2048 data bytes.

The sidelink packets have a maximum payload size of 1049 bytes by using the configured MCS 11 (16-QAM and coding rate of 0.41). Above this size, an UDP packet is split in multiple sidelink packets. This effect can also be observed again at multiples of 1049 bytes. The maximum allowed size of an UDP packet is about 6300 bytes. Above

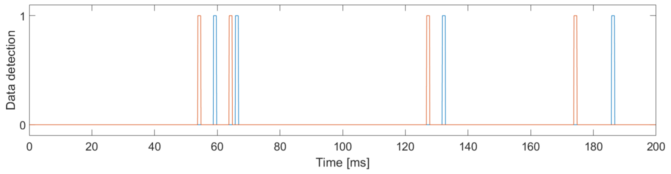

Fig. 8. 200 ms snippet of the RF signal of the OBU during slow transmission (10 packets per second); blue: port CV2X1; red: port CV2X2.

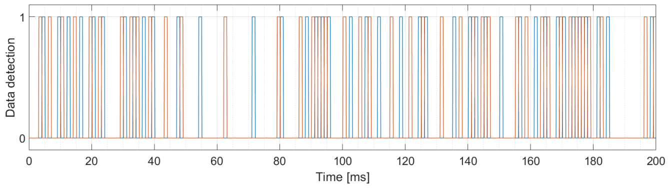

Fig. 9. 200 ms snippet of the RF signal of the OBU during fast transmission (100 packets per second); blue: port CV2X1; red: port CV2X2.

this value, no transmission is detectable at the RF ports. This effect multiplies by using a repeater. Thus, for a reliable transmission, a lower data rate has to be chosen.

IV. CONCLUSION

The measurements confirm the feasibility of using 5G sidelink communication with existing C-V2X OBUs for some broadband public safety applications. The stability and coverage of the system during measurements with a measured data rate of about 200 kbps allow the transmission of sensor data or speech in mission-critical situations. This allows for some use cases, especially in combination with 5G campus networks and gateway nodes.

However, for applications with higher data rates, such as live video streaming, the used configuration is inappropriate. In addition, the necessity of a GNSS signal is a problematic restriction in realistic scenarios. The upcoming 3GPP releases will tackle many of the encountered challenges. Before broad deployment of hardware using Release 16 or even Release 17, different configurations of Release 15 could lead to an improvement because the standard use case is optimized for short messages.

The next step in developing a demonstration platform for public safety organizations within the project ”5GCampBOS” is the implementation of real-world scenarios using sensor data. Additionally, the use of multiple relays and users is relevant for public safety applications

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