Analysis of Modulation Techniques for Short Range V2V Communication

Vansha Kher, Sanjeev Sharma, R. Anjali, M. N. Greeshma, S. Keerthana, and K. Praneetha

Abstract Vehicle-to-vehicle or V2V communication, a progressively developing technology that uses IEEE 802.11 p-based systems to enable vehicular communication over a few hundreds of meters, is being introduced in numerous vehicle designs to equip them with enhanced sensing capabilities. However, it can be subjected to a lot of interference due to sensitivity that can cause potential channel congestion issues. V2V can be complemented using visible light communication (VLC), an alternative technology that uses light emitting diodes (LEDs), headlights or tail lights to function as transmitters, whereas the photodiodes or cameras function as receivers. Although, in real-time applications, a V2V-VLC cannot be demonstrated due to unreliability. In this paper, the overall performance of the vehicle-to-vehicle communication is being implemented using orthogonal frequency division multiplexing (OFDM) in combination with amplitude shift keying (ASK), also termed as on–off keying (OOK) modulation, binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) digital modulation techniques. All the above-mentioned modulation techniques, i.e., OFDM-OOK, OFDM-BPSK and OFDM-QPSK, are being compared using the following design parameters, i.e., signal to noise ratio (SNR) versus bit error rate (BER) as well as spectral efficiency, in order to choose the best technique for V2V communication. By extensive analysis, in terms of rate and error performances, we have observed that QPSK modulation technique with OFDM performs better when compared to OFDM with OOK and BPSK modulation techniques for V2V communication.

Keywords Vehicular communication · Visible light communication · On–off keying · Orthogonal frequency shift keying

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1 Introduction

There has been a commendable development in the past decade with regard to vehicular technologies. Multiple up gradations have been implemented in transport systems [1] to provide driving assistance and guidance to the driver. Vehicle-to-vehicle communication (V2V) is an integral part of smart transport systems and has been progressively introduced and deployed in vehicular designs to enhance the overall safety of the transport system. The associated safety applications also include collision avoidance, lane-change warnings, traffic efficiency enhancement, etc. V2V communication, a vital part of the intelligent transport systems (ITS), makes use of IEEE 801.11p [2] standard based on a dedicated short range communication (DSRC), used for the establishment of vehicular communication over moderately large distances that ultimately allows vehicles to exchange critical information between one another.

However, it has been observed that such technologies have high sensitivity toward interferences due to which the medium access control (MAC) layer of the IEEE 802.11p standards describes vigorous protocol structure with reference to the anticipation of channel congestion issues that might arise, more specifically in a dense-traffic scenario. Such heavy protocols may not turn out to be very compatible with most of the critical safety applications. In recent times, VLC has emerged as a very convenient possible replacement to the V2V-based wireless communication systems [3]. VLC can efficiently reduce channel congestion by generating optical signals that are predominantly directional and capable of propagating with line of sight (LoS) paths that causes reduced sensitivity toward interferences [4, 5]. Despite the generous bandwidth of the optical systems, VLC channels are subjected to natural reflection and scattering phenomenon that results in inter-symbol interference (ISI) which provide a lower data rate.

Several approaches have been made to realize this system and orthogonal frequency division multiplexing (OFDM) stands out to be a very effective way in the aspect of VLC links. The technique of single sub-carrier modulation by using several sub-carriers within channel is called OFDM [6–8]. OFDM is employed on the closely spaced orthogonal sub-carriers that are transmitted simultaneously. This enables multiple users to share one common link by dividing the available bandwidth into different, overlapping sub-channels that exist orthogonal to one another. Thus, it is observed to be a very effective technique to achieve high bit rate transmission with minimized multipath fading over wireless communication channels [9]. Figure 1 depicts the schematic block diagram of an OFDM transmitter–receiver system as well as the stages involved for signal transmission in an OFDM system.

