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MULTIMEDIA TRANSMISSION TECHNIQUE FOR SMART AMBULANCE WITH MULTI-CARRIER OFDM IN A V2V AND V2I CHANNEL MODEL USING SOFTWARE DEFINED RADIO TECHNOLOGY

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ABSTRACT
This research explores the implementation of a cutting-edge Software Defined Radio (SDR) framework to transmit multimedia files that can be assumed to be medical data in smart ambulances. The system utilizes multi-carrier Orthogonal Frequency-Division Multiplexing (OFDM) across V2V and V2I channels. The research is based on the notion that adaptive real-time communication is essential for the uninterrupted supply of key patient data to medical facilities and vehicles in transit, in order to address the problems posed by high mobility and dynamic environmental conditions. A comprehensive SDR system has been constructed and assessed in comparison to conventional communication mechanisms, demonstrating notable advancements in data accuracy and uninterrupted transmission. Our system successfully established stable connections in V2I channels, even in the presence of environmental obstacles. It maintained average power levels of approximately 32.074 dBm and a Peak-to-Average Power Ratio (PAPR) of 1.037 dB. These results indicate a constant signal envelope that promotes optimal signal transmission with excellent fidelity. In V2V scenarios, we successfully maintained data integrity with a low Peak-to-Average Power Ratio (PAPR) of 3.316 dB, even while vehicles were moving at a speed of 20 km/h. Additionally, we secured a high likelihood (94.5%) that the signal power remained close to the average, showing the robustness of our system against Doppler effects and signal dispersion. Text transmissions experienced errors when subjected to a Doppler shift of 20 km/h, which impacted the decoding of the received text. Similarly, image transmissions revealed limitations in bandwidth, as a transmitted image of 3640 KB was received with a degraded 4 KB. This emphasizes the importance of implementing effective error handling and recovery mechanisms. The results illustrate the efficacy of the suggested system in maintaining a high Quality of Service (QoS), offering proof of the effectiveness of contemporary wireless communication technologies in improving emergency medical services and setting new standards in smart ambulance capabilities.
Keywords : *OFDM, Software Defined Radio (SDR), Smart Ambulance, V2V, V2I.*

1. Introduction

In recent years, the advancement of technology has revolutionized various sectors, including healthcare. One significant application of technology in the healthcare domain is the concept of a "smart ambulance" (Zhai et al., 2021). A smart ambulance is an innovative approach that utilizes cutting-edge technologies, such as Software Defined Radio (SDR) (Bosquez et al., 2017) and Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, to improve emergency medical services (EMS). The integration of multimedia transmission techniques in smart ambulances has the potential to enhance the quality of healthcare services during critical situations (Abdeen et al., 2022).

During emergencies, such as accidents or medical crises, every second counts (Harja, 2018). The prompt and efficient delivery of medical assistance can significantly impact the outcomes for patients(Rehman et al., 2018). However, the communication between ambulances and the hospital or emergency response centers can often be challenging, especially in densely populated areas or areas with poor network coverage (Tebe et al., 2022). Conventional communication methods, such as voice calls, may not always provide the necessary information or transmit real-time data, hindering the ability of healthcare professionals to make informed decisions(Leis, 2018).

To address these challenges, the concept of smart ambulances has emerged (Ochoa et al., 2023). Smart ambulances leverage advanced technologies to establish seamless communication between the ambulance, hospitals, and emergency response centers (Qureshi et al., 2022). This enables the real-time transmission of critical patient data, such as vital signs, medical history, and video feeds, ensuring that healthcare professionals have accurate and up-to-date information to make timely and informed decisions(Usman et al., 2019).

Software Defined Radio (SDR) technology is a pivotal asset in the implementation of smart ambulances, particularly for the transmission of multimedia medical data to other ambulances or the nearest hospital through V2V and V2I communication systems (Fliedner et al., 2018). In a V2V scenario, SDR can be utilized to establish direct communication links between ambulances (Singh et al., 2014a). By using software to control radio functions that were traditionally managed by hardware components, SDR allows for on-the-fly adjustments to transmission protocols, frequencies, and bandwidths. This flexibility is crucial when conveying patient data such as vital signs, audio communications (Hendry et al., 2019), and even live video feeds, ensuring that the receiving ambulance can access and prepare to provide the necessary medical assistance upon the patient's arrival. For V2I communications, SDR enables the smart ambulance to interact with fixed infrastructure like cellular towers, hospital communication systems, or dedicated roadside units. The SDR can quickly adapt to the best communication standards available and optimize the data packets for transmission over these channels, ensuring high-quality delivery of multimedia data(Kshatriya, 2019). Hospitals can receive critical patient information ahead of time, allowing medical staff to make informed decisions and prepare for immediate intervention upon the patient's arrival.

The inherent programmability of SDR is highly beneficial in the dynamic environment in which smart ambulances operate(Pamungkas & Fitrian, 2023). It can compensate for the varying signal qualities and transmission speeds required when an ambulance is moving at high speeds or when it transitions between urban and rural areas. SDR also allows for encryption and secure transmission of sensitive medical data, addressing privacy concerns and compliance with health information regulations. Moreover, SDR's ability to handle a wide range of frequency bands means that a smart ambulance can communicate across various emergency and commercial frequency allocations, depending on which is the most appropriate for the situation(Singh et al., 2014b). In essence, SDR provides a versatile communication toolkit that can be tailored in real-time to the specific needs of a smart ambulance, enhancing its ability to provide life-saving medical services in transit.

In a V2V channel (Arena & Pau, 2019; Campuzano et al., 2012; Liang et al., 2017), the smart ambulance directly communicates with other vehicles on the road. This channel faces challenges primarily due to the relative speeds of the vehicles involved. As both the ambulance and the other vehicles are in motion, the Doppler effect can cause shifts (Feukeu et al., 2016; Pamungkas & Suryani, 2018) in the frequency of the transmitted signals, potentially leading to miscommunication or data loss. Moreover, the rapidly changing topology of the vehicular network due to movement causes frequent variations in the communication path, requiring the system to continuously adjust to maintain a stable connection (Pamungkas et al., 2021).

In a V2I channel (Dey et al., 2016; Noh et al., 2013), the smart ambulance communicates with roadside infrastructure, such as traffic signals, emergency location transmitters, or base stations, which can facilitate a broader communication range and connectivity to hospital networks. The challenges in a V2I channel are somewhat different (Machardy et al., 2018; Yang et al., 2017); they include maintaining a stable connection despite obstacles like buildings or trees, which can cause signal reflection, scattering, or diffraction. Furthermore, as the ambulance moves through different environments – from open highways to cluttered urban settings – the V2I communication must seamlessly transition between various infrastructures without interrupting the multimedia transmission.

The SDR technology within the smart ambulance combats these issues by dynamically adjusting its operational parameters. For instance, it can change the frequency, modulation scheme, or power levels in response to the conditions sensed by the onboard systems. It can also switch between different communication protocols or channels to ensure the most reliable pathway for data transmission at any given moment.

This study presents an advanced method for transmitting multimedia using a combination of multi-carrier OFDM and SDR technologies. Our approach addresses the inherent limitations of traditional V2V and V2I communications by employing a resilient OFDM system that is adept at handling the rapid channel variations and interference patterns unique to EMS scenarios. The SDR technology facilitates a flexible and adaptive communication system that can be dynamically adjusted to the condition of the vehicular network environment.

The main contribution of this research lies in the novel integration of multicarrier OFDM with SDR specifically tailored for V2V and V2I communications in smart ambulances. While previous studies have extensively explored OFDM for various wireless communication systems, its application in real-time vehicular environments remains limited. Furthermore, most existing works focus on simulation environments or theoretical models that do not fully capture the complexities of real-world vehicular scenarios. In contrast, our research implements and tests the proposed system in actual V2V and V2I channels, utilizing SDR technology for dynamic adaptation in rapidly changing vehicular conditions. This contribution is unique because it addresses key challenges such as Doppler shifts, multipath fading, and signal reliability in a practical and real-time setup. By integrating OFDM into a real-world SDR framework, we provide a flexible and resilient communication system that can maintain high Quality of Service (QoS) in dynamic emergency scenarios, which is critical for smart ambulance applications. This combination of real-time SDR adaptation and OFDM in vehicular communication channels for emergency medical services is largely unexplored in existing literature, making this study a significant advancement over prior works.

2. Literature Review

Several studies have explored multimedia transmission techniques and technologies for smart ambulances, focusing on different aspects such as SDR technology, multicarrier OFDM, and V2V/V2I communication channels. In this review, we critically evaluate these studies, compare their methodologies and findings, and discuss the practical implications for emergency medical services (EMS) (Debnath et al., 2024; Krygier et al., 2024; Yakar & Kilinc, 2024).

(Moer et al., 2012) introduced a cognitive radio framework for smart ambulances, which dynamically selects the optimal frequency band for data transmission. While this approach is innovative in applying cognitive radio for emergency communication, it lacks the integration of OFDM, a key technology for handling frequency-selective channels in vehicular scenarios. Without OFDM, the system remains vulnerable to multipath fading, especially in dynamic environments, limiting its applicability in real-world vehicular contexts. Additionally, the study does not consider the practical challenges of implementing this system in actual EMS scenarios, where latency and reliability are crucial.

