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Performance Evaluation of CAM Broadcast Message and Vehicle Safe Distance Under Nakagami-m Radio Channel Conditions

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ABSTRACT

Many potentials exist in the 5G era for effectively managing vehicle safety on the road. The European Telecommunications Standards Institute (ETSI) 5G C-V2X standards for Cooperative Aware Messages for Intelligent Transport Systems (ITS) provide necessary upper-layer requirements for safety message distribution between vehicles using Cooperative Aware Messages (CAM). In addition, the Long Term Evolution (LTE) mobile radio technology in Release-14 has two modes of communication, mode 3 and mode 4, to facilitate vehicle-to-vehicle communications. The focus of this study is on vehicle communications in a mode 3 environment, in which the cellular network chooses and manages the radio services utilised by vehicles for direct vehicle-to-vehicle communication. The performance modelling of Safety Avoidance Time (AT) and safety CAM message broadcast for vehicle-to-vehicle communication in LTE C-V2X under the Nakagami-m radio channel, which has two components, LOS and NLOS, is studied in this thesis. Under the Nakagami-m radio channel, the LOS and NLOS components will affect the CAM message disseminating to other vehicles within safe time gaps. Therefore, the aim of this study is to look into the various radio channel characteristics in a vehicle-to-vehicle communication environment that are related to CAM message dissemination and vehicle safe distance, as well as to evaluate the performance of the relationship between PDR, throughput, and transmit power proportional to safe time gaps under the Nakagami-m radio channel with various setting shape factors.

1. Introduction

Transportation necessitates the use of vehicles. People drive vehicles in order to have the freedom to get where they need to go, when they need to get there. As a result, the number of vehicles has increased. The increased number of vehicles on the road causes number of mishaps, which can occur on highways or in urban areas.

According to the NHTSA [1], 38,680 individuals died in road crashes in 2020, up 7.2 percent from 36,096 fatalities in 2019. Although stay-at-home orders owing to the COVID-19 pandemic, the number of fatalities increased by 13.2% in 2020 compared to the previous year. As a result, the death rate per 100 million vehicle miles travelled increased to 1.37 in 2019 from 1.11 in 2019, reaching its

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highest level since 2007. According to NHTSA, the increase of death rate most likely because of faster driving in road. The factors of people dying or colliding in car accidents is due to human factors or the environment road itself. The human factors in vehicle collisions may be related to other road users who may have contributed to the collision or drivers. For example, the human behavior of driving at high speeds without taking a break in order to avoid colliding with other vehicles. The time gap is the safe distance needed for the vehicle to apply the brakes before colliding. The time difference is significant due to human factors driving at different speeds of the vehicle. Different vehicle speeds necessitate different time gaps because they require a proper distance between the vehicle before stopping. To avoid a collision, the vehicle must maintain a safe time gap for a safe distance while braking. Therefore, a good communication network between the vehicles is required to overcome these disasters. This results in a new advanced technology known as 5G-V2X. 5G-V2X is aims to provide drivers with a safe, secure, and smart travel experience that includes technologies and autonomous devices that collaborate with minimal human interaction. 5G-based V2X is expected to enable very high throughput, high reliability, low latency and accurate position determination use cases [2]. 5G can be used in conjunction with other devices such as cameras, radar, and lidar in some situations. Cellular V2X (C-V2X) Communications Towards 5G describes these use cases, starting with the advanced driving categories identified in 3GPP, including ranging or positioning, extended sensors, platooning and remote driving [2]. Massive multiple-input multiple-output communications, vehicle-to-vehicle communications, high-speed train communications, and millimeter wave communications are among the new technologies being investigated for 5G systems. Each of these technologies brings novel propagation features and necessitates specific 5G channel modelling requirements. A series of 5G-V2X radio channel measurements can be distributed in various situations, such as open highway, suburban, campus, junction, and so on. The Nakagami distribution best fits the fading amplitudes of V2V channels, according to the measurements. Due to the strong LOS components, fading amplitudes tend to be Rician distributed when vehicles travel within a short distance. The LOS path weakens as the distance between the two vehicles increases, and fading amplitudes tend to be Rayleigh distributed which dominance of NLOS path. Therefore, the goal of this study is to evaluate the CAM message broadcasts within safe distance between the vehicles under Nakagami-m radio channel condition. Furthermore, this research will be carried out in Release 14, also known as LTE-V2X, but only in mode 3 which the cellular network selects and manages the radio services used by vehicles for direct V2V communications.