OOK follows the single carrier modulation (SCM) technique. The transmission of data bit 0 results in the transmitter light turning off and that of data bit 1 results in the transmitter light turning on. The SCM techniques, i.e., pulse amplitude modulation (PAM) and the pulse position modulation (PPM), are possessing their own advantages and limitations. In PAM, as spectral efficiency is increased, the power efficiency will

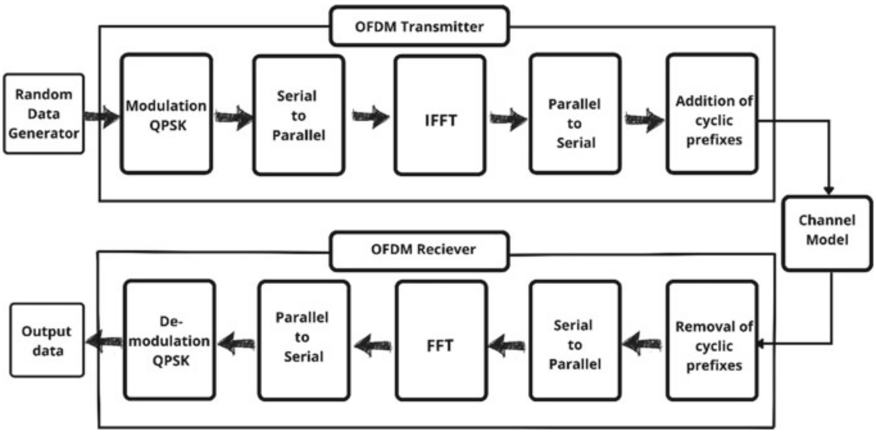

Fig. 1 Schematic block diagram representing an OFDM transmitter and receiver

be reduced and vice-versa for PPM. Thus, OOK is a better choice between PPM and PAM as these two SCM fail in spectral efficiency and nonlinearity, both of which are two most constraining parameters for LEDs.

Binary phase shift keying (BPSK) is also known as phase reverse keying. This form of keying includes two points that represent binary information and are placed 180 degrees apart from each other. These locations can be random and plotted anywhere, with any degree from the reference but must have an angle of 180° between each other [10]. BPSK transmits one bit per symbol and can handle very high noise levels or distortions, making it the most robust of all PSKs. QPSK or quadrature phase shift keying is equivalent to adding to more information symbols in a conventional BPSK. A conventional BPSK system consists of two signal elements, whereas a QPSK system consists of four signal elements, and each of this signal element is 90° apart from each other. QPSK transmits two bits per symbol which can give a higher data rate. This is done by a QPSK transmitter which can be seen in Figs. 3 and 4 which depict a closer look of a QPSK receiver that follows a double side band suppressed carrier (DSBSC) scheme which transmits digital information as digits. In this proposed work, we have compared all the three mentioned digital modulation techniques, i.e., OFDM-OOK, OFDM-BPSK and OFDM-QPSK in terms of their error performances and bandwidth efficacy [11].

In the proposed system, comparison is being performed modulation techniques for a signal to be projected for V2V communication using OFDM. The error performance analysis of the three mentioned digital modulation schemes that is OFDM with QPSK, OFDM with OOK, OFDM with BPSK has been analyzed by considering the fast Fourier transform (FFT) bin size as 128, number of OFDM symbols to be taken as 16, phase offset is equal to 0° and cyclic prefix sample length is taken as 8. We have concluded that OFDM with QPSK modulation outperforms in symbol error rate performance than other two modulation techniques that is OFDM with OOK and OFDM with BPSK in V2V communication. Since the data rate or the spectral efficiency is better in OFDM-QPSK, it has proven to be a better modulation technique that can be used for the V2V communication as compared to the other mentioned modulation techniques.

2 Literature Survey

In accordance with numerous former researches, it has been observed that OOK would be widely applied, in the view of its practicality and feasibility with regard to both modulation and demodulation. OOK, the most basic form of amplitude shift keying (ASK), has mostly been employed for the transmission of Morse code over radio frequencies. OOK can perform the depiction of digital data in terms of the presence or absence of a carrier wave. Although OOK has proven to have more spectral efficiency when compared to frequency shift keying (FSK), it has turned out to be more immune to when a super-heterodyne receiver has been implemented [12].

Meanwhile, on comparison with OOK, BPSK is said to have a better performance in terms of spectral efficiency. Another digital modulation technique based on the concept of phase shift keying (PSK), BPSK mostly constitutes of the alteration of the carrier wave in accordance with the modulating waveform, i.e., the digital signal [8]. A general BPSK transmitter block will consist of a balanced modulator, to which the baseband signal is applied. This modulator mimics a phase reversing switch that can transmit the carrier to the output, either in phase or out of phase by 180° with regard to the condition of the digital input [13].