(Usman et al., 2019) presented a 5G-enabled framework for remote healthcare services, offering real-time analysis and guidance for ambulance crews. Despite leveraging 5G technology, the study overlooks the adaptability and flexibility offered by SDR, which is crucial for ensuring stable communication across varying network conditions. SDR's absence in this framework restricts its ability to adapt to diverse communication environments, a limitation that could significantly impact its reliability in real-world EMS scenarios. The study also lacks a detailed evaluation of the system’s performance in high-mobility environments, which are typical in emergency situations.

(Mohandass & Umamaheswari, 2014) explored the use of OFDM-based Cognitive Radio for biomedical signal transmission, highlighting its benefits for mitigating time dispersion effects. However, the study is confined to a simulated AWGN channel, which does not reflect the complexities of real-world vehicular communication, such as Doppler shifts and multipath fading. The lack of a detailed methodological discussion on SDR integration further limits the study's relevance to dynamic vehicular environments. In contrast, our research not only integrates OFDM with SDR but also tests this combination in practical V2V and V2I channels, addressing these real-world challenges directly.

(Nikbakht Bideh et al., 2019) proposed an SDN-based emergency traffic management system, focusing on route optimization for emergency vehicles. While the study provides valuable insights into reducing emergency response times, it does not focus on the communication technologies required for high-quality multimedia transmission in EMS. The methodologies applied are relevant for traffic management but do not address the technological requirements for robust V2V/V2I communication, leaving a gap in the context of multimedia data transmission for smart ambulances.

In summary, the existing literature provides fragmented solutions, often focusing on either communication frameworks or traffic management, without adequately addressing the integration of OFDM and SDR in real-world vehicular scenarios. These studies highlight the potential benefits of various technologies but do not fully explore their application in the context of EMS, where low latency, high reliability, and adaptability are essential. Our study fills this gap by proposing and validating a hybrid system that combines OFDM and SDR in practical vehicular environments, demonstrating its resilience against common challenges like Doppler shifts, signal dispersion, and multipath fading.

3. Research Methods

1. Smart Ambulance proposed

Smart ambulances equipped with USRP (Universal Software Radio Peripheral) for SDR technology can revolutionize emergency healthcare services by enabling high-speed, reliable communication of multimedia medical signals as we proposed in this paper. Figure 1 explains a smart ambulance setup, various types of multimedia medical signals can be collected, such as X-ray images, text (like doctor's notes), and audio files from medical instruments like stethoscopes or ultrasound machines. The USRP acts as a versatile hardware platform that allows the ambulance to transmit and receive a wide range of radio signals, manipulated by software on a host computer. This flexibility is provided by the SDR technology, which can process signals across a wide spectrum without the need for different hardware for each frequency band.

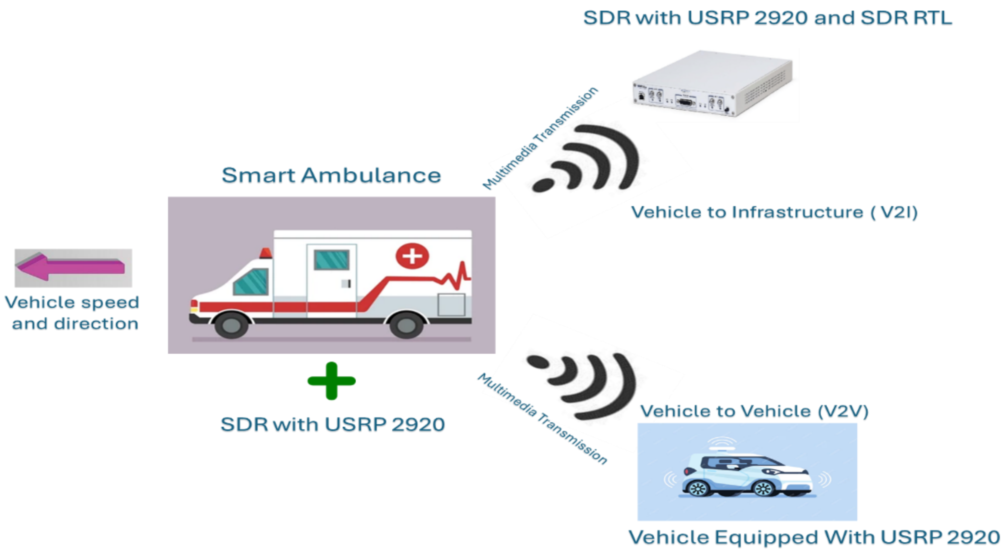

Fig. 1. Proposed Smart Ambulance with software-defined radio (SDR).

The communication takes place through outdoor channels, specifically through V2I and V2V modes. For the V2I, the smart ambulance can communicate with medical facilities or emergency services through infrastructure like cellular BTS or dedicated medical communication networks. Furthermore, for the V2V, the ambulance can also communicate with other vehicles equipped with USRP and SDR technology. This can be used for direct sharing of patient information to another ambulance or medical vehicle or to communicate with vehicles in its vicinity to clear traffic and create a faster path.

When the transmitters and receivers move and communicate with one another, the transmission frequency varies as well. The transmitter's frequency drops as it gets farther away from the receiver. The frequency rises with increasing proximity between the transmitter and receiver. We refer to this phenomenon as the Doppler Effect. Doppler Shift, the frequency shift caused by the Doppler Effect, has a value of as below (Pamungkas, 2018):

$$\Delta f = f_d = \pm f_c \frac{v}{c} cos\beta \quad (1)$$

Doppler spread is the movement of the carrier frequency fc within the channel as a result of this channel modeling. This movement is due to the Doppler effect, which widens the frequency range (Doppler spectrum), which is exacerbated by the presence of multipath (Campolo & Molinaro, 2014). The spectrum widens to the right as the frequency of fc is added to that of fd (fc+fd). In the meantime, the spectrum widens to the left if fc is decreased by fd (f – fd). The Doppler spread is the name given to this phenomenon. Doppler shift circumstances can expand the transmitted signal's bandwidth, which is why Doppler spread is often referred to as maximal Doppler shift (Campolo et al., 2015).

$$B_d = 2 f_d \quad (2)$$

The carrier frequency, denoted by fc, is 5.8 GHz. Meanwhile, v represents the vehicle's speed, c denotes the electromagnetic wave's velocity, which is equivalent to 3x108 m/s, and β denotes the angle of movement between the transmitter and receiver. When β = 0, the value of Δf will be at its maximum.

Technical parameters used in this research have been identified as seen on table 1. The transmitter and receiver operate at a frequency of 700 MHz, which is optimal for long-distance communications since it can effectively penetrate and cover extensive areas(Bou Saleh et al., 2012). The transmitter's output power of 17 dBm suggests effective power utilization that is appropriate for local wireless communications. Additionally, an antenna gain of 3 dB implies that the signal is amplified to a level that is twice as high as the input, so ensuring adequate gain without generating excessive interference.

The allocated bandwidth for both transmission and reception is 20 MHz, which is deemed adequate for accommodating the speedy data transmission frequently demanded by multimedia applications. The I/Q sampling rate of 25 MS/s enables precise signal sampling, a crucial aspect in OFDM signal demodulation to guarantee clear transmission and reception of information. A system noise figure of 5 dB signifies that the system introduces minimum noise in addition to the natural noise, hence facilitating a reduced level of interference and minimizing errors during transmission.

Table 1 - Technical Parameter of Smart Ambulance Used.

No	Parameter	Value
1	Frequency Used as Tx and Rx	700 MHz
2	Power Output Tx	17 dBm
3	Gain Tx	3 dB
4	Real Time Bandwidth Tx/Rx	20 MHz
5	I/Q Sampling Rate Tx/Rx	25 MS/s
6	Noise Figure	5 dB
7	Ambulance Speed	20 km/h

Ultimately, the ambulance's velocity during testing was established at 20 km/h, a crucial element that influences variables like Doppler shift, which necessitates consideration in the development of wireless communication systems. This observation suggests that the ambulance is situated at a somewhat modest velocity, thereby facilitating its monitoring and interaction with infrastructure or other vehicles. The combination of these criteria constitutes the fundamental basis that will impact the effectiveness, dependability, and effectiveness of communication systems in practical situations.

2. SDR block system communications diagram
1. Transmitter Side

This study employs a software-defined radio device comprising both hardware and software components. We utilize USRP 2920 and SDR RTL as our hardware components. We utilize GNU Radio and Matlab software. In order to construct a communication system that utilizes software defined radio for the transmission of medical multimedia signals, we employ the GNU Radio software, which encompasses both transmitting and receiving software components. To configure the GNU Radio software on the transmitting side, refer to the provided image Figure 2.

