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Handover mechanisms in VMC systems: Evaluating the reliability of V2X as an alternative to fiber networks in handover areas

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Abstract. Despite advances in communication ways in autonomous driving, including Vehicle-to-Vehicle Communication (V2V), Vehicle-to-Everything Communication (V2X) and Vehicular Micro-clouds (VMC). In this paper, the potential of V2X as a substitution for the artificial connections (mainly optical-fiber cables) between base stations and edge servers are discussed. The quality and latency of communication in Handshake--referring to the scenario of cars moving from one station's operation scope to another one's, is mainly concerned, within the frame of VMC. Additionally, the communication performance, referring to latency performance and data rate performance, for both pure V2X and a combination of LTE and V2X are simulated and analyzed using a Python simulator. Finally, the test results showed that the performance of pure V2X Communication is always superior compared with any combination in every categories as the density of cars gradually increase, which confirms that replace physical inter-station-cables as V2X communication is serious possibility.

Keywords: Communication Delay, Vehicular Micro-Clouds, Vehicle-To Everything Communication.

1. Introduction

As the demand for more intelligent and autonomous cars show a significant increasing trend, auto manufacturers are more motivated to renew communication equipment. In the past decade, Vehicle-to-Vehicle Communication (V2V) and Vehicle-to-Infrastructure Communication (V2I) is developed [1], which is the first light of morning for autonomous driving. To make cars smarter, Vehicle-to-Everything Communication (V2X) is developed. Different from the former, V2X can handle the tasks for both V2V and V2I together at a high data rate. That means, V2X is an efficient and reliable technology for vehicle communication even in complex road conditions or traffic congestion, which is helpful to build a safe and talented traffic system [2].

However, reliable communication is not the whole. When cars are moving on the roads, everything is dynamic, which means everything is constantly varying. The cars need to make adjustments and readjustments frequently, so the request for sufficient data rate is also dynamic. Thus, it is essential to propose a mechanism that could distribute the data rate required for each car, store the parameters of each car, and maintain that communication is always stable. Therefore, Vehicular Micro-cloud emerges as it has just been required [3]. VMC is regarded as a virtual edge server, the VMC is formed by a cluster of hardware and computers in cars on the road, the cars could be either moving or parked. VMC helps cars to gather data such as the location, velocity and acceleration of other cars. Then, one or several cluster heads are selected, responding to data transmission between different clusters and uploading to macro-clouds. Furthermore, a chain of command is established, and there will be detailed information on the sequence of requests, the amount of requests and what information in this cloud is needed to be called. Finally, the level of data will be graded, which means the data gathered from cars and sensors will be decided to report to the central macro cloud or just stay at cluster head level. With VMC, the efficiency of V2X is largely increased [4]. In relay races in Olympiad, the most important thing is handover and takeover, and so do vehicular communication. Vehicular communication is just another form of relay race, when cars are moving from one station’s operation region to another one, not only the actual car is moved, but the virtual data is also moved. That is called a handshake. The communication performance of pure V2X and a combination of LTE and V2V in the scenario of a handshake is simulated in a Python simulation program. Communication performance is divided into two parts: latency performance and data rate performance. By comparing the results of simulations of the two different groups, the potential of replacing the physical inter-station-cable with V2X is analyzed by comparing the performance of pure V2X and the combination of V2V and LTE technology. If the performance of pure V2X always outweighs that of the combined one in multiple car densities, then, the hypothesis is practical.

The contributions of this study are to present a review of reliable tools that could be grabbed to improve the quality of vehicle communication and propose a protocol for the possibility of removal of physical inter-station cables. In section 1, a brief introduction to the frame and concepts are provided. In section 2, the concern is introduced and the basic model of our protocol is established, as well as the formulation of the problems. In Section 3, the proposed framework is shown in four stages, and the simulation results are analyzed in Section 4, including delay performance under different conditions and data rate reliability. The conclusion proposal for replacing the cable is also to be discussed. Section 5 contains the conclusion.

2. System model

In this section we describe the concept of our model, which is a VMC system based on the idea[1] of utilizing fog computing to compute the resources of nearby vehicles to enable distributed computing This enables vehicles to share resources, such as processing power and storage, and collaborate to perform tasks more efficiently.

2.1. Introduce concern

The VMC system is a promising solution, and we want to devise a model to provide reliable and efficient communication to service vehicles in highly dynamic and dense traffic environments. Here is essential to introduce two metrics of our model is latency performance and data rate performance.

Latency performance refers to the time it takes for a request to be processed and responded to or the time it takes for a packet to travel from the source to destination. Latency performance can be affected by various factors such as the distance between source and destination, the processing delay of each node and the channel quality of the information convey between edge stations, which an original idea is whether a fibre is connected between two edge stations, and that will talk to a later section.

The data rate performance, on the other hand, refers to the amount of data that can be transferred between vehicles over a wireless channel in a given amount of time. These two factors are essential to ensure reliable communication and high data throughput between vehicles. Data rate performance can be affected by various factors such as the bandwidth of the wireless channel, modulation schemes and interference from other nodes.

We take both of their reliability in our model, and it is an important measure of the system's ability to provide consistent and efficient communication services. Latency performance and data rate performance are two key factors that affect the reliability of our model. A latency-sensitive application requires low latency, meaning that packets should arrive at their destination as quickly as possible. A data-intensive application requires high throughput, which means that a large amount of data should be transmitted in a short period. Therefore, to ensure the reliability of our model, both latency performance and data rate performance should be optimised. In addition, the system must be designed with fault tolerance in mind so that it can continue to operate even in the event of failure or interruption.

2.2. Basic model

This basic VMC system consists of two main components: data collection and cloud processing. The data collection layer is responsible for acquiring data from the sensors on the vehicle and transmitting it to the cloud processing layer. The cloud processing layer performs cooperative sensing algorithms that fuse the data to generate a more accurate representation of the environment and improve the safety and efficiency of the vehicle network.

The edge server is an important component in this system, responsible for coordinating the communication and computational tasks of the vehicle sensing system. The edge server is located near the vehicle network and is easily accessible to senders and workers via wireless communication. Through the coordination of the edge server, the sender and worker can efficiently complete data transmission and processing, improving the performance of the entire vehicle awareness system.

A sender is a vehicle equipped with sensors that collect data from its surroundings, such as traffic, weather and road conditions. The sender communicates with the edge server to process the collected data. At the same time, the edge server is responsible for transmitting the data to the worker so that he can carry out further data processing and analysis. Through collaborative sensing with the worker, the sender can obtain more accurate information about the environment and thus gain a better understanding of the surrounding roads and traffic.

The worker is a computing device located in the cloud and is responsible for receiving data from the sender and performing further processing and analysis, such as tasks such as data fusion, feature extraction and object detection. Depending on their availability and processing power, the edge servers assign tasks to different workers to maximise the efficiency and performance of the overall vehicle awareness system. Workers can better understand their surroundings and provide more accurate data analysis and predictions through collaborative sensing with senders and edge servers.

The receiver is the vehicle that receives the processed data from the worker via the edge server. The receivers use this processed data to improve their perception of the environment and make better decisions, such as planning the best route to travel and avoiding traffic congestion. Through collaborative sensing with workers, receivers are provided with more accurate and real-time information about their environment and are thus better equipped to deal with different driving situations and road conditions.

System parameters and performance indicators are also very important in the overall vehicle sensing system. System parameters include the number of senders, workers and receivers, packet size, transmission and processing rates. Performance metrics include communication latency, computation latency and end-to-end delay. The value of parameters as TABLE 1 is as follow:

Table 1. Basic value of VMC system.

Parameter	Value	Parameter	Value
LTE_max	27000000 b/s	Data_per_sender	5000 b/s
V2V_max	16000000 b/s	Comp_per_send	500000000
Sender_share	0.8	Comp_power_V2V	1000000000
Receiver_share	0.8	Comp_power_LTE	5000000000

Model optimisation: To further improve the performance and efficiency of the system, we propose a new algorithm based on the existing model [5] that considers the incoming receiver to further improve the processing speed and accuracy of the system.

2.3. *Formulations and basic result*

We build on this system architecture [5], in which vehicles equipped with various sensors collect data about their surroundings and transmit them to a cloud server, and on the basic concept of using the computational resources of nearby vehicles for distributed computing, to improve on a system in which the algorithm currently used for the original architecture does not take into account the receiver, which may affect the performance of the system. Therefore, we propose a new algorithm that takes into account the receiver, focusing on a single VMC at the base, which then evolves into a large VMC.

The original authors evaluate the proposed architecture using simulation methods and show that the cooperative perception algorithm can improve the accuracy of the environmental representation compared to the single-vehicle perception. They also demonstrate that the proposed architecture can handle a large number of vehicles and scales well as the number of vehicles increases. The algorithm we propose on this basis considers a limited scenario where there is a part of the car acting as a receiver. This can help to increase the efficiency of the system and reduce the processing time. In addition, we consider the locations of the sender and receiver and that the locations of the sender and receiver are relatively fixed, with the sender at the front of the road and the receiver at the back of the road. This can help reduce interference between the sender and receiver and improve the overall performance of the system.

To evolve the single VMC into a VMC road line or even a large VMC network, several challenges are to be faced. First and foremost, the consideration of the coverage range of VMC, either scale up each VMC model or increase the number of servers, to support the tasks of communication and coordination among larger numbers of vehicles. Second, optimizing resource allocation, role assignment and task scheduling is indispensable to adapt to multiple situations, such as different traffic conditions, surge or plummet in the number of cars and intersections of roads. Also, the process of exchanging such extensive information has to be efficient when each vehicle travels from one VMC to another.

Specifically for the last challenge, all the corresponding information needs to be synchronously transmitted from one edge server to another during the shifting of vehicles between clouds. In traditional cases, considering the latency of wireless transmission and multiple sources of interference modern vehicles always carry, such important transmissions typically use wired media such as fibre optic. However, in practical applications, the usage and maintenance of wired media cost too much. To address such challenges, we continue to improve on the originally distributed algorithm, allowing it to optimise resource allocation and task scheduling in large VMC models. Our algorithm will be designed to take into account communication and coordination issues between VMCs and it will be able to adapt to different traffic conditions and network congestion. We will use simulated experiments to evaluate the performance of the proposed algorithm to demonstrate its effectiveness and scalability. The goal is to design a new algorithm that considers receivers in a VMC model and to develop a distributed algorithm that can optimise resource allocation and task scheduling in a large VMC model.

3. Proposed Framework

3.1. Basic Model

The basic model of a VMC system in this article considered multi-station scenarios, which are dependent on the combination of two overlapping base stations (or edge servers). While the system must also contain an extra area to allow the servers to respond to a fast handover, that is, alert areas.

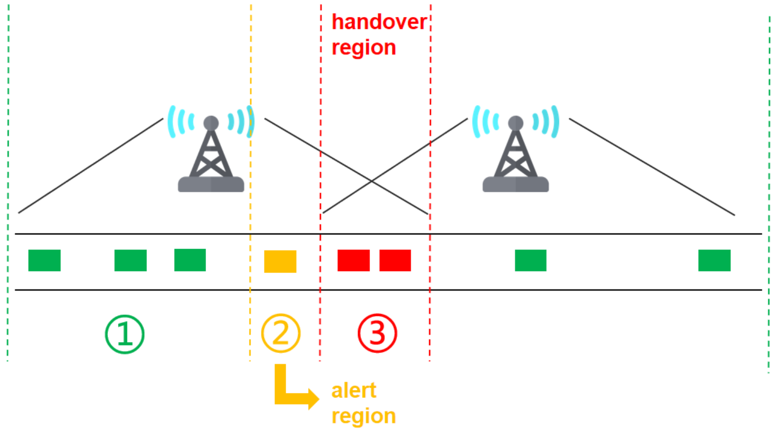

Figure 1. Basic VMC handover model.

As demonstrated in Figure 1, the system is divided into three main categories. In category one, the vehicles serving basic purposes such as basic senders, and basic receivers, or is null. This part of the system is also considered the main function, where abundant information is sent and gained. Position two, as mentioned earlier, is the alert area. This part mainly serves the system by leaving out enough space and time for the next station to be informed about upcoming vehicles. By this far, not only the basic information exchange occurs, but also additional confirming information. The size, and commuting rate required for this confirming information depends on the type of protocol selected. The third area, where the station overlaps, is the beneficial position for data exchange from station one to another since it has access to all the cars and stations in range one and similar conditions in range two. Many VMC papers do not consider the receiver as a contributor to the network, but in this article, the receiver is considered due to its important role in the system. By doing so, part three will act as the bridge of information flow to the receivers, which is a significant amount of a data rate that needs to be considered in modulation. This is why taking the third area as a possible alternative pathway for transmitting data is the optimal solution.

It is not hard to see that different protocols must be considered before any modulation take place. In this case, traditional LTE and V2V links are considered, while V2X (vehicle to everything)[6] is another wise choice to be included. V2X is a fast, reliable, and a quick switching system which centralized IEEE 1609.4, IEEE 802.11p, and DSRC (Dedicated Short-Range Communication). V2X have its benefits, since it can run at unsilenced 5.9GHz bandwidth in short range within 1 kilometer, allowing it to gain explicit transmission rate and large capacity. Its advanced protocols also allow it to switch between nodes in a very short time, while V2V and LTE cannot.

3.2. Modulation and realization

In this part of the framework, a precise modulation process is suggested. Basic variables in VMC are considered first, and then additional variables are added in. In this modulation, the vehicle matrix, data pack volume, and computational power are randomized to find the data rate and computing power as a function of the number of cars (or car density).

The car matrix(1), as the most essential factor to be considered, is formed with this format:

$$\boldsymbol{Mc} = \begin{bmatrix} 1 & 0 & \cdots & 1 & 1 \\ 0 & 0 & \cdots & 0 & 1 \end{bmatrix} \tag{1}$$

Where:

'1' represent one vehicle and '0' represent no vