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Improving Vehicular Safety Through Constant Modulation: A Robust Solution for High- Mobility Scenarios



Abstract: - This paper addresses the pressing global issue of road traffic safety, which results in an estimated 1.19 million fatalities annually, by leveraging the potential of the Wireless Access in Vehicular Environments (WAVE). The WAVE standard plays a critical role in reducing accidents by enabling communication between vehicles and infrastructure. The success of Vehicular Ad Hoc Networks (VANETs) in enhancing road safety relies heavily on the effective exchange of Cooperative Awareness Messages (CAMs) and Decentralized Environmental Notification Messages (DENMs). However, the mobility of vehicles introduces challenges due to the Doppler Effect (DE), which disrupts communication and message dissemination, particularly in high-mobility conditions. To mitigate this, we propose an existing simple strategy called Constant Modulation (Cte), designed to improve communication efficiency in VANETs under varying Doppler Shift conditions. Comparative evaluations show that Cte outperforms more advanced techniques like Auto Rate Fallback (ARF) and Adaptive Modulation and Coding (AMC), particularly under high Doppler Shift values of 750 Hz and 1500 Hz. The results indicate that Cte offers a robust, cost-effective solution for improving throughput, reducing transmission duration, and ensuring reliable safety message dissemination in dynamic VANET environments. Furthermore, Cte serves as a benchmark for future communication algorithms, making it a promising approach for enhancing road safety, especially in high-mobility scenarios.

Keywords: Doppler Shift (DS), Vehicular Ad Hoc Networks (VANETs), Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), Wireless Access in Vehicular Environments (WAVE).

I. INTRODUCTION

The World Health Organization (WHO) reported on 13 December 2023 that the global estimate of road traffic deaths is 1.19 million annually since 2021 [1]. It was also stated that road traffic deaths and injuries have remained a major global health and development challenge since 2019 [1]. The same report further indicated that road traffic crashes are the leading cause of death for children and youth aged 5 to 29 years and are the 12th leading cause of death when considering all ages [1]. Two-thirds of these deaths occur among people of working age (18 to 59 years), causing significant health, social, and economic harm throughout society [1]. To address the aforementioned problem, the Wireless Access in Vehicular Environment (WAVE) standard, also known as Dedicated Short-Range Communication (DSRC), was created to enable inter-vehicular communication. This ensures that vehicles can effectively exchange and communicate with other vehicles or fixed infrastructure, sharing valuable information about road conditions to avoid car crashes, accidents, or related incidents [2], [3]. Operating at a frequency of 5.9 GHz, the WAVE standard is part of the Federal Highway Administration's Vehicle Infrastructure Integration (VII) program for developing Intelligent Transportation Systems (ITS) [4]. Under the WAVE standard, a vehicle can connect with other vehicles using the Vehicle-to-Vehicle (V2V) protocol or with other wireless communication infrastructure using the Vehicle-to-Infrastructure (V2I) protocol. The WAVE standard comprises two other standards: IEEE 802.11p, which handles all operations related to the Medium Access Control (MAC) and physical layers (PHY), and the IEEE 1609 standard, which focuses on managing operations performed by the upper layers [4].

In terms of road safety applications, the success of Vehicular Ad Hoc Networks (VANETs) relies primarily on two types of messages that are regularly exchanged [5]. The first type, known as Cooperative Awareness Messages (CAMs), are transmitted regularly [6] and contain information about the locations of other vehicles in the vicinity of the involved nodes. The second type, called Decentralized Environmental Notification Messages (DENMs), are high-priority notification messages with extremely low latency that are only generated in emergency situations (e.g., accidents, collisions). CAMs provide road state awareness information and are transmitted at a frequency of 1 to 10 Hz, while DENMs are time-sensitive and must be delivered promptly. DENMs are crucial for notifying vehicles about accidents or incidents, helping incoming vehicles to respond effectively before reaching the accident scene.

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Due to the versatility and high mobility of the involved VANET nodes, successful communication is not always guaranteed, especially during periods of higher node mobility. The mobility factor introduces a phenomenon known as the Doppler Effect (DE) [7]. When a wave source and a receiver are moving relative to one another, the frequency of the received signal will differ from the source frequency. When they are moving towards each other, the received signal's frequency is higher than the source frequency. As they move closer, the frequency decreases. The rate of frequency change, called Doppler Shift (DS), depends on the relative motion between the source and receiver as well as the speed of propagation of the wave. The impact of induced DS makes it challenging to achieve effective and efficient safety message dissemination in VANETs, particularly under conditions of high node mobility. This calls for the implementation of specific methods, techniques, or strategies to ensure optimal performance when communicating and exchanging information within this type of network.