2. Related Work

Intelligent Transportation System (ITS) has recently received a lot of attention as a critical component for our society, in part due to the demand of the transportation development. ITS aims to provide drivers with a safe, secure, and smart travel experience that includes technologies and autonomous devices that collaborate with minimal human interaction. In 5G era, Release 14 known as LTE-V2X as the starter of 5G standardization in 3GPP. Release 14 has introduced two modes of communication to support the communication between vehicle-to-vehicle, which are mode 3 and mode 4. In mode 3, for direct V2V communications, the cellular network selects and manages the radio services used by vehicles while in mode 4, vehicles autonomously select the radio resources for their direct V2V communications.

According to the research work done by [3] on passenger vehicle delay, the analyst vehicle following security in the passenger vehicle, the time gap was used instead of time headway because time gap represents the actual time available for the following vehicle to avoid a rear-end collision with a leading vehicle performing a uniform deceleration in a VANET. In a densely trafficked area, the concept of a time gap in VANET serves as a warning system to following vehicles, preventing collisions with leading vehicles. When both vehicles apply the emergency brakes due to unexpected conditions, TGFD is defined as the accompanying vehicle's base time to decelerate and safely stop without colliding with the primary vehicle. According to the findings of the study [3], time-gap is a critical factor for safety, and proper time-gap calculations can lead to better performance and allow for in-vehicle distraction. In the VANET environment, the TGFD model for passenger vehicles must consider the braking time of a passenger vehicle as well as the time factors of time perception, time decision, time broadcast, and time propagation. Author [4] studied shadow fading model targeting system simulations based on real measurements in urban and highway environments using the Nakagami radio channel. With the use of video footage taken during the measures, the measurement data is divided into three categories: line-of-sight (LOS), obstructed line-of-sight (OLOS) by vehicles, and non-line-of-sight due to structures. According to the findings, vehicles that block the LOS cause an extra average attenuation of around 10 dB in the received signal intensity. However, the author does not mention properly about the dissemination of safe message between vehicle with safe distance.

The existing works mostly address safety messages which CAM messages transmit between vehicles, but they do not clearly mention safety messages that are broadcast between vehicles within a safe distance under the Nakagami radio channel. Therefore, majority of this research fails to mention or claims that the safe distance between vehicle must be considered when sending and receiving a message under Nakagami radio channel.

3. Methodology

Figure 1 shows CAM message transmission in C-V2X with three different radio channel fading models. The Rician shows the vehicles exchanging CAM messages in the Rician radio channel, in which the LOS is the dominant radio signal component. The Rayleigh scenario shows the vehicles communicating through a Rayleigh radio channel with NLOS dominance. Nakagami radio channel is a generalized distribution that represents both line-of-sight (LOS) (or Rician channel model) and non-line-of-sight (NLOS) (or Rayleigh radio channel) components. In V2V, when vehicles broadcast or exchange CAM messages between them, these different radio channels exist between any transmitter and receiver that may degrade or improve reception. There can be multiple NLOS signal components depending how extreme the channels are between vehicles especially in urban environment, or there can be a dominant LOS signal component and several NLOS signal components. The NLOS state occurs when buildings, trees, hills, mountains, vehicles, and high voltage electric power lines block the LOS path. In other words, there are obstacles or multipath components (MPCs) between transmitter and receiver with the radio signals travel two or more paths to reach the receiving antenna due to atmospheric effects such as reflection, refraction, diffraction, and scattering, as well as equivalent effects from other natural or man-made terrestrial objects and cause the NLOS state. This situation can affect the signal and increase interferences and cause the message to arrive late at the receiver (PRx). These delayed copies of the signal cause self-interference at receiver (PRx), which can be either constructive or destructive. In vehicular communication environment, vehicles themselves can become the source of scatterers and interferers causing multipath signal components arriving in multiple directions at the receiver. Therefore, this study will be focusing more on evaluating CAM message dissemination between vehicle while maintaining proper safe distance or safe time gaps between them to avoid collisions at the desired speed under Nakagami-m fading channel model environments only in Rel-14 mode 3. It is important to mention here Nakagami-m radio channel model is used as it represents both extremes of the Rician and Rayleigh channel models. Different shape factor or (m value) represents different radio channel conditions either having only the LOS or only NLOS signal components or both LOS and NLOS signal components. The study will evaluate most importantly if CAM message dissemination between vehicles is impacted by the radio channel conditions, and eventually the safe distances to be maintained. Initial studies have indicated that with higher vehicle speeds, longer distances (longer time gap) must be maintained between vehicles to ensure vehicle safety, the performance of CAM message dissemination drops. With more extreme radio channels between vehicles, the performance of CAM message dissemination is expected to be worse thus reducing further vehicle safety.