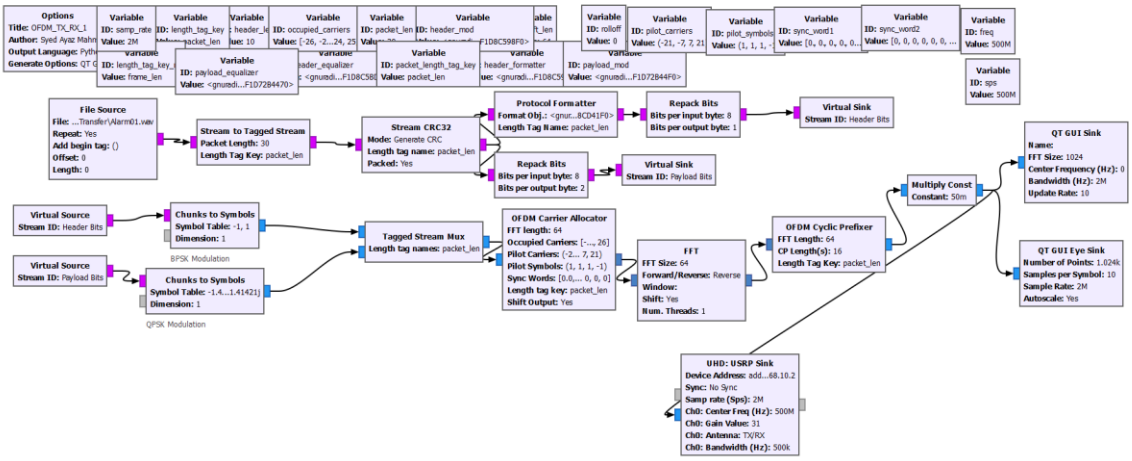

Fig. 2. Transmitter Side of Smart Ambulance Communications System Using USRP.

The functionality of the transmitter side block diagram can be dissected into the subsequent components.

1. Multimedia Conversion

The diagram illustrates the process of converting a multimedia signal into a format suitable for playback on a device, focusing on audio signals. The process consists of two main stages, they are Decoder and player. This stage involves the reception of encoded bits (r_n) which represent the multimedia content in a compressed and possibly encrypted form. These bits are processed by the decoder to reconstruct the digital signal (s[n]). The decoding process includes several steps, such as demodulation when the signal is transmitted over radio frequency, error correction to fix any transmission errors, decompression if the data was compressed, and decryption if the data was secured. The final output is a digital signal that replicates the original content prior to being encoded for transmission.

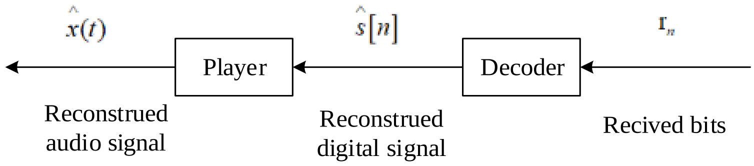

Fig. 3. Reconstruction process of Audio Signal to Bit Received.

2. Converted into bit stream and Checking with CRC 32

CRC, or Cyclic Redundancy Check, is a method used to detect accidental changes to raw data in digital networks. CRC-32 specifically refers to the variant of CRC that produces a 32-bit hash. The calculation of CRC-32 can be viewed as a series of mathematical operations on a binary sequence. Converting bits into a bit stream and checking them with CRC-32 involves two main steps. Those step are arranging the bits into a sequential stream and then applying the CRC-32 algorithm to generate a checksum. This checksum is used to verify the integrity of the data. The next process could be Bit stream Construction that consist of a sequence of bits in a specific order and typically represented as an array or a sequence of bytes. The process of constructing a bitstream involves the following process, they are ordering and framing. In ordering process, bits must be arranged in a specific order. The sequence is essential because it represents the information content. The order is typically determined by the protocol or standard being used. For framing process, bits are grouped into frames or packets. Each frame may include a header, payload, and could be a footer. The header often contains synchronization information, source and destination addresses, and other meta data. The payload is the actual data, and the footer can include error checking data like CRC.

We represent the message as $M(x)$ and the generator polynomial as $G(x)$, then the CRC is the remainder $R(x)$ obtained from:

$$R(x) = M(x).x32 \bmod G(x) \quad (3)$$

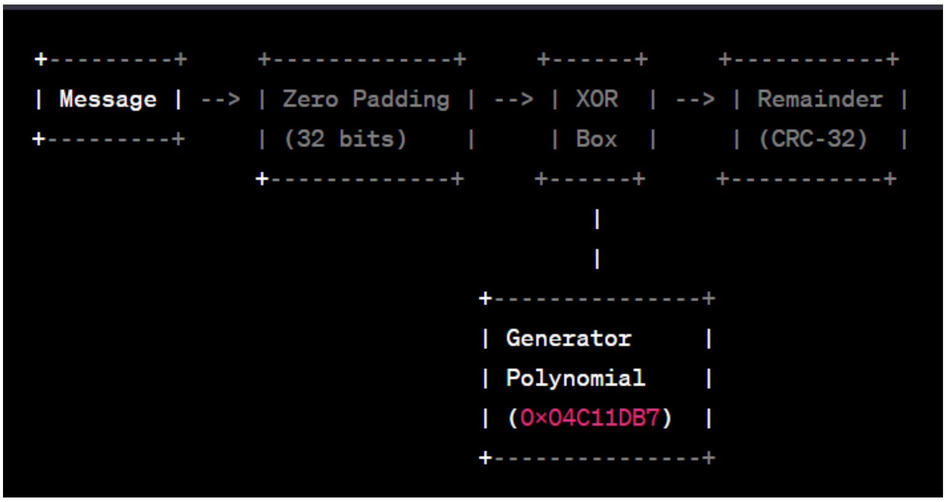

Fig. 4. Block Diagram of CRC 32.

The process of the CRC 32 can be seen on the Figure 4. The input bit stream enters a shift register of the same size as the CRC. As the bits are shifted through the register, they are XOR with the output of the CRC polynomial if the leftmost bit (the one being shifted out) is a '1'. The output of these XOR gates feeds back into the shift register, simulating the polynomial division. After all bits have been processed, the contents of the shift register represent the CRC value. The XOR box signifies the XOR operation in the division step, where each bit of the message, with appended zeros, is XORed with the corresponding bit of the polynomial when the leading bit is '1'. If the leading bit is '0', the polynomial is skipped, and the process moves on to the next bit. The CRC procedure generates an output that is split into two components by the protocol formatter: payload bits and header bits. Payload bits are the primary bits of information that carry data from the multimedia signal being transmitted. Header bits are utilized for the purposes of error repair and error detection operations. Header bits is modulated with BPSK Modulation scheme, while Payload bits is modulated with QPSK Modulation.

3. OFDM Multi Carrier Streaming Multiplexer

During this process, the multimedia file is first divided into packets, modulated onto different carriers using OFDM, and then transmitted wirelessly via the USRP. The CRC-32 checksums are used to ensure that the data received is the same as the data sent, allowing for error detection at the receiving end. The OFDM technique is highly effective in dealing with multipath propagation issues, which are common in wireless communication environments. OFDM divides the wideband channel into several orthogonal narrowband sub-channels or subcarriers, allowing for the close packing of channels without interference. This increases the efficient use of the spectrum.

Table 2 – OFDM Symbol.

No	Parameters	Value					
1	FFT Length	64					
2	Occupied Carrier	-26	-25	-24	-23	-22	-20
			-19	-18	-17	-16	-15
			-14	-13	-12	-11	-10
			-9	-8	-6	-5	-4
			-3	-2	-1		
		26	25	24	23	22	20
			19	18	17	16	15
			14	13	12	11	10
			9	8	6	5	4
			3	2	1		
3	Pilot Carrier	-21, -7, 7, 21					

4	Pilot Symbols	1, 1, 1, -1

The OFDM signal can be mathematically represented as the summation of prototype pulses that are shifted in both the time and frequency domains, and then multiplied by the data symbols. The kth OFDM symbol is expressed in continuous-time notation as this (Prasad, 2004):

$$S_{RF,k}(t-kT)=\begin{cases}\mathrm{Re}\left\{w(t-kT)\sum_{i=-N/2}^{N/2-1}x_{i,k}e^{j2\pi\left(f_c+\frac{i}{T_{FFT}}\right)(t-kT)}\right\} \\ kT-T_{win}-T_{guard}\le t\le kT+T_{FFT}+T_{win} \text{ otherwise} \\ 0\end{cases} \quad (4)$$

T : Symbol length; time between two consecutive OFDM symbols;

T_{FFT} : FFT time; effective part of the OFDM symbol;

T_{guard} : GI; duration of the cyclic prefix;

T_{win} : Window interval; duration of windowed prefix/postfix for spectral shaping;

f_c : Center frequency of the occupied frequency spectrum;

F : 1/T

FFT : Frequency spacing between adjacent SCs;

N : FFT length; number of FFT points;

k : Index on transmitted symbol;

i : Index on SC; i ∈ {–N/2, –N/2+1, … –1, 0, 1, … N/2–1};

$x_{i,k}$: Signal constellation point; complex {data, pilot, null} symbol modulated on the ith SC of the kth OFDM symbol.