Given the complexity, cost, time consumption, and other challenges associated with deriving or designing each strategy, a simple and acceptable strategy would be very beneficial in the context of limited resources. Therefore, this work proposes a simple yet effective and resilient strategy for use in VANETs. The proposed strategy, called Constant Modulation (Cte), is evaluated against more advanced techniques such as Auto Rate Fallback (ARF) [8] and Adaptive Modulation and Coding (AMC) [9]. Comparative results show that the Cte outperforms its peers in terms of throughput and transmission duration, especially at higher Doppler Shift values of 750 Hz and 1500 Hz.

The rest of this work is organized as follows: Section 2 briefly discusses related works on this subject. The Doppler Shift analysis and derivation are presented in Section 3. Section 4 presents the simulation of the proposed simple strategy's performance assessment. Finally, the conclusion is drawn in Section 5.

II. RELATED WORKS

In terms of applicable communication strategies, mechanisms, or methods used in VANETs, most methods employ some variant of Link Adaptation (LA) techniques, which can adjust the transmitter power, modulation coding scheme, transmission mode, or other transmission parameters. In this work, the focus will primarily be on adjusting the modulation coding scheme. With reference to conventional wireless communication, several works have already been published in the field of LA using either simple or complex methodologies. For instance, some recent works, such as [10], [11], and [12], are not tailored for the VANETs environment. Many well-known works, such as [8], [13], and [14], were developed for the legacy IEEE 802.11 standard, which was created for conventional Wireless Local Area Networks (WLAN) and does not consider the higher mobility aspects of the involved nodes. Auto Rate Fallback (ARF) is one of the most commonly used rate adaptation mechanisms in wireless environments [8]. In the ARF strategy, a rate upshift is performed after ten consecutive successful frame transmissions, while a rate downshift occurs after two consecutive frame transmission failures. However, ARF is unable to respond quickly to a rapidly changing channel, as it takes 10 successful frame transmissions to increase the transmission rate. Numerous ARF techniques based on various up/down counter algorithms have been incorporated into most firmware [15].

In the area of relative mobility impact on VANETs communication scenarios, very few works have been published. To develop the mathematical model for each Modulation and Coding Scheme (MCS), Khaldoun examined the effects of Doppler Shift (DS) as a function of relative speed on signal quality [9]. Furthermore, simulation experiments were conducted, and an Adaptive Modulation and Coding (AMC) scheme was developed, simulated, and tested. Although restricted to a maximum DS range of 500 Hz, which corresponds to a relative speed of about 92 km/h, the AMC approach exhibits improved performance compared to its peers. The study in [16] addressed a domain-specific problem by developing a machine learning-based LA model aimed at enhancing communication efficiency in VANETs. The analysis derived from the proposed model demonstrated consistent prediction of optimal MCS values, accounting for both the relative mobility of the involved nodes and the available Signal-to-Noise Ratio (SNR). Furthermore, it was shown that the machine learning-based LA approach holds great potential for optimizing vehicular communication performance, contributing to the development of safer and smarter transportation systems.

To address the gap regarding the impact of relative mobility between VANET nodes, the authors in [17] proposed a new link adaptation strategy that incorporates Doppler Shift caused by relative velocity, utilizing a Neural Network (NN) and the Levenberg-Marquardt algorithm. Simulation results demonstrate that the NN-based approach outperforms traditional algorithms such as CTE, ARF, and AMC, achieving substantial improvements in transmission duration (1075%), transmitted bit count (180%), and model efficiency (115%). To enhance user experience and achieve seamless connectivity among all vehicles, the authors in [18] developed a decentralized