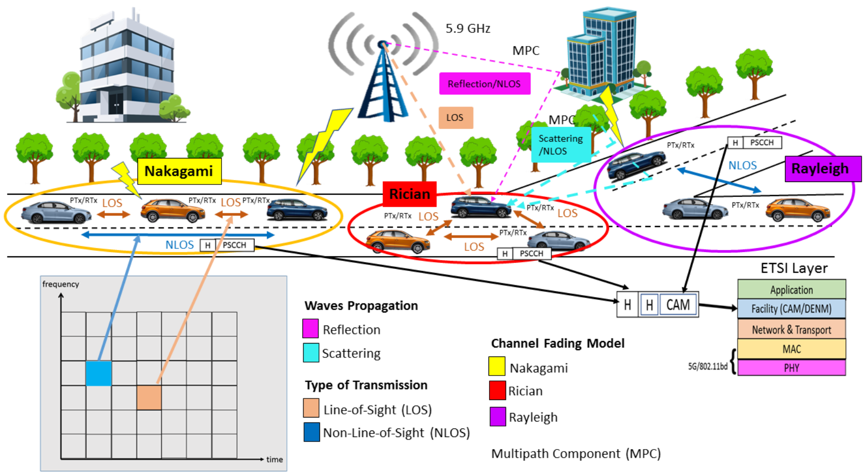

Fig. 1. Message Transmission Scenarios in Various Channel Fading Models

In Figure 1, the Nakagami fading model is the most popular radio channel model used in V2V communication modelling. The m value, also known as the shape factor, determines the environment of the Nakagami-m fading model. If the environment is Nakagami distributed, the analogous instantaneous power is gamma distributed. The parameter m is the shape factor of the Nakagami or gamma distribution. Rayleigh and Rician fading are included under Nakagami distributed. In the exceptional cases of m = 1 and m < = 1 for extreme Rayleigh fading, the Rayleigh fading is recovered with an exponentially distributed instantaneous power, which is dominant over the NLOS component. When m > 1, signal strength fluctuations are decreased, which is known as Rician fading, and the LOS component is dominated. Fig. 2. shows how vehicles communicate in a LOS and NLOS environment by sending CAM messages from transmitter to receiver. In Nakagami-m fading, the m value has an impact on the packet delivery ratio (PDR) and throughput. If m > 1, the PDR and throughput values will be higher than if m = 1. This is due to the fact that m > 1 represents Rician fading, which is dominant with LOS components and results in a stronger signal than m = 1, which is dominant with NLOS components and is known as Rayleigh fading. Because of additional interferences between transmitter and receiver, such as reflection, scattering, or MPCs, the value of m < = 1 will result in a drop in PDR and throughput. Therefore, this study will evaluate the performance of PDR and throughput using m value which are m = 0.5 and m = 1 under Nakagami-m fading channel model. Under higher density of vehicles where vehicles may move at slower speeds, the performances may get worse due to NLOS signal components arriving at each vehicle receiver becoming the dominant factor. PDR and throughput in this situation get reduced due to the NLOS influence (interference dominated channel conditions) even though vehicle safety can be maintained. In situations where vehicles move at higher speeds, and the distance must be kept apart higher, PDR and throughput performances are affected by both the distances between vehicles and the influence of NLOS radio channel. The NLOS radio channel in this situation degrades further the reception of CAM messages.