QPSK, on the other hand, can safely be called a much improved and upgraded version of BPSK as it can transmit twice as much information as a BPSK modulation would allow to within the same parameters. This is possible due to modulation of two bits at once, whereas a BPSK modulation could transmit only one [11]. This places it in an advantageous position in terms of bandwidth efficiency. Just like BPSK, QPSK is also used in numerous wireless cellular standards like LTE, GSM, satellite, cable TV applications and furthermore.

The main application of OFDM techniques in V2V communication is the enhancement of the physical layer in order to overcome multipath fading successfully. The IEEE 802.11 is a group of amendments that consists of various specifications for the physical layer and the MAC layer to operate in certain frequency bands. However, the most recent amendment would be IEEE 802.11p that allows wireless access in vehicular environments (WAVE). This allows high-end V2V communication that includes data-exchange between high-speed vehicles and vehicle to infrastructure (V2I) communication for infrastructures present in the licensed ITS band.

3 Proposed Methodology

The parameters like, spectral efficiency and error performance (SER versus SNR), have been considered for analysis. We will be assuming a clear sky and all the reflector surfaces to be having the same reflective factor. It is supposed that all the vehicles are maintaining the same speed and traveling in the same direction.

Figure 1 represents the stages of transmission of a QPSK signal through an OFDM transmitter and a receiver. A basic QPSK-OFDM modulation is performed by subjecting a QPSK modulated signal through OFDM and then sent through an AWGN channel before being demodulated and de-multiplexed.

A basic V2V communication comprises of two vehicles, one following the other, termed as the following vehicle and the leading vehicle, respectively. Figure 2 shows the algorithm of a basic V2V communication. Both these units collect their own individual sets of information from their respective environments to analyze and transmit the data to the other vehicle. These parameters are examined to check for

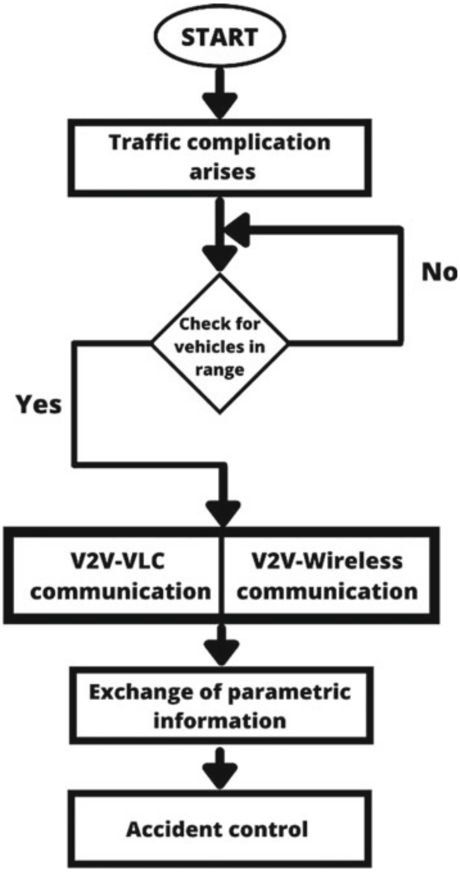

Fig. 2 Flowchart depicting the algorithm of a basic V2V communication

any possible hazards such as collision or traffic congestion. Upon the acquisition of the RF signals, an alert message is generated to be sent to the respective vehicles in potential danger, instructing them the appropriate measures to be taken in order to avoid any damage. This V2V communication can be performed on a large-scale basis where a vehicle can communicate with multiple other vehicles to create a network and mimic a real-world traffic situation. However, the reliability of a V2V network can be affected by propagation issues that can occur due to multipath fading. This issue is solved by inducing OFDM techniques for signal transmission where high power transmission is employed to overcome multipath fading, resulting in the enhancement of the physical layer.