The expression of a continuous sequence of transmitted OFDM symbols is finally shown (Prasad, 2004):

$$S_{RF}(t)=\sum_{k=-\infty}^{\infty}S_{RF,k}(t-kT) \quad (5)$$

4. Receiver Side

This GNU Radio program at Figure 5 demonstrates a typical setup for receiving and processing OFDM signals, used in wireless communication systems for multimedia transmission. The receiver's function is to accurately recover the transmitted data despite the impairments and variations introduced by the wireless channel. The USRP hardware is configured to receive signals at a specific frequency and sample rate. In this setup, the center frequency is set to 500 MHz, and the sample rate is 2 MSPS (Mega Samples Per Second). Schmidl & Cox OFDM Sync is responsible for synchronizing the received signal using the Schmidl & Cox algorithm, particularly useful for OFDM signals(Schmidl & Cox, 1997) . It detects the start of an OFDM frame and aligns the receiver accordingly. Header/Payload Demux block demultiplexes the header and payload of the received OFDM frames. It uses parameters such as header length, items per symbol, and guard interval for proper demultiplexing. FFT Blocks are used to convert the signal from the time domain to the frequency domain. FFT size is set to 64, indicating the number of points in the FFT.

s

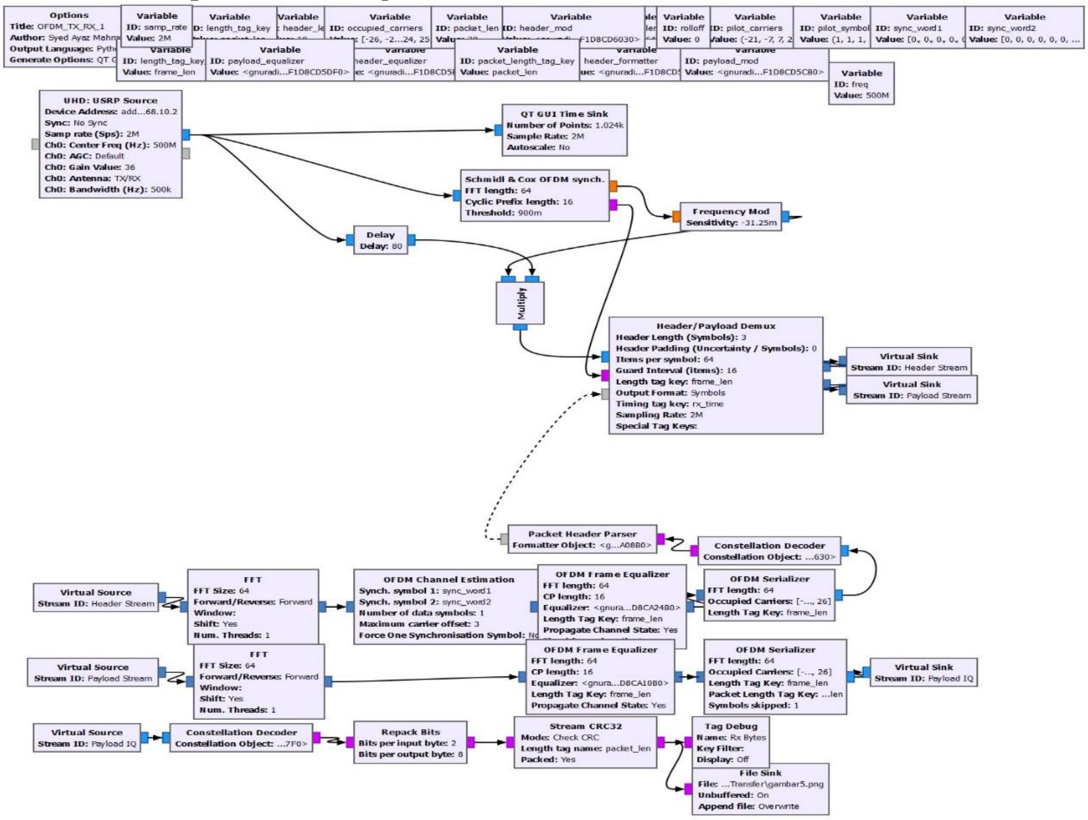

Fig. 5 . Receiver Side of Smart Ambulance Communications System Using USRP.

Furthermore, OFDM Channel Estimation and Frame Equalizer blocks estimate the channel characteristics and apply equalization to compensate for channel effects like fading and frequency offset. This is crucial for accurately decoding the received OFDM symbols. Constellation Decoder block decodes the received symbols based on the modulation scheme used. It maps the received symbols back to bits. OFDM Serializer converts the parallel streams of the OFDM sub-carriers back into a serial stream of data. Repack Bits block adjusts the bit alignment, converting the received bits into the correct format for further processing. CRC32 and Tag Debug blocks are used for error checking and debugging purposes. CRC32 checks for errors in the received packets. On the File Sink block, The processed data is then stored in a file saved in computer, indicating that the receiver might be processing multimedia data transmitted over the OFDM link.

The PAPR is the ratio of the peak power level of a signal to its average power level over time (Hossain & Shimamura, 2018). It is a critical parameter in communication systems, particularly in multicarrier modulation schemes like OFDM (Jayati et al., 2019). High PAPR indicates that the signal has substantial power peaks in comparison to its average, which can result in power amplifiers operating at higher power levels to prevent distortion, thereby causing inefficiency (Gulo et al., 2023). Reducing PAPR is crucial for improving the performance and efficacy of wireless communication systems, as it reduces the risk of non-linear distortion in transmitted signals and enables more consistent power consumption.

In order to evaluate the efficacy of multicarrier transmission systems, such as OFDM, it is essential to consider the relationship between the Complementary Cumulative Distribution Function (CCDF) and the PAPR. The PAPR measures the ratio of the peak signal power to its average power. A high PAPR indicates that the signal has significant peaks, which can result in signal distortion and inefficiencies in power amplifiers. The CCDF is employed to statistically analyze the occurrence of such peaks (Isnawati et al., 2023). The probability of a signal's PAPR exceeding a specific threshold is represented by the CCDF curve, which provides a visual representation of the frequency with which high PAPR values occur(Hossain & Shimamura, 2018). The frequency and likelihood of power peaks can be evaluated by analyzing the CCDF, which is essential for the development of systems that can accommodate such fluctuations without compromising performance. Consequently, the CCDF is a critical instrument for the assessment and mitigation of the effects of elevated PAPR on communication systems.

The CCDF is typically used instead of the CDF to assess the possibility that the PAPR of a certain data block will exceed the specified threshold. The CDF formula is described :

$$CDF = F(z) = 1 - e^{-Z} \tag{6}$$

with Z as the threshold value. The CCDF refers to the probability that the PAPR value of the OFDM symbol is greater than or equal to a specific threshold Z.

$$CCDF = P\{PAPR > Z\} \tag{7}$$

Based on both formula, the relationship between CDF, CCDF, and PAPR is obtained as follows:

$$P\{PAPR > Z\} = 1 - P\{PAPR \le Z\} = 1 - F(z)^N = 1 - (1 - e^{-Z})^N \tag{8}$$

5. Indoor Channel

Indoor channel propagation is a complex phenomenon influenced by a variety of factors, including building materials, walls, furniture, and other obstructions that can block, reflect, or scatter radio waves. The characteristics of indoor channel propagation can significantly impact signal quality, coverage, and data rates in wireless networks operating in indoor environments. In the case of signals that have a larger value of channel coherence bandwidth, then for calculating path loss it is necessary to consider the channel frequency selectivity. The expression for calculating loss in the frequency domain (FD) can use Parseval's theorem. If we assume that h[n] is the channel impulse response (CIR) measured at the receiver at N temporal samples, we can define the channel path gain (PG), as:

$$PG = \frac{P_r}{P_t} = \sum_{n=0}^{N-1} \left|h[n]\right|^2 = \frac{1}{N} \sum_{k=0}^{N-1} \left|H[k]\right|^2 \tag{9}$$

Pr is the received power, Pt is the transmitted power normalized to units, and H[k] is the complex channel transfer function (CTF) at the receiver. Based on the measurements and calibrations that have been carried out, it can be stated that:

$$H[k] = S_{21}[k] \tag{10}$$

S21[k] as the k th frequency tone scattering parameter. CTF has an antenna transfer function, where this function depends on the radiation pattern and gain. To calculate pathloss, H can be corrected by the antenna gain (gt and gr), as given in (3):

$$H'[k] = \frac{H[k]}{\sqrt{gt\ [k]\ gr\ [k]}} = \frac{S_{21}}{\sqrt{gt\ [k]\ gr\ [k]}} \tag{11}$$

The wideband pathloss value is obtained from the FD using the following formula:

$$PL(dB) = 10\log_{10}\left(\frac{1}{PG}\right) \tag{12}$$

$$= 10\log_{10}\left(\frac{1}{N}\sum_{k=0}^{N-1}\frac{\left|S_{21}[k]^2\right|}{gt\ [k]\ gr\ [k]}\right) \tag{13}$$

N is the value of frequency measured.

Path loss modeling has generally been considered acceptable, so that the average pathloss follows the potential law with distance and the pathloss in dB at a distance d between Tx and Rx, can be formulated by:

$$PL(d) = PL_0 + 10\gamma \log_{10}\left(\frac{d}{d0}\right) + X_\sigma \tag{14}$$

PL_0 has a function as pathloss at the reference distance d_0, which has a value equal to 1 m. γ is the pathloss exponent and X_s is a normally distributed random variable, with standard deviation σ.