congestion control system that adjusts message rates based on an exponential function. Simulations conducted using the SUMO and OMNET++ platforms showed that this technique effectively reduces channel busy time and packet loss. Additionally, the rate of reduction improved as the decay factor increased, particularly with a larger number of vehicles, highlighting the potential of message rate control mechanisms in enhancing vehicular network performance by reducing congestion. A multistate active transmit data rate control mechanism as part of a decentralized congestion control strategy was proposed in [19]. Simulations using real-world scenarios generated from the SUMO platform demonstrate that their data rate control method outperforms traditional transmit power control and static adaptation mechanisms. To address transmission interference between VANET nodes, the work in [19] introduced the Packet Rate Adaptation based on the Bloom filter (PRAB) protocol, which mitigated hidden terminal collisions in broadcast communication. PRAB derived the optimal packet generation rate based on the average number of hidden terminals. By incorporating Bloom filters to estimate the number of hidden terminals, the protocol reduced overhead while maintaining packet reception rates of 90% or higher, even in high-vehicle-density scenarios. Simulations show that PRAB provides a 15% to 24% improvement in packet reception compared to previous protocols.

This review highlights some previous works in the field, which, although performing well individually, are embedded with some implementation complexity. In terms of limitations, some do not consider higher mobility, while others, which make use of machine learning techniques, rely on historical data or feedback. Feedback strategies are very challenging in VANETs, where communication between vehicles is temporary. The current work proposes a simpler method or solution to address some of these limitations and implementation complexities, without relying on any feedback or historical data, especially under conditions of limited resources and expertise.

III. DOPPLER SHIFT ANALYSIS AND DERIVATION

In view to understand the reason why it is important to take care of the relative mobility while transmitting in VANETs environment, a mathematical analysis of the impact of relative mobility affecting the received signal is highly imperative. In general, based on the IEEE802.11 standard, the Doppler shift in frequency can be written as,

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

where Δf is the change in frequency of the source seen at the receiver, f_c is the frequency of the source, V is the speed difference between the source and transmitter, C is the speed of light and β is the angle of velocity vector. The change in frequency is maximal when $\beta=0$. OFDM symbols are very sensitive to this change. The change in frequency is also called frequency shift. An OFDM baseband signal can be represented by,

$$V(t) = \sum_{i=1}^{N_s} A_i \cos (w_i + \phi_t) \quad (2)$$

where A_i , w_i , and ϕ_t is the amplitude, angular frequency, and the phase of i th subcarrier. N_s is the number of subcarriers.

In the OFDM, subcarrier must be orthogonal to each other. This can be achieved if $f_i = w_i / 2\pi$ is an integer multiple of $1/2T$ [13], where T is the symbol period of the data, and f_i are spaced in frequency by $R_s=1/T$. The described baseband OFDM signal is generally modulated on a higher frequency carrier before transmission. However, this signal can also be directly transmitted without conversion into higher frequency [21]. It has been demonstrated in [22] that the Doppler shift affects the carrier frequency and the envelope frequency by the same percentage.

If the OFDM signal component A_i is up converted for transmission into the wireless channel, the resulting signal will be of form:

$$V_i = A_i \cos [w_i(t) + \phi_t] e^{-(j2\pi f_c)\tau_i} \quad (3)$$

if we pose $A_i \cos [w_i(t) + \phi_t] = s_i$ then,

$$V_i = s_i [e^{-(j2\pi f_c)\tau_i}] \quad (4)$$

where $e^{-(j2\pi fc)}$ and τ_i represent the carrier frequency and the delay of the i th path component respectively. If the mobiles move with a relative speed V and with a maximum angular velocity vector $\beta = 0$, then the transmitted signal will be affected by the value $V/C \cos\beta$. The resulting equation becomes,

$$V_i = s_i e^{-(j2\pi fc)[\tau_i - \frac{V}{C} \cos\beta t]} \quad (5)$$

which is equivalent to:

$$V_i = s_i e^{-(j2\pi fc)\tau_i} e^{(j2\pi fc) \frac{V}{C} \cos\beta t} \quad (6)$$

Substituting equation (1) into equation (6), the resulting signal can be represented as,

$$V_i = s_i e^{-(j2\pi fc)\tau_i} e^{(j2\pi \Delta f t)} \quad (7)$$

where $e^{(j2\pi \Delta f t)}$ is the time varying phase of the transmitted signal. If it is considered that $t=1/4\Delta f$, then,

$$V_i = s_i e^{-(j2\pi fc)\tau_i} e^{(j2\pi \Delta f / 4\Delta f)} \quad (8)$$

which result in $V_i = s_i e^{-(j2\pi fc)\tau_i} e^{(j\pi/2)}$ and $e^{(j\pi/2)} = j$. If $t=1/4\Delta f$ then the transmitted signal becomes:

$$V_i = j s_i e^{-(j2\pi fc)\tau_i} \quad (9)$$

From the above derivation, considering the coherence time to be,

$$T_c = 1/4\Delta f \quad (10)$$

It can be seen that if the transmission duration period exceeds T_c , the transmitted symbols will undergo a drastic change resulting in the real part of signal becoming imaginary and the imaginary part becoming real. Hence this is what generally occurs when the nodes of the network are subjected to higher mobility such as in VANETs environment.

IV. SIMPLEST STRATEGY PERFORMANCE ASSESSMENT

To facilitate the comprehension of the proposed simplest strategy (Cte) analysis and evaluation, it is important to clarify the simulation environment as well as all simulation parameters used. Additionally, since the simplest strategy under evaluation needs to be compared with AMC and ARF, a brief review of these strategies is also presented in the subsequent subsections.

A. Simulation Setup Brief

In order to evaluate and explore the performance of the proposed strategy, the current work makes use of the channel model proposed and implemented in MATLAB. This channel model has been proven effective in simulating the V2V wireless channel environment [23]. The communication channel begins at the transmitter, where the Medium Access Control (MAC) Protocol Data Unit (MPDU) is emitted and sent to the physical layer. At the physical layer, the MPDU is encapsulated to form the Physical Layer Convergence Protocol (PLCP) Service Data Unit (PSDU). Subsequently, the PSDU is used to generate waveform packets transmitted over the wireless channel. This adopted wireless channel model was developed for both V2V and V2I environments and has been shown to comply with IEEE 802.11p [24]. Further information on this channel model can be found in [25]. The simulation parameters used for this experiment are provided in Table 1. It should be noted that these parameters were used for each of the three strategies (ARF, AMC, and Cte). A brief description of ARF and AMC is presented in the following subsection, while constant modulation code (Cte) is represented by Binary Phase Shift Keying rate 1/2 (BPSK 1/2).

Table 1: Simulation Parameters.

Parameter	Value	Parameter	Value
Pilot	2 Bytes	Number of Frame	1000
Carrier Frequency	5.85 GHz	Frame Size	600 Bytes
Speed of light	300 000 Km/s	SNR Max	30 dB
Angle of signal arrival	0 deg	Delay Spread	3 us
Sample time	1 us	OFDM Sym duration	8 us
Number of subcarrier	48	Doppler Shift	0, 750, 1500 Hz

B. Review of ARF and AMC

Auto Rate Fallback (ARF): This is one of the oldest and most widely adopted adaptive rate mechanisms, used by Alcatel Lucent in its WaveLAN2 [8]. The ARF mechanism is summarized as follows: After 10 successful frame transmissions, the current MCS is upgraded and replaced by MCS+1. After two consecutive unsuccessful frame transmissions, the current MCS is downgraded and replaced by MCS-1. This process repeats until the highest or lowest achievable MCS is reached, or the transmission is completed.

Adaptive Modulation and Coding (AMC): The AMC presented in [9] was developed and tested as described. Further overviews of the method can be found in [9]. In summary, the author proposed MCS 3 for Doppler Shift (DS) values less than 200 Hz, MCS 2 for DS values between 201 and 250 Hz, and MCS 1 for DS values between 251 and 500 Hz. It was also highlighted that no acceptable communication can be achieved for DS values greater than 500 Hz.

C. Simulation

Using the simulation setup as described earlier, it is worth noting that for each SNR point in all figures, 1000 packets were transmitted, although some did not reach the receiver and were counted as errors. In each figure, the comparison of Cte is made against ARF and AMC. It should be noted that the method of concern, the simplest strategy, defined as Cte, is represented by a solid line in all figures. Before exploring the computed figures, the different assessment metrics used need to be defined. Therefore, the successfully transmitted packet is named “Packet xx,” where “xx” can be AMC 750, AMC 1500, ARF 750, ARF 1500, Cte 750, or Cte 1500. “Packet xx” is expressed as follows:

$$Packet\ xx = TxPacket - Err \quad (11)$$

where TxPacket is the total number of transmitted packets at a given SNR and Err is the number of packets which fail to reach the receiver.