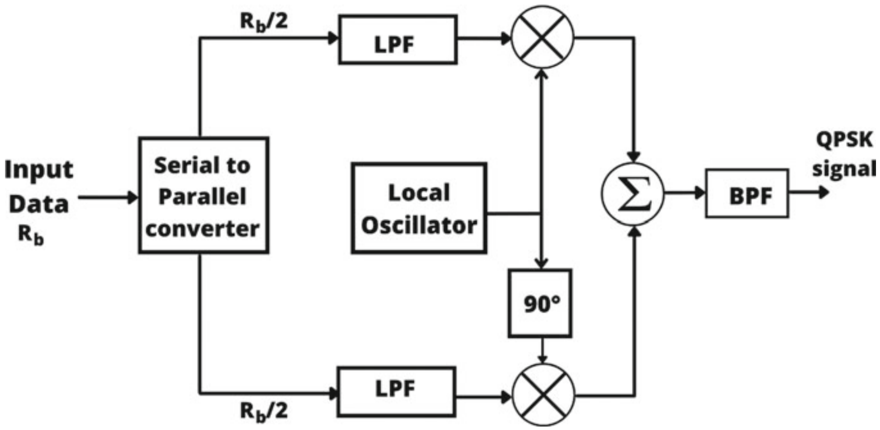

Fig. 3 Schematic representing a QPSK transmitter

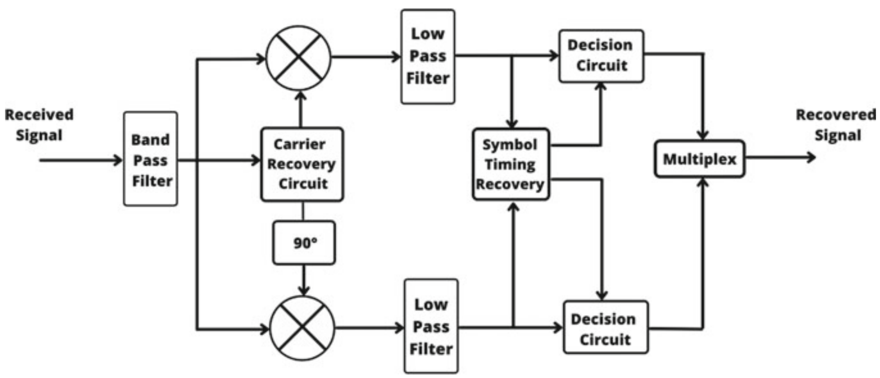

Fig. 4 Schematic representing a QPSK receiver

3.1 BER Calculation for QPSK Modulation Technique

Bit error rate (BER) is an essential element for the determination of the quality of a transmitted signal and can be simply described as the number of bit errors per unit time. These errors can be a result of interference, noise or other technical issues. Similarly, symbol error rate (SER) can be defined as the probability of receiving a symbol per unit time. Both these parameters are critical to measure the signal efficacy and reliability in order to form a concrete conclusion through comparison.

QPSK modulation consists of two BPSK modulations of the signal. Each branch as the same BER as that of BPSK,

$$P_{\mathrm{e}} = Q\sqrt{2\alpha_b} \tag{1}$$

where α_b represents energy per bit to noise power spectral density ratio, and Q is the error function.

The probability of each branch having a bit error is the symbol error rate (SER), which is

$$P_{\mathrm{sum}} = 1 - \left[1 - Q\left(\sqrt{2\alpha_b}\right)\right]^2 \tag{2}$$

The total energy of the symbols is divided into in-phase and quadrature components, $\alpha_s = 2\alpha_b$, Eq. (2) becomes,

$$P_{\mathrm{sum}} = 1 - \left[1 - Q\left(\sqrt{\alpha_s}\right)\right]^2 \tag{3}$$

where α_s represents energy per symbol to noise power spectral density ratio.

To get the upper bound for SER of QPSK, we make use of the union bound. The probability of error gets bounded by the sum of probabilities P_{sum} as given by: $0 \to 1$, $0 \to 2$ and $0 \to 3$. By assuming that the symbol zero has been sent. Equation (3) can be mathematically represented as,

$$P_{\mathrm{sum}} \leq Q\left(\frac{p_{01}}{\sqrt{2N_0}}\right) + Q\left(\frac{p_{02}}{\sqrt{2N_0}}\right) + Q\left(\frac{p_{03}}{\sqrt{2N_0}}\right) = 2Q\left(\frac{K}{\sqrt{N_0}}\right) + Q\left(\frac{\sqrt{2} * K}{\sqrt{2N_0}}\right) \tag{4}$$

Since $\alpha_s = 2\alpha_b = \frac{K^2}{N_0}$, we can write Eq. (4) as,

$$P_{\mathrm{sum}} \leq 2Q\left(\sqrt{\alpha_s}\right) + Q\left(\sqrt{2\alpha_s}\right) \leq 3Q\left(\sqrt{\alpha_s}\right) \tag{5}$$

where N_0 is the AWGN noise power spectral density.