We compute the integral of the Power Distribution Function (PDF) to get CDF. Ultimately, the CCDF is obtained by inverting the CDF. Power CCDF curves are most useful when used to clearly and thoroughly define the power characteristics of the signals that are amplified, encoded, mixed, and sent over communication systems. For instance, by utilizing CCDF curves, baseband Digital Signal Processing (DSP) signal designers are able to fully specify the power characteristics of signals to the RF designers. There are numerous designs uses for CCDF curves. Spread-spectrum system evaluation, integrating numerous signals via system components, creating, and testing RF components, and illustrating the impacts of modulation formats are a few of these uses.

The power characteristics of signals that are amplified, encoded, mixed, and transmitted over communication networks are defined by the power in CCDF curves. Two formulas below typically state the CDF and CCDF of a continuous or discrete signal (X):

$$F_X(x) = P(X \le x) = \int_{-\infty}^{x} f(t)dt \quad \text{for } x \in \mathbb{R} \tag{15}$$

The CCDF is formulated as in Eq. (16) below :

$$\bar{F}_X(x) = P(X > x) = 1 - F_X(x) \tag{16}$$

A plot of relative power levels versus probability is called a CCDF curve.

6. V2I Channel Model

V21 measurements are carried out in 3 stages, namely Channel Sounder V2I, sending text V21 and sending audio V21 as seen in Fig.1. In the first stage, the transmitter was prepared in front of the ITTP rectorate, while the receiver was prepared in front of the covered parking lot. The next step is to test the sounder channel signal from the Transmitter to the Receiver. Then the receiver walks to the transmitter side and measures speed, frequency spectrum, CCDF, time domain signal, constellation diagram on the second laptop. Then when the receiver stops in front of the transmitter, the measurement is stopped. The transmitter starts sending signals and the receiver starts receiving channel sounder signals. The receiver moves straight east away from the transmitter, and begins to record the speed, ccdf, time domain signal, spectrum, and constellation diagram. After the receiver reaches the rear gate, the measurement stops.

The second phase involves transmitting the V2I Text. Just as in the initial phase, the transmitter was positioned in front of the rectorate, while the receiver was positioned in front of the enclosed parking lot. Subsequently, the transmitter generates a text file and the receiver receives such file. Upon reaching the transmitter side, the receiver proceeds to measure several parameters including speed, frequency spectrum, CCDF, time domain signal, constellation diagram, and text file reception data. Once the receiver comes to a halt in front of the transmitter, the measurement ceases. The second phase involves transmitting the V2I Text. Just as in the initial phase, the transmitter was positioned in front of the rectorate, while the receiver was positioned in front of the enclosed parking lot. Subsequently, the transmitter generates a text file and the receiver receives such file. Upon reaching the transmitter side, the receiver proceeds to measure several parameters including speed, frequency spectrum, CCDF, time domain signal, constellation diagram, and text file reception data. Once the receiver comes to a halt in front of the transmitter, the measurement ceases. Finally, the last step is to attempt to transmit V2I Audio. Identical to the two preceding stages. However, the transmitted data contains an audio file.

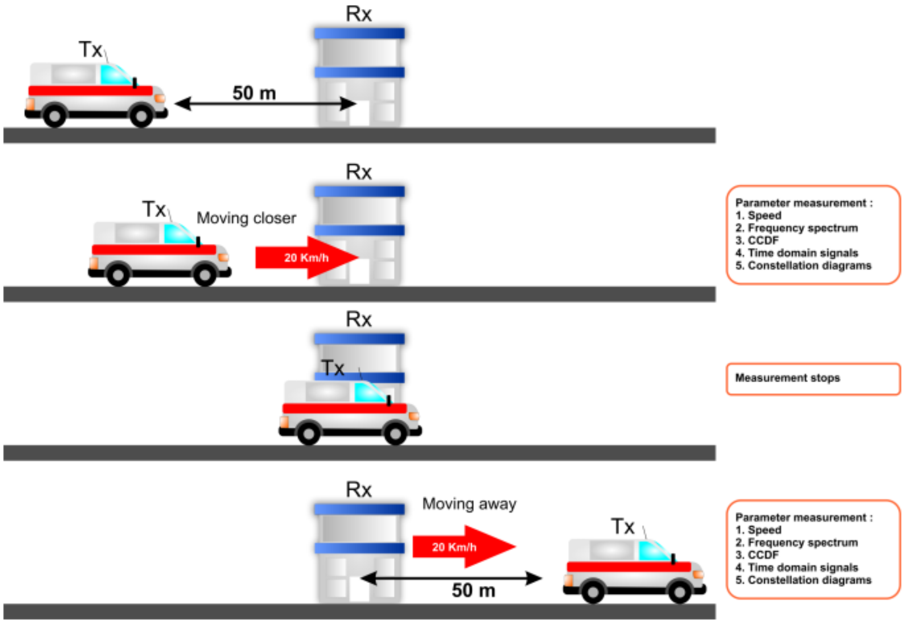

Fig. 6. V21 Measurements.

7. V2V Channel Model

In the V2V channel model, as was done in the V2I experiment, there are 3 types of V2V measurement scenarios, namely V2V Channel Sounder measurements, V2V text file transmission measurements and V2V audio file transmission measurements. The V2V measurement scenario is shown in Figure 7.

Scenario 1 involves the execution of a channel sounder test. Prior to commencing the measurement, it is necessary to configure the mobile transmitter and mobile receiver by positioning them 50m apart. Subsequently, Tx and Rx approach one other with a velocity of around 20 km/h. In the presence of mutual motion, Tx transmits a signal and Rx receives the signal. Measurements conducted on the Rx side encompass speed measurements, frequency spectrum analysis, CCDF, time domain signals, and constellation diagrams. Upon reaching the same location as Tx, Rx ends all measurements. Subsequently, Tx and Rx systematically separate from each other, reaching a distance of 50m. On the Rx side, measurements are once again conducted using the identical parameters. Discontinue measuring once the distance between Tx and Rx reaches 50 metres. Measurements in situations 2 and 3 follow the same procedure as channel sounder measurements, with the exception that the transmitted signals are text files for scenario 2 and audio files for scenario 3.

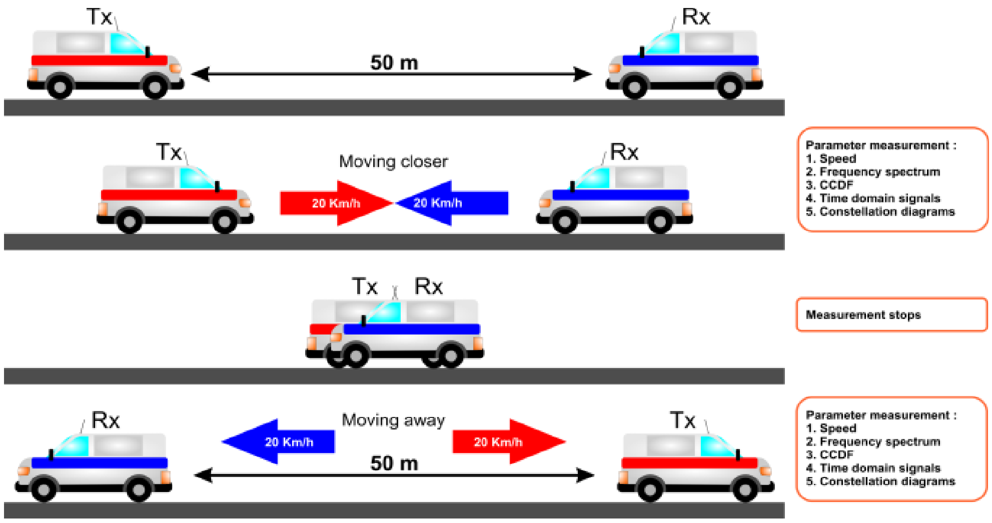

Fig. 7. V2V Measurements

4. Results and Discussions

1. Outdoor V2I Analysis Result

1. Channel Sounder Result

The CCDF curve can provide insights into the dynamic range and power variability of the signal, which are important factors in designing and optimizing wireless communication systems, particularly for ensuring that the transmitters operate efficiently and within their power capabilities (Omar & Ma, 2021).The CCDF plot in figure 8 represents the probability that a random variable exceeds a certain value. In the context of wireless communication, it refers to the power distribution of the signal. The x-axis shows the dB (decibel) above average power, and the y-axis is the probability (%), plotted on a logarithmic scale. From the graph, we can observe that the average power is around 32.074 dBm, while the maximum power recorded is slightly higher at 33.07 dBm. The PAPR is indicated as 1.037 dB. With the PAPR being close to 0 dB, it suggests that the signal has a relatively constant envelope, which is desirable in many communication systems to minimize distortion and reduce power back-off requirements for amplifiers(Schulz et al., 2021)

Certain power levels are aligned with their respective probabilities on the right side of the diagram. For instance, the probability of the power being 10 dB above the average is 0.937%, which suggests that the probability of the power exceeding this threshold is extremely low. Similarly, the likelihood of the voltage being only 1 dB higher than the average is 94.5%, which is significantly more prevalent.