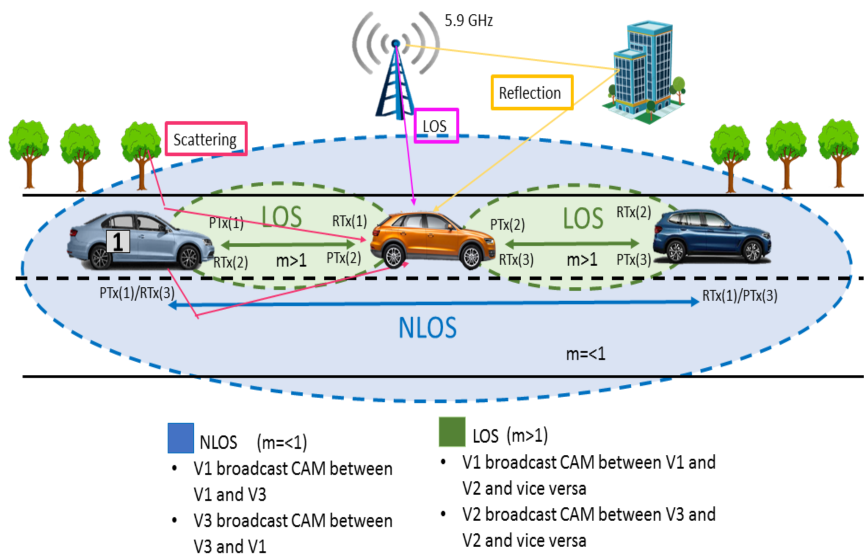

Fig. 2. Message Transmission Scenarios in Various Channel Fading Models

If Vehicle B disseminate a CAM message, Vehicle A, C, F and G will potentially receive the sent CAM message with the good SINR/SNR since there are LOS radio channels between them and Vehicle B. However, there are also some multipath signal components from Vehicle B to Vehicles A, C, F and G, which may degrade or further improve reception. Vehicles A, C, G and F can also reflect the signals causing multipath. All other vehicles in Fig. 3., Vehicles J, E, D, H and I potentially have no LOS reception of the sent CAM message from Vehicle B. For example, Vehicle D may receive the CAM message from Vehicle B in multipath directions either reflected or scattered by other vehicles. It is shown that, the CAM message received is composed of signal shadowed by Vehicle C, reflected by Vehicle G and scattered by Vehicle H. The higher the density of vehicles on the road, the more the concentration of multipath NLOS signal arriving at Vehicles J, E, D, H and I for the single CAM message broadcasted by Vehicle B. The concentration of NLOS signal components under high vehicle densities and under extreme Rayleigh radio channel may rise to lower SINR/SNR due to higher interference components.

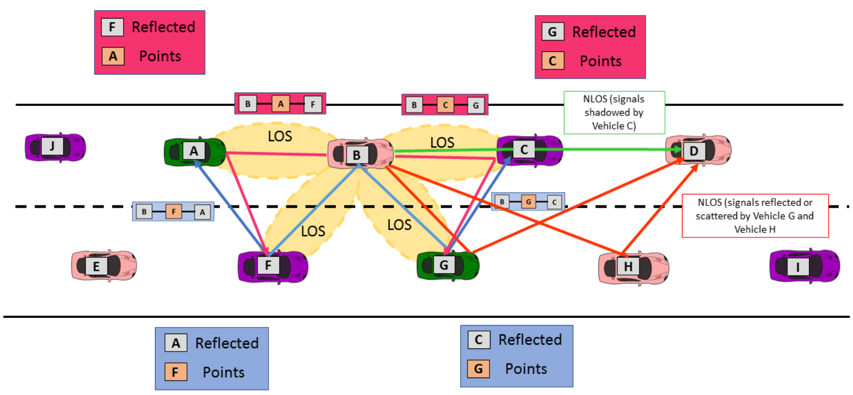

Fig. 3. LOS and NLOS components

Fig. 4. shows the message dissemination between two vehicles which are V1 and V2. The 'a' is referring to a safe avoidance time (AT) and 'b' is referring to an actual avoidance time (AT) between these two vehicles. While V1 and V2 broadcast a message, both vehicles will transmit and receive messages at a safe distance. However, if time a < b, the AT time was not safe, and a collision between these two vehicles might be occurred. In actual work, it does show even if a message successfully transmits, if it does not maintain an appropriate distance (AT safe), it considers unsafe for vehicle to move in the lane. As a result, the goal for safe vehicle movement is to maintain a proper distance. If the PDR was affected or the result was lower than expected at the end of the study, it signifies that some of the vehicles failed to send or receive the message during the broadcast. For the vehicle to transmit and receive a message at a safe distance, the time gap(s) settings must be included.