Approximating Q function for z >> 0,

$$Q(z) \leq \left[\frac{1}{z\sqrt{2\pi}}\right] e^{-\frac{z^2}{2}} \quad (6)$$

we get,

$$P_{\text{sum}} \leq \left[\frac{3}{\sqrt{2\pi\alpha_s}}\right] e^{-0.5\alpha_s} \quad (7)$$

Assuming for the highest SNR, the errors predominantly are present for the nearest neighbor P_e, using gray coding and it can be approximated as P_{sum} by $P_e \approx {}^{P_{\text{sum}}}/_{2}$.

3.2 BER Calculation for BPSK Modulation Technique

The signal received by the BPSK system can be written as:

$$y = x + n \quad (8)$$

where $x \in \{-K, K\}$, $n\epsilon\left(0, \sigma^2\right)$and $\sigma^2 = N_0$, as x is the transmitted symbol and n is the additive white Gaussian noise (AWGN).

We can deduce the real part of the above equation as:

$$y_{\text{re}} = x + n_{\text{re}}$$

where
$n_{\text{re}}\ N\left(0, \frac{\sigma^2}{2}\right) = N\left(0, \frac{N_0}{2}\right)$.

In BPSK digital modulation technique, $d_{\min} = 2K$ and α_b is given as $\frac{E_b}{N_0}$, and hence, it can be termed as SNR per bit. K represents the symbol per bit.

Hence, we have:

$$\alpha_b = \frac{E_b}{N_0} = \frac{K^2}{N_0} = \frac{d_{\min}^2}{4N_0} \quad (9)$$

where $d_{\min}$ is the minimum distance between the constellation symbols.

Now, the bit error probability is calculated by,

$$P_b = P\{n > K\} = \int_K^\infty \frac{1}{\sqrt{2\pi\sigma^2/2}} e^{-\frac{a^2}{2\sigma^2/2}} \quad (10)$$

Using Q function, the equation can be simplified as,

$$P_b = Q\left(\sqrt{\frac{d_{\min}^2}{2N_0}}\right) = Q\left(\frac{d_{\min}}{\sqrt{2N_0}}\right) = Q(\sqrt{2\alpha_b} \quad (11)$$

where the Q function is defined as,

$$Q(a) = \frac{1}{\sqrt{2\pi}} \int_a^{\infty} \mathrm{e}^{\frac{-a^2}{2}} \mathrm{d}x \tag{12}$$

3.3 Calculation of Spectral Efficiency of BPSK:

The spectral efficiency is calculated based on its pulse shape. The baseband of BPSK signal can be written as,

$$s(t) = \sum k_a k_p (t - kT_b) \tag{13}$$

where a_k is equal to either $\sqrt{E_b}$ or $-\sqrt{E_b}$, E_b the bit energy, T_b is the bit interval so that the bit rate is, $(R_b = 1/T_b)$, and $p(t)$ is a Nyquist pulse. The bandwidth of $s(t)$ is equal to the bandwidth of $p(t)$.

$$p(t) = \{1,\ \text{if} 0 \le t < T_b; 0,\ \text{otherwise}. \tag{14}$$

This means that the spectrum of $s(t)$ is infinite.

3.4 Determination of Spectral Efficiency of QPSK

Here, four signals are defined, each with a phase shift of 90° and then we have quadrature phase shift keying (QPSK). For QPSK, $M = 4$,

We get,

$$s(t) = \frac{1}{\sqrt{2}} a_1(t) \cos\left(2\pi f t + \frac{\pi}{4}\right) + \frac{1}{\sqrt{2}} a_Q(t) \sin\left(2\pi f t + \frac{\pi}{4}\right) \tag{15}$$

$$s(t) = K \cos\left[2\pi f t + \frac{x}{4} + \theta(t)\right] \tag{16}$$

where

$$K = \sqrt{\frac{1}{2}\left(e_I^2 + e_Q^2\right) = 1} \tag{17}$$

$$\theta(t) = -a \tan \frac{a_Q(t)}{a_I(t)} \tag{18}$$

Table 1 Comparison of OFDM-OOK, OFDM-BPSK and OFDM-QPSK in different parameters

Parameters	OOK	BPSK	QPSK
Bit error rate	Medium	Higher	Lower
Spectral efficiency	Low	Medium	High
Ease of implementation	Hard	Easy	Easy
Noise immunity	Very less	Good	Very good

Here, aQ(t) represents the quadrature part of the amplitude, and aI(t) represents the in-phase component of the amplitude. $\theta(t)$ represents the phase angle between the in-phase and quadrature components of a QPSK signal.