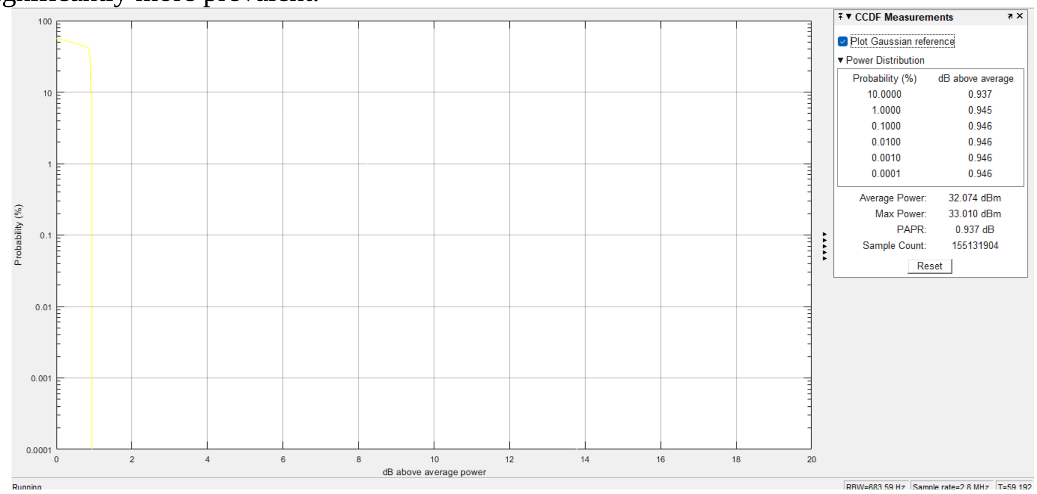

Fig. 7. CCDF Channel Sounder at 20 km/h.

Figure 8 shows the CCDF curve, which is directly related to the theoretical formulation in Formula 16. By displaying the empirical data for PAPR occurrences against the probability values, we can see how closely the observed data matches the theoretical CCDF model. The curve shows that, in most cases, the PAPR does not exceed the low threshold, confirming that the communication system is running efficiently with few power peaks that could cause amplifier distortion or inefficiency.

We compared the CCDF parameters between the position of the smart ambulance moving in V2I mode and the position of the ambulance stopping in the fix to fix position. The ccdf graph at this position is shown in Figure 9 below. A better CCDF curve in the context of signal power would typically have a lower probability of the signal exceeding the average power by a high margin, indicating a more uniform power distribution and thus a lower PAPR. Considering these factors, the first graph on figure 8 generally shows a better CCDF characteristic with a lower PAPR than figure 9, a steeper drop in probability indicating a less dispersed power distribution, and a larger sample size which can indicate more reliability in the measurements. A low PAPR is often sought after in communications because it suggests that the transmitter can operate more efficiently, with less need for high-power amplifiers and reduced potential for nonlinear distortion.

The average power is lower in the second graph. A lower average power could be better for energy conservation but might not be better for signal quality depending on the application. Furthermore, if energy conservation is a priority and the system is designed to work with lower average power, then the second scenario on figure 9 be more suitable despite the higher PAPR. Conversely, if maintaining a consistent power level close to the average is critical, then the first scenario is preferable due to the lower PAPR.

This study's CCDF analysis is in close alignment with recent research (Sârbu et al., 2019), including the real-time statistical measurement of wideband signals using SDR technology presented by (Şorecău et al., 2023) in their study on modern communication standards. In both studies, the probability of PAPR exceeding a specific threshold is assessed using CCDF, a method that is essential for comprehending the power distribution of signals. In our context, CCDF offers valuable insights into the performance of multimedia transmission over V2V and V2I channels, where the management of power peaks is essential for the establishment of reliable and efficient communication. Our utilization of SDR technology enables the precise measurement of CCDF and PAPR under varying conditions, similar to the results of previous research. This enables real-time adaptability to dynamic vehicular environments. This capability not only emphasizes the efficacy of SDR in vehicular communication systems but also illustrates the significance of CCDF in evaluating the overall signal integrity and reducing transmission errors. Both studies emphasize the importance of signal power management in improving the efficiency and reliability of communication systems in real-time scenarios by utilizing CCDF.

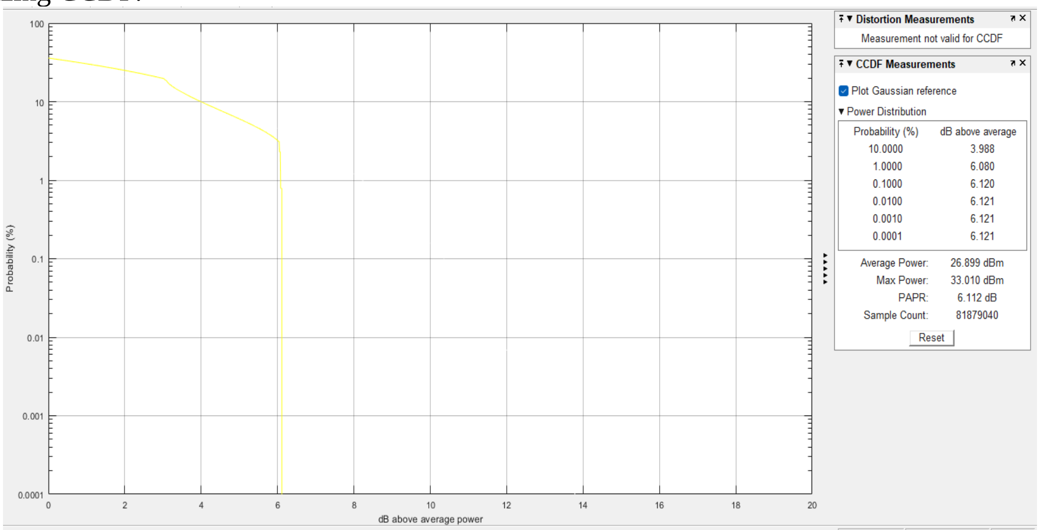

Fig. 8. CCDF Channel Sounder when the smart ambulance stop.

The curve in Figure 9 corresponds to Formula 16, which calculates the chance of PAPR reaching a specific threshold. As the PAPR grows, the curve of the CCDF in Figure 9 decreases, showing that the likelihood of these high peaks is low but still substantial in this scenario. When compared to Figure 8, the communication system under the conditions in Figure 9 has a higher PAPR, indicating that the system must accommodate for larger power swings. This is consistent with CCDF's theoretical framework, which predicts that when mobility or environmental complexity grows, so does the risk of experiencing greater PAPR values.

8. Text Transmission

The combined effects of the Doppler shift, PAPR, and CCDF are analyzed in Figure 10 to evaluate their impact on text transmission in a V2V and V2I communication system. The Doppler effect, which is induced by the relative movement of the transmitter and receiver, can result in frequency fluctuations that can compromise the quality of signal transmission, particularly in high-speed environments. This phenomenon is defined by the Doppler shift formula, which demonstrates that frequency distortions are more pronounced at higher velocities. The voltage variations in the signal are exacerbated by these distortions, resulting in an increase in PAPR. The efficacy of power amplifiers is not the only factor that is influenced by a higher PAPR; it also increases the likelihood of signal distortion, which is particularly problematic in multimedia transmission, including text.

The CCDF, which is calculated using the formula $CCDF = P(PAPR > Z)$ CCDF=P(PAPR>Z), represents the probability that the PAPR will exceed a specified threshold. The probability of encountering higher PAPR values increases as the Doppler shifts intensify as a result of vehicular movement, as illustrated in the CCDF curve in Figure 10. This rise in PAPR results in a greater possibility of transmission errors, particularly when transmitting text in dynamic vehicular environments. The significance of managing Doppler-induced distortions and mitigating PAPR to guarantee reliable and efficient text transmission is underscored by the results in Figure 10. These observations emphasize the necessity of optimized communication protocols and robust error correction techniques to address the obstacles presented by high mobility in V2V and V2I communication systems.

Figure 10 shows that Doppler shift has a major effect on text transmission in a V2I communication scenario. As the vehicle's speed increases, Doppler shifts produce frequency changes, which can result in signal degradation and transmission mistakes (Nyongesa et al., 2015). This is especially important in high-speed environments, where real-time communication is essential. (Hua et al., 2014) present a detailed investigation of Doppler shift estimation, emphasizing how Doppler shifts generated by high vehicle speeds have a direct impact on communication performance in mobile networks. The findings in their work stress the need of precisely calculating Doppler shift to ensure signal integrity, which is closely related to our study's performance measures presented in Figure 10.

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Fig. 9. Text received with V2I channel.

9. Image Transmission

In this section we send an image that is sent in Figure 11, when the smart ambulance is moving at a speed of 20 km/h. Delivery is carried out using the USRP 2920 device which is placed in the smart ambulance. The image is received on the other side with a stationary condition. The results of the images received show a degradation in image quality compared to the images sent as seen on figure 12. The degradation in the quality of the received image can be analyzed in relation to the V2I channel characteristics and the transmission process.