$$Er\ Err\ xx = TxPacket - Packet\ xx \quad (12)$$

The transmission rate is defined as,

$$Rate\ xx = \frac{\left(\frac{(Packet\ xx \times packet\ length) \times 8}{1024} \right) \times Mcs\ rate}{Time\ xx} \quad (13)$$

Subsequently, the transmission efficiency is defined as,

$$Efi\ xx = \frac{TxPacket}{Packet\ xx} \times 100 \quad (14)$$

Fig. 1 presents the simulation results in terms of successfully transmitted packets. In this figure, it can be observed that the number of successfully transmitted packets increases gradually in line with the increase in the SNR value. Looking at the performance discrepancy between Cte and its peers, it can be seen that at lower SNR values (less than 7 dB), the performance of all methods is the same. However, when the SNR rises above 8 dB, a clear separation between the 750 Hz and 1500 Hz cases can be observed, especially for AMC and Cte. While the number of transmitted packets for ARF remained almost the same for both DS values, the number of successfully

transmitted packets increased as the SNR rose. While the number of transmitted packets at 750 Hz is far greater than at 1500 Hz, AMC and Cte display similar performance at different DS levels of 750 Hz and 1500 Hz.

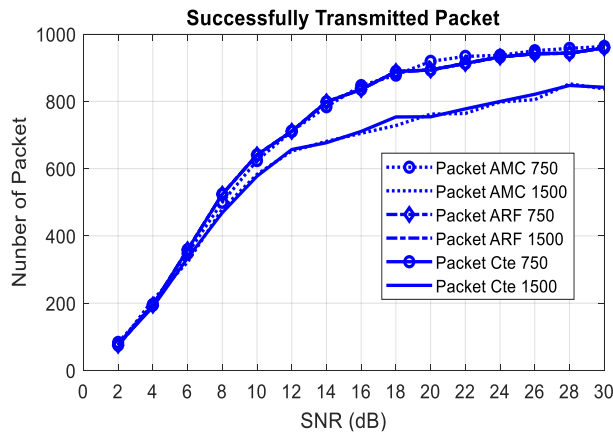


Fig. 1. Successfully transmitted packets.

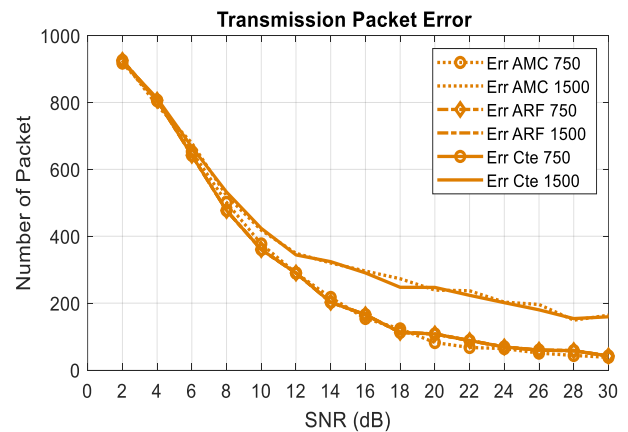


Fig. 2. Transmission error.

The number of packet errors resulting from multiple communication transmissions is depicted in Fig. 2. An overview of this figure shows that the number of packet errors diminishes considerably with the increasing SNR value. As in Fig. 1, while the number of transmission errors at 1500 Hz is far greater than at 750 Hz, AMC and Cte display similar performance at different DS levels. It can be noted that the number of transmission errors for ARF at both 750 and 1500 Hz, as well as for AMC and ARF at 750 Hz, are almost the same. The transmission rate of all three strategies is presented in Fig. 3.

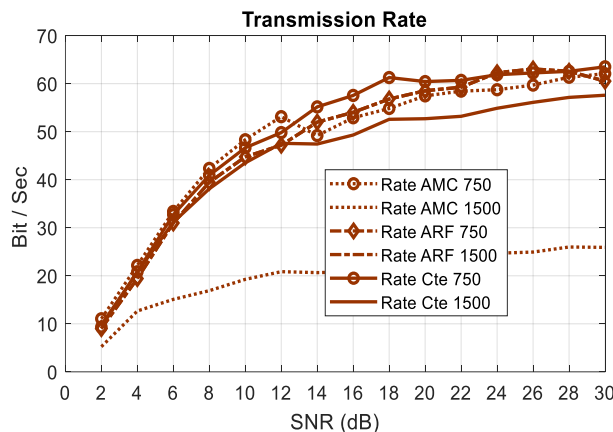


Fig. 3. Transmission rate.