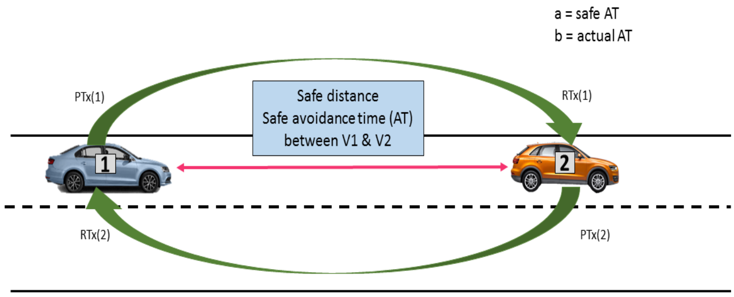

Fig. 4. V2V Communication within Safe Time Gap

As shown in Fig. 5., if there is another vehicle in between the vehicle, it will shadow the reception of the LOS signal component and potentially will absorb the signal energy and still cannot received the CAM message due to NLOS interference, which may degrade the received signal either partially or full cancellation of signal. Therefore, the situation is considered unsafe due to the CAM message not received by other vehicles although the safe time gaps are maintained. The situation above may get worse if the safe distance between vehicles is increased due to an increase in the travelling speed. When safe distances increased, the reception of the main signal component (energy) from LOS path gets reduced due to increased free space path losses, and this further becomes severe if that LOS signal component's energy is shadowed, and also composed of multiple NLOS signal components.

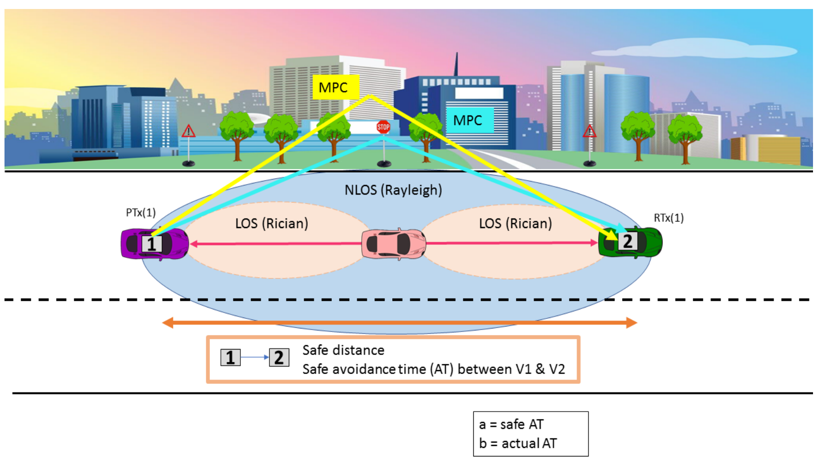

Fig. 5. NLOS Multipath Components within V2V communication

4. Results

This study's findings and analysis were based on a specific scenario. In order to measure the results, other simulation parameters must also be set. The parameter values for this research were chosen in order to achieve the required results and analysis. The vehicle density will be set to 20, 30, and 50 with varying vehicle speeds ranging from 50 to 120 kilometers per hour. Furthermore, the shape factor for this investigation will be set to m = 0.5 and m = 1 for the Nakagami-m fading radio channel. The alpha value will be set to 2. The simulation settings have a bandwidth of 20 MHz. The 5.9 GHz will be used in this method as carrier frequency since it is 5G-V2X. When a CAM message include the CAM packet is broadcasting from transmitter (PTx) to receiver (PRx) with power level which is maximum 23 dBm as mentioned in standard 3GPP and ETSI. The CAM packet will be sent to CAM header and it will go through ETSI layer that contain application, facility, network and transport, MAC and PHY layer and then send CAM message to receiver (PRx). The road was supposed to be 7 kilometers long and two lanes in the same direction. The cell type was set to urban macro cell, the eNodeB count was set to 1, and the vehicle model was set to Krauss model.