The impact of the Doppler shift, PAPR, and CCDF on image transmission within a V2V and V2I communication environment is the primary focus of Figure 11. The Doppler effect, which is analogous to text transmission, results in signal degradation by introducing frequency variations as a result of the relative motion of vehicles. This effect is especially noticeable when vehicles are traveling at a high rate of speed, as it results in more significant distortions in the transmitted signal. The signal's PAPR increases, which can result in signal distortion and negatively impact the performance of power amplifiers by reflecting higher power peaks relative to the average power. Figure 11 analysis is similar to (Shi et al., 2020) quick Doppler shift acquisition method for hypersonic vehicle communications. Their method shows the need of speedy and accurate Doppler shift estimation, especially in high-speed V2I communication, where the Doppler effect greatly effects signal integrity. Doppler shifts can distort signal and degrade transmission reliability in vehicle picture transmission, as shown in Figure 11. Similar to hypersonic communications, where significant and dynamic Doppler shifts decrease signal quality, our system undergoes frequency shifts that require quick correction for smooth multimedia delivery. Shi et al.'s blind Doppler rate estimate and search-range adjustment method supports our methods for minimizing Doppler's influence on wideband communication channels. Figure 11 shows how exact Doppler compensation improves transmission quality, emphasizing the requirement for precise compensation to ensure signal stability.

Fig. 10. Image transmitted with size 177 Kb.

V2I communication channels might have bandwidth limitations. In this research the channel doesn't support the bandwidth required for high-quality image transmission, thus making the received image have lower quality. The signal strength decreases with distance as the ambulance was far from the receiver, the signal attenuate to a point where image quality degrades due to insufficient signal strength. Furthermore, the image is compressed using a lossy compression technique before transmission to meet channel capacity or bandwidth constraints, it result in a loss of quality that is noticeable in the received image. As mentioned previously, the Doppler effect caused by the relative speed between the ambulance as transmitter and the infrastructure as receiver can lead to frequency shifts, which may adversely affect the modulation and demodulation processes.

Figure 11 relates to the (Soliman et al., 2015) by examining how PAPR and mitigation approaches affect wireless image transmission. Discrete transformations like DWT or DCT are used in the relevant paper to reduce PAPR to improve transmission reliability and image quality in frequency-selective fading channels. Figure 11 shows that high PAPR values in picture transmission cause power fluctuations and transmission mistakes. The paper stresses decreasing PAPR for picture transmission since high PAPR distorts signals, reducing power amplifier efficiency and image quality. High PAPR reduces picture transmission in V2V or V2I channels, increasing signal distortion as seen on Figure 11. Discrete transforms and other PAPR reduction methods described in the referenced study could be used in your system to improve image fidelity and transmission stability, especially in Doppler shift and multipath fading environments.

Fig. 11. Image Received with size 127 Kb.

When examining PAPR, CCDF, and wideband pathloss, Figure 11 and Figure 12 showed significant changes in communication system performance. Figure 11 indicated that image transmission had higher PAPR values due to larger file sizes and more advanced encoding. The steeper CCDF curve suggested larger power peaks and an increased risk of transmission errors. The increased PAPR in Figure 11 showed more frequent power fluctuations, which could have caused power amplifier inefficiencies and signal distortion. In this situation, wideband pathloss was greater, reducing signal strength and making image transmission over different distances more challenging. The study done by (Ghanim & Omran, 2021; Shao & Gunduz, 2023) which examines OFDM image transmission PAPR reduction methods, supports these findings. The study presents a modified tone reserve mechanism to lessen PAPR, reducing power fluctuations and improving signal integrity. Figure 11 shows that image transmission's high PAPR values cause greater power peaks and a steeper CCDF curve. Increased PAPR increases transmission mistakes and power amplifier inefficiencies, which can distort signals. The linked research notes that decreasing PAPR by 2 dB enhances image transmission quality without adding system complexity. To stabilize V2V and V2I communication channels, comparable PAPR reduction strategies could reduce power fluctuations and transmission issues seen in Figure 11. Figure 11's increased wideband pathloss is due to PAPR control. In high-mobility contexts, reducing PAPR enhances signal strength and minimizes pathloss over different transmission distances, improving multimedia transmission dependability.

Figure 12 presented a more stable transmission with fewer power peaks and lower PAPR values. The flatter CCDF curve indicated stability and a lower risk of exceeding high PAPR thresholds. Figure 12 demonstrated that reducing PAPR decreased power surges, improved power utilization, and reduced transmission errors. In Figure 12, the wideband pathloss was less severe, suggesting that the signal retained its strength over distance better than in Figure 11, which improved transmission reliability and reduced disruptions.

Figure 11 highlighted the challenges of high PAPR and significant wideband pathloss in image transmission, while Figure 12 exhibited lower PAPR, a more favorable CCDF curve, and reduced pathloss, resulting in improved signal stability and performance. These findings showed that wideband vehicular communication systems needed to manage PAPR and pathloss, especially in dynamic situations involving high-data-rate applications like image transmission.

10. V2V Analysis Result

This V2V communication scenario based on figure 7 is critical for ensuring real-time data transfer in mobile emergency situations, where timely and reliable communication can be crucial for patient outcomes. The depicted measurements are vital for the continuous assessment and adaptation of the communication system to maintain data integrity and communication quality. The communication occurs between two moving vehicles, the ambulance as transmitter, and a receiver vehicle as receiver, which could be another emergency vehicle or a mobile command center.

1. Channel Sounder

In a V2V communication system, the CCDF plot is critical for designing and optimizing the transmitter power levels and understanding the dynamic range required for the RF components in the communication devices. The maximum power being 33.010 dBm indicates the highest signal strength recorded, which might occur due to occasional peaks in transmission power or multipath effects in the V2V environment as seen on Figure 13. PAPR is a significant parameter in signal transmission, representing the ratio of the peak power to the average power of the signal. A PAPR of 3.316 dB mean that the peak power is just over 3 dB higher than the average power. This is relatively low, which is beneficial as it suggests that the power amplifiers do not need to handle a wide range of signal levels, thus potentially improving their efficiency. The relatively low PAPR value is beneficial as it indicates a lower likelihood of nonlinear distortion and allows for a more consistent quality of service within the communication system. There is a probability of 5.277% that the signal's power will be 10 dB above the average. As the dB above average power decreases, the probability increases, which is typical because there's always a higher likelihood that the signal will be closer to the average power level. The maximum power and the PAPR indicate the extent of fluctuation from the average power level. As the ambulance moves away, the likelihood of deep fades and signal shadowing increases, which lead to a more significant variation in the signal levels at the receiving end. However, because the transmitted power levels (including peaks) remain consistent, the PAPR on the CCDF stay unchanged.

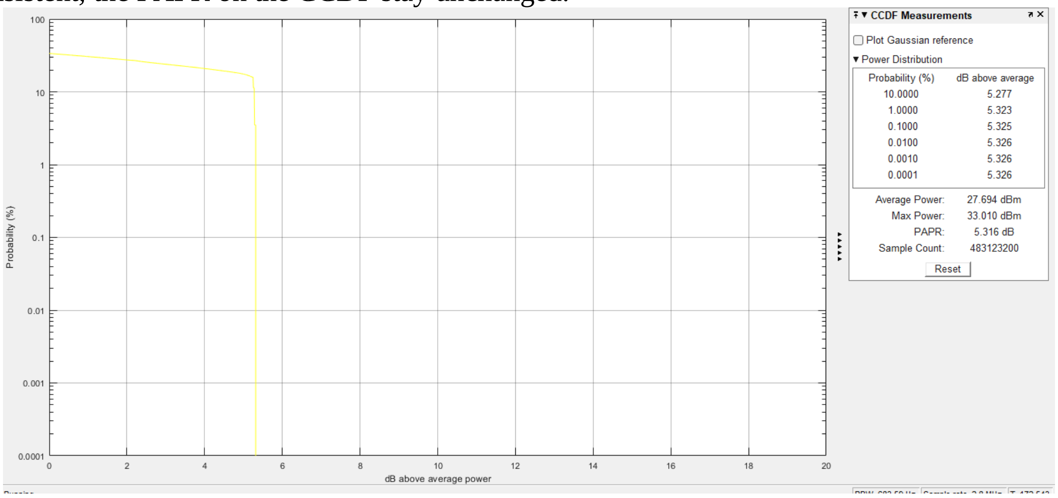

Fig. 12. CCDF Channel Sounder when the smart ambulance moving away other vehicle.

The CCDF graph where the ambulance is approaching other vehicles is shown in Figure 14. The average power reached 24.795 dBm. This is a measure of the mean power level of the signal. A lower average power compared to the previous graph on figure 13 might indicate that the transmission power has been adjusted or that environmental factors are affecting the signal as the ambulance gets closer to other vehicles. The Peak-to-Average Power Ratio is higher in this CCDF compared to the previous one on figure 13. A higher PAPR indicates a larger range between the average and peak power, which can be more challenging for power amplifiers due to increased dynamic range requirements. The probability that the signal's power will be 10 dB above the average is 7.328%, which is a higher probability compared to the previous graph, indicating more frequent high-power peaks.

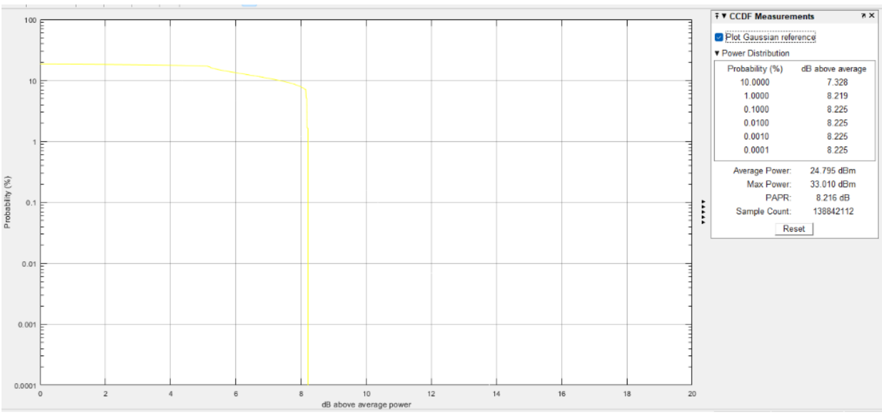

Fig. 14. CCDF Channel Sounder when the smart ambulance moving closer to other vehicle.

Figure 13 demonstrates that the CCDF exhibits elevated PAPR values as the vehicles separate, resulting in more frequent power fluctuations and an increased probability of signal distortion. This phenomenon reflects the influence of heightened pathloss in V2V communication. This finding is consistent with the analysis conducted by (Hamarsheh et al., 2023), which highlighted the significance of PAPR control in enhancing signal dependability in dynamic vehicular settings. In contrast, Figure 14 depicts lower PAPR as the vehicles approach each other, leading to fewer transmission mistakes and more stable communication. Managing PAPR and pathloss is crucial for maintaining reliable and efficient V2V communication, especially in high-mobility situations.

2. Text Transmission

Experiments are conducted in this section by transmitting text files while the transmitter and receiver vehicles are in motion apart. The smart ambulance is operating at a predetermined velocity of 20 kilometers per hour as seen on figure.7. The image of the text file sent can be seen in figure 15 while the image of the text file received is shown in figure 16. While the text file we transmitted appears to be functional on the recipient's vehicle, it is missing a number of components. Certain segments of the text are omitted due to the Doppler effect and the increasing signal attenuation caused by the two vehicles' separation. Given that the ambulance as transmitter and receiver are moving away from each other, the Doppler effect can play a role in changing the frequency of the received signal. This can cause inappropriate adjustments during OFDM demodulation, which in turn results in errors in the received symbols (Lang et al., 2024).

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Eko Fajar Cahyadi,Ph.D
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Fig. 13. Text Transmit when smart ambulance moving with 20 Km/h.

In V2V, the transmitter and receiver are separate, reducing signal strength and making it more susceptible to noise and interference. Multipath effects, when the broadcast signal reflects off buildings and cars, delay and change the signal at the receiver. These reflections can significantly degrade signal quality. (Gopalam et al., 2024) research on DD-OFDM modulation is helpful. DD-OFDM improves channel estimation and reduces out-of-band emissions in doubly dispersive channels by addressing Doppler spread and delay spread. The DD-OFDM modulation framework manages dynamic changes caused by Doppler shifts and multipath interference(Oshiro et al., 2023), similar to our V2V system's signal deterioration. In complex scenarios with high mobility and multipath, our SDR system's real-time signal processing limitations are mirrored by the need for advanced modulation schemes like DD-OFDM, which maintain stable performance under such challenging conditions.

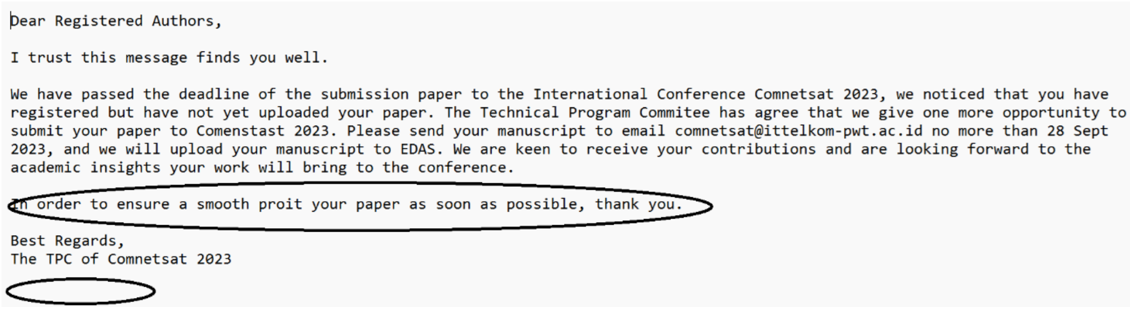

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Fig. 14 . Text receive when smart ambulance moving with 20 km/h.

3. Image Transmission

In this experiment, we transferred a.png image file with a size of 3,640 KB, as illustrated in Figure 17. The setting remained the same as before, with automobiles traveling away from each other at a speed of 20 kilometers per hour. Figure 18 shows that some files received are of poor quality, i.e., the image is not whole and the size is just 4 KB. This indicates a major problem in the transmission or reception process.

Fig. 15. file .png transmit with size 3,640 KB.

Several possible causes for the poor quality of image files received using the V2V scenario with a smart ambulance as the sender can be studied as follows. The first possibility as the main cause of this phenomenon is the communication channel capacity which is smaller than the file being sent. It is possible that the communications channel does not have sufficient bandwidth to support the transmission of a 3,640 KB file. This can cause significant data packet loss during transmission.

Fig. 16. file .png receive at 20 Km/h with size 4 KB.

The Error Handling and Recovery factor is the subsequent potential. Transmission errors that occur may not be corrected, resulting in only a small percentage of the files being effectively received, if the system lacks an efficient error recovery mechanism, such as Automatic Repeat request (ARQ). Additionally, the Doppler Effect is the subsequent hypothesis that may be investigated. Signal quality can be significantly impacted by frequency variations caused by vehicles moving away from each other, as was the case in the previous scenario. However, the impact is more pronounced in this instance due to the large file size. The SDR system or software involved in the process may have limitations on buffer or memory capacity, which may result in only a small portion of the file being buffered and transmitted, depending on the SDR technology used.

The study done by (Liu et al., 2024) addresses Error Handling and Recovery and the Doppler Effect in V2V and V2I communication systems, especially in high-mobility contexts. Hybrid Automatic Repeat Request (HARQ), an improved version of ARQ, improves error correction by providing intelligent retransmissions for data recovery. This addresses transmission errors, especially during big file transfers, that may not be fixed without an efficient recovery method, resulting in just a small percentage of the file being received. By reducing error rates and enhancing transmission reliability, HARQ in 6G systems overcomes this issue. The research also explores sophisticated Doppler compensation methods including reconfigurable intelligent surfaces (RIS) and adaptive beamforming to reduce frequency changes caused by high vehicle speeds. This is important when vehicles move apart and Doppler changes degrade signals. These methods minimize the Doppler Effect, which worsens with bigger file sizes and distances. Without these methods, V2V and V2I SDR systems may struggle with real-time signal processing, particularly in complex file transmissions under high mobility conditions

5. Conclusion

This research explored and improved the emerging paradigm of smart ambulances, driven by the need for advanced communication mechanisms that overcome high mobility and unpredictable environmental conditions.The smart ambulance scenarios that proceeded via V2V and V2I communication channels demonstrated the transmission of a variety of multimedia files, such as text and images, while evaluating technical parameters such as frequency spectrum, CCDF, and constellation diagrams with great attention to detail. Regardless of the challenges posed by multipath fading, our system exhibited exceptional stability in V2I conditions, maintaining mean power levels at approximately 32.074 dBm and attaining a PAPR of 1.037 dB. In the interim, V2V trials ensured the preservation of data integrity with a PAPR of 3.316 dB despite the ambulances traveling at 20 km/h. This further strengthened the robustness of our system in the face of Doppler shifts and signal dispersion. The trials exposed the inherent technological difficulties of this field. As an illustration, the inconsistency in the textual information obtained during the ambulance's 20 km/h speed demonstrated the possibility of

Doppler shift-induced errors. The image file transmission was particularly remarkable; upon receipt, a 3640 KB file was reduced to a mere 4 KB, demonstrating the severe limitations of bandwidth and the urgent need for effective error handling. Our findings highlight the clear potential for incorporating modern wireless communications technologies into emergency medical services. This study not only represents the theoretical capabilities of such systems, but also confirms their practical viability, as long as the challenges of bandwidth, error correction, and the Doppler phenomena are properly addressed.

This study established the groundwork for future research that would improve smart ambulances. First and foremost, V2V high-resolution multimedia transmission bandwidth must be addressed. Advanced data compression or adaptive modulation algorithms that retain data fidelity under bandwidth limits could be studied in the future. Second, better error correction and handling algorithms could increase system performance, especially in high-speed ambulance applications with Doppler effects and multipath fading. Third, machine learning algorithms could improve system flexibility by predicting communication parameter changes based on real-time traffic and network conditions.

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