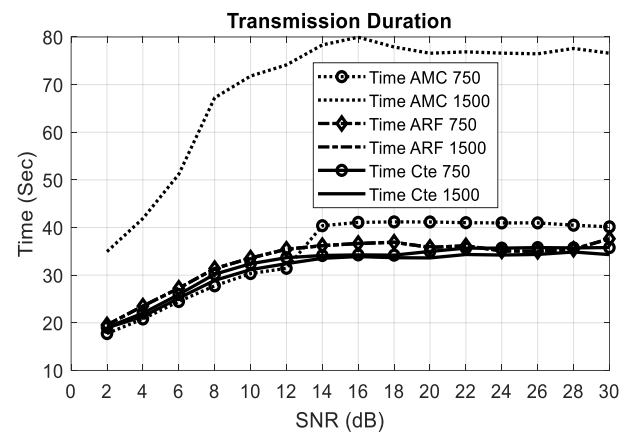


Fig. 4. Transmission duration.

With the exception of the AMC transmission rate at 1500 Hz, the transmission rates of all methods remained the same until the point where the SNR became greater than 10 dB. The second-lowest performance above 10 dB is observed for the simplest method (Cte) at 1500 Hz. Moreover, at 750 Hz, this same Cte proved to be the best performer. The transmission duration of all three methods is displayed in Fig. 4. This figure shows that not only did AMC at 1500 Hz offer a lower transmission rate (as seen in Fig. 3), but it also spent a lot of time transmitting at the same DS value. This figure further confirms that, although Cte is the simplest strategy to use in the case of higher Doppler Shift (DS), it still offers the overall best and shortest transmission duration.

The exploration of the effectiveness of each approach is depicted in Fig. 5. The overall appearance of this figure displays a similar pattern to that presented in Fig. 1, with the exception that, contrary to Fig. 1, it presents the performance in terms of transmission efficiency. Looking at Fig. 5, it can be seen that Cte and AMC offer almost identical responses at 750 Hz and 1500 Hz. The worst performer in this figure is Cte and AMC at 1500 Hz, while Cte at 750 Hz still offers a good performance, similar to ARF at 750 Hz, AMC at 750 Hz, and ARF at 1500 Hz.

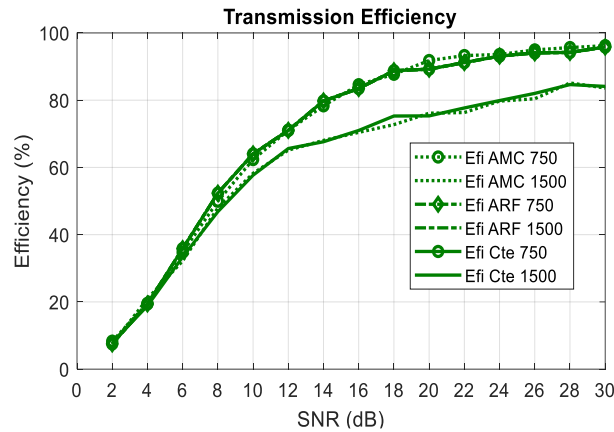


Fig. 5. Transmission efficiency.

Having gone through these figures, it is still difficult to clearly determine the best of the three proposed methods. This is why the summarized table of all metrics evaluated during the simulation was computed and presented in Table 1.

Table 1. Summarized simulation table.

ASSESSMENT METRIC	COMMUNICATION STRATEGIES					
	AMC 750	AMC 1500	ARF 750	ARF 1500	Cte 750	Cte 1500
Total PER	4,3802	5,7562	4,4026	5,7227	4,4026	5,7227
Total Efficiency	1062	924,3756	1059,7	927,7323	1059,7	927,7323
Total Throughput	725,1335	302,2807	719,9027	635,15	745,5677	671,8905
Total Error	4384,6	5762	4407	5728,4	4407	5728,4
Total Transmitted Packe	10630	9253	10608	9286,6	10608	9286,6
Total Run Time	519,8951	1038	495,6108	494,4025	479,4149	464,66

This table presents each strategy's response against all assessment metrics. Although each value in the table can be used and compared against other values within the same metric to identify the best performer, Table 2 was computed to make this comparison task much easier. Since the focus is to assess the performance of Cte against the others, some additional metrics were added to the table to signify the percentage difference of Cte against AMC (named Di_{AMC}) and the difference of Cte against ARF (defined as Di_{ARF}).

$$Di_{AMC}(\%) = \left(\frac{Cte - AMC}{AMC} \right) \times 100 \quad (15)$$

Similarly,

$$Di_{ARF}(\%) = \left(\frac{Cte - ARF}{ARF} \right) \times 100 \quad (16)$$

In Table 2, all values highlighted in green indicate the outperformance of the simplest method (Cte) over its peer. Similarly, all values highlighted in light red indicate the outperformance of the peer over Cte. The value zero in all table entries indicates equal performance between Cte and its peer. The exploration of this table clearly demonstrates that although similar results can be observed in some cases, the simplest (Cte) method outperformed ARF in all scenarios. As for AMC, at lower DS values, AMC proved to be more resilient than Cte. However, when the DS value increased to a certain level (in this case, 1500 Hz), Cte proved to be more robust.

It should be noted that in a non-mobile or fixed wireless environment, both ARF and AMC would offer better performance compared to Cte. But when the Doppler Effect (DE) starts affecting the network due to node mobility, ARF and AMC progressively lose their strength as the DS value increases. This is why developing an effective communication algorithm in VANETs is not an easy task. It is also the reason why this work was developed to assist and inform experts in understanding the implications of DS degradation in wireless networks, especially at

higher DS values. Furthermore, the simplest method (Cte) proposed here can also serve as a benchmark strategy to assess the performance of any future communication algorithm developed for VANETs. If any developed algorithm outperforms Cte at all DS values, this will signify that the newly developed approach is valid and worthy of use.

Table 2. Performance comparison.

Performance Comparison of Cte against AMC and ARF (%)				
ASSESSMENT METRIC	DS = 750 Hz		DS = 1500 Hz	
	Di_AMC	Di_ARF	Di_AMC	Di_ARF
Total PER	0,511392	0	-0,58198	0
Total Efficiency	-0,21657	0	0,363132	0
Total Throughput	2,817991	3,5650651	122,2737	5,784539
Total Error	0,510879	0	-0,58313	0
Total Transmitted Packe	-0,20696	0	0,363125	0
Total Run Time	-7,78622	-3,267867	-55,2351	-6,01585

The holistic analysis of this work shows that sometimes it is not worthwhile to embark on complex model development, especially when dealing with higher DS in VANETs. The demonstration of this work proves how Cte, which is simply a BPSK 1/2 modulation, can be used directly to handle communication under higher DS while offering better performance compared to ARF (one of the oldest adopted rate adaptation techniques) as well as the more advanced AMC proposed in [9]. In cases of limited resources and time constraints in a VANETs environment subjected to higher mobility, Cte is the best choice.

V. CONCLUSION

This study presents and demonstrates how a simplest strategy Constant Modulation (Cte) offers a highly effective and simple solution for improving communication in VANETs, especially in high-mobility environments where Doppler Shift challenges are prominent. While more complex techniques such as Auto Rate Fallback (ARF) and Adaptive Modulation and Coding (AMC) may perform better in stable, low-mobility settings, Cte outperforms them in high-mobility scenarios, making it an ideal choice when facing time, resource, and mobility constraints. The work begins by analyzing the impact of Doppler Shift (DS) on the received signal before undertaking a comparative analysis to explore and assess the performance of Cte. The results highlight that, contrary to the assumption that more complex models are always superior, simplicity can lead to better outcomes in certain contexts. Cte's resilience under high Doppler Shift conditions makes it a robust and practical solution for enhancing road safety and communication reliability in dynamic VANET environments. Additionally, the simplicity of Cte positions it as a benchmark for evaluating future communication algorithms in VANETs. This work underscores the importance of factoring in mobility when designing communication protocols for safety-critical systems, proving that effective solutions can emerge from even the most straightforward strategies.

As a main contribution, this work:

1-Explores, investigates, and introduces the simplest strategy (Cte), which is both effective and practical for Vehicular Ad Hoc Networks (VANETs), particularly in high-mobility environments where Doppler Shift significantly impacts communication reliability.

2-Demonstrates how higher mobility can negatively impact the quality of the received signal in VANETs.

3-Suggests, based on comparative analysis, how Cte can serve as a benchmark for evaluating future communication algorithms in VANETs.

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