Based on packet delivery ratio, Figure 6 shows the graph findings for several radio channel models, including Free Space Path Loss and Nakagami radio channels (PDR). The vehicle density was set to 20 and the UE transmit power was set at 23 dBm. At 50 km/h, the PDR for the Free Space Path Loss radio channel is 44.31%, which is higher than the 44.10% for the Nakagami radio channel. The PDR of the Free Space Path Loss radio channel is 43.99% at 90 km/h, which is slightly higher than the PDR of the Nakagami radio channel, which is 43.97%. According to the graph, PDR performs better under the Free Space Path Loss radio channel than the Nakagami radio channel. This is due to the fact that a radio channel with Free Space Path Loss has less interference than one with Nakagami.

According to Figure 7, the parameters for the Nakagami radio channel were set to m = 0.5 and m = 1, the UE power transmit was set to 15 dBm, the vehicle density was set to 30, and the default time gaps were set to 0.774 second, with distance of 4 meters for each vehicle speed. The PDR at 50 km/h is 37.88% at m = 1, which is greater than the PDR at m = 0.5, which is 37.44%. PDR at m=1 is 37.55% at 120 km/h, which is higher than PDR at m=0.5, which is 37.39%. As a result, it has been shown that the CAM message is successfully delivered between vehicles with better PDR at m = 1 due to less NLOS component interferences.

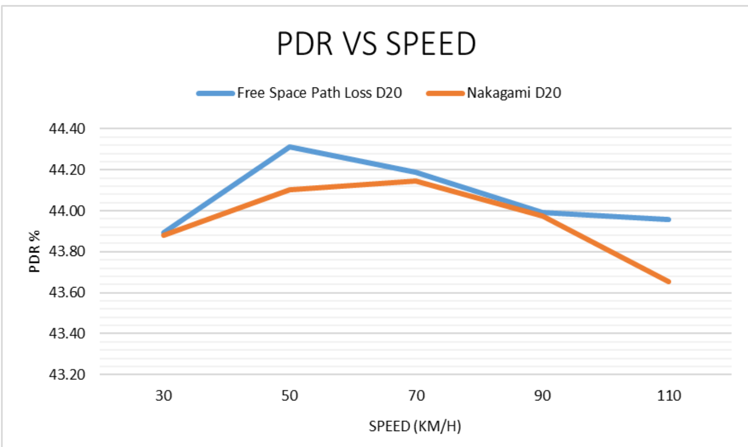

Fig. 6. PDR versus Different Radio Channel Models

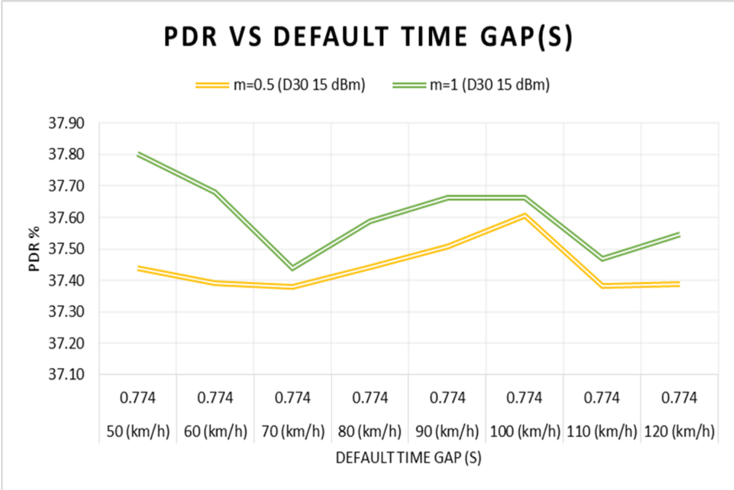

Fig. 7. PDR versus Default Time Gap

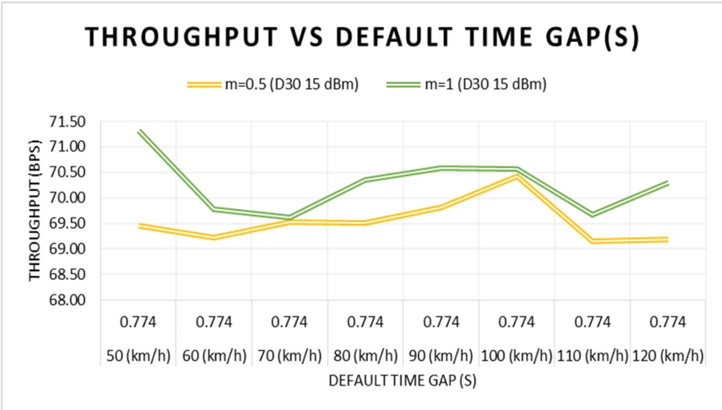

Fig. 8. Throughput versus Default Time Gap

According to Fig. 8., the parameters for the Nakagami radio channel were set to m = 0.5 and m = 1, the UE power transmit was set to 15 dBm, the vehicle density was set to 30, and the default time gaps were set to 0.774 second, which distanced each vehicle speed by 4 meters. The graph shows that the throughput at 50 km/h is 71.33 bps at m = 1, which is higher than the throughput at m = 0.5, which is 69.46 bps. In addition, at 120 km/h, the throughput at m=1 is 70.30 bps, which is higher than the PDR at m=0.5, which is 69.20 bps. Therefore, it has been proved that the CAM message is successfully sent between vehicles with greater throughput at m = 1 due to less NLOS component interferences.

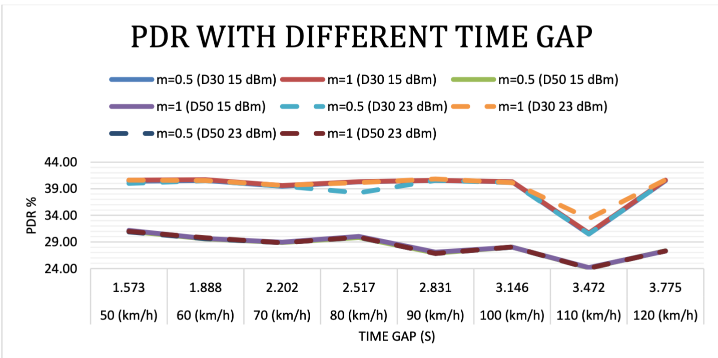

Fig. 9. PDR with Different Time Gap

In the VEINS simulation, the graph of PDR with different time gaps settings is shown in Fig. 9. Under the Nakagami radio channel, the parameters were set to m = 0.5 and m = 1, the UE power transmit was set to 15 dBm, and the vehicle density was set to 30 and 50 vehicles. The PDR at m = 0.5 with 30 vehicles density at time gap 1.573 second = 50 km/h is 40.39%, which is lower than the PDR at m = 1 of 40.60%, as shown in the graph. The PDR is lower for 50 vehicle density when m = 0.5, with a value of 31.01%, than when m = 1, with a value of 31.18%. Apart from that, with 30 density vehicles and time gaps of 3.472 seconds = 110 km/h, the PDR at m = 0.5 decreased to 30.48%, compared to 30.67% at m = 1. For a vehicle density of 50, the PDR is also decreased when m = 0.5, with a value of 24.13%, but the PDR when m = 1 is 24.19%.

When UE transmit power was set to 23 dBm, value of shape factor, m = 0.5 and m = 1, and the vehicle density was set to 30 and 50 vehicles. The PDR at m = 0.5 with 30 vehicles density at time gap 1.573 second = 50 km/h is 40.01% which is lower than the PDR at m = 1 of 40.60%, as shown in the graph. The PDR is lower for 50 vehicle density when m = 0.5, with a value of 30.88% than when m = 1, with a value of 30.99%. Apart from that, with 30 density vehicles and time gaps of 2.202 second = 70 km/h, the PDR at m = 0.5 decreased to 39.51% compared to 39.65% at m = 1. For a vehicle density of 50, the PDR is also decreased when m = 0.5, with a value of 28.84%, but the PDR when m = 1 is 28.87%. As a result of the increased vehicle density and decreased m value, the PDR will drop, which will have an impact on the CAM message broadcast between vehicles.

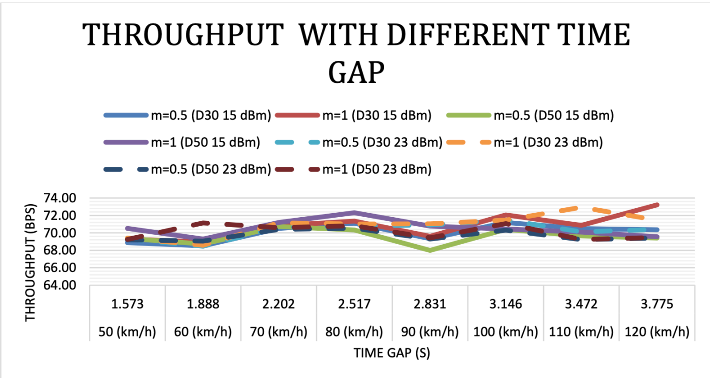

Fig. 10. Throughput with Different Time Gap

In the VEINS simulation, the graph of throughput with different time gaps settings is shown in Fig. 10. Under the Nakagami radio channel, the parameters were set to m = 0.5 and m = 1, the UE power transmit was set to 15 dBm, and the vehicle density was set to 30 and 50 vehicles. The throughput at m = 0.5 with 30 vehicles density at time gap 2.517 second = 80 km/h is 71.10 bps, which is less than the throughput at m = 1 of 71.34 bps. When m = 0.5, the throughput with 50 vehicle density is 70.33 bps, and when m = 1, the throughput is 72.31 bps. Other than that, with 30 density vehicles and time gaps of 2.831 second = 90 km/h, the throughput at m = 0.5 was reduced to 69.34 bps, compared to 69.62 bps at m = 1. When the m = 0.5, the throughput drops to 67.99 bps, compared to m = 1, the throughput is 70.77 bps.

When UE transmit power was set to 23 dBm, value of shape factor, m = 0.5 and m = 1, the UE power transmit was set to 23 dBm, and the vehicle density was set to 30 and 50 vehicles. The throughput at m = 0.5 with 30 vehicles density at time gap 2.831 second = 90 km/h is 70.92 bps, which is less than the throughput at m = 1 of 71.03 bps. When m = 0.5, the throughput with 50 vehicle density is 70.33 bps, and when m = 1, the throughput is 72.31 bps. Other than that, with 30 density vehicles and time gaps of 3.775 second = 120 km/h, the throughput at m = 0.5 was reduced to 70.40 bps, compared to 71.46 bps at m = 1. When the m = 0.5, the throughput drops to 69.40 bps, compared to m = 1, the throughput is 69.47 bps. As a result of the increased vehicle density and decreased m value, the throughput will drop, which will have an impact on the CAM message broadcast between vehicles.

The distribution of CAM messages across V2V communication through the Nakagami radio channel has a greater impact on PDR and throughput than the Free Space Path Loss radio channel, depending on the shape factor, speed, time gap, UE transmit power and vehicle density. According to the findings, the packet delivery ratio (PDR) and throughput were impacted by the relationship between vehicle time gap and speed. On the worst situation of Nakagami with more NLOS components, the PDR and throughput are worse with m = 0.5 than with m = 1. Because there are more MPCs such as scattering, reflection, and diffraction, the signal will be absorbed, and the message will not be received by the receiver due mainly to NLOS interference. As a result, it may be demonstrated that the scenario is unsafe because the CAM message is not received by other vehicles to exchange messages in order to ensure safety; nevertheless, even when they are maintaining safe distances between them under the Nakagami radio channel, this does not guarantee safety.

5. Conclusion

This research aims to study the different radio channel characteristics in V2V communication environment that relates to a CAM message dissemination and vehicle safe distance and to evaluate the performance of relationship between PDR, throughput and transmit power proportional to safe time gaps under Nakagami-m radio channel The performance of PDR and throughput was impacted when the parameters of different shape factors, m = 0.5 and m = 1, vehicle density, time gaps settings, and UE transmit power were implemented in the simulation, as seen in all of the graph plots. The PDR and throughput are worse under the Nakagami-m radio channel with shape factor, m = 0.5, than the PDR and throughput under shape factor, m = 1. The transmission and reception of messages between vehicles is not complete due to high concentrations of NLOS components that interfere with the signal, resulting in communication loss although the vehicles maintaining safe time gaps.

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