4 Results and Discussion

We have deduced from Table 1 that QPSK with OFDM has an overall good performance compared to the other two modulation techniques since both of them lack in one or the other parameter. QPSK modulation technique has a lesser bit error rate compared to OOK but slightly higher than that of BPSK and a higher spectral efficiency compared to both other techniques. Thus, the implementation of QPSK and BPSK modulation technique in combination with OFDM is easier than OOK. QPSK modulation technique has also shown to possess commendable noise immunity than the other two techniques. With all these four parameters, we have concluded that QPSK is best modulation technique among OOK and BPSK techniques and is recommended for V2V communication.

We have considered fast Fourier transform (FFT) sample size as 128, number of OFDM symbols used as 16, phase offset as 0 degree and cyclic prefix samples as 8 for the error performance analysis of the above three mentioned digital modulation schemes. From Fig. 5, we have concluded that OFDM with QPSK modulation outperforms in symbol error rate performance than other two modulation techniques that is OFDM with OOK and OFDM with BPSK. We have observed that as SNR (in dB) increases, symbol error rate decreases in OFDM-QPSK at a faster rate as compared to its digital counterparts, whereas symbol error rate follows almost same trend for OFDM-OOK and OFDM-BPSK digital modulation. Moreover, the symbol error rate for OFDM-QPSK scheme is very less as compared to OFDM-OOK and OFDM-BPSK, making it a more reliable means of data transmission in V2V systems.

5 Conclusion

In this proposed paper, we have compared various modulation techniques for a signal that would be subjected through OFDM in V2V models. The quality of transmission is determined by bit error rate (BER) versus signal to noise ratio (SNR) for different

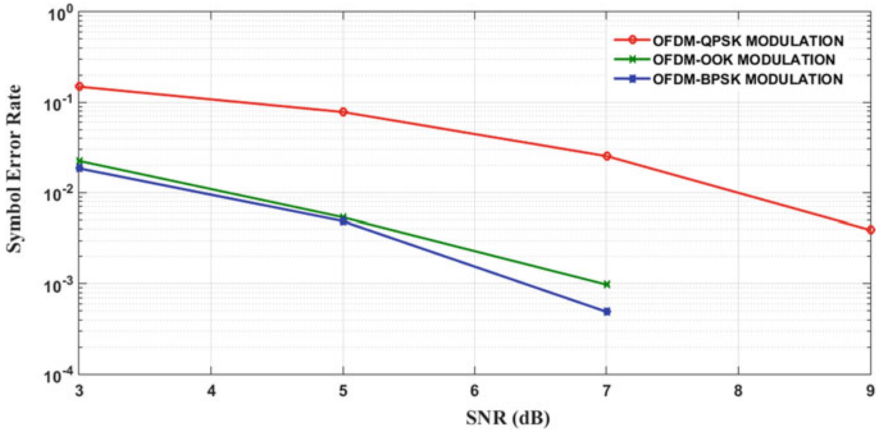

Fig. 5 Comparison graph obtained for SNR (in dB) versus symbol error rate for three different modulation schemes—OFDM-QPSK, OFDM-OOK and OFDM-BPSK

types of coding techniques applied for the transmitted data. The preamble OFDM sample size is considered as 16, with FFT size of 128 and cyclic prefix length of 8 for evaluating the performance of OFDM systems. Through practical analysis, we have concluded that OFDM-QPSK when compared to OFDM-OOK and OFDM-BPSK performs better in SNR (in dB) versus symbol error rate performances. It is also observed that the data rate or the spectral efficiency is comparably higher in OFDM with QPSK than its counterparts. Since OFDM with QPSK performs better than the other two modulation techniques, this technique has proved to be efficient and has been adopted in various wireless communication systems and V2V communication systems. On this note, we can say that ODFM-QPSK method of modulation is preferred because of its advantage, i.e., ease of implementation and subtle performance parameters. Hence, an inference has been drawn that for vehicle-to-vehicle communication, OFDM performs better with the QPSK modulation technique, as compared to OOK and BPSK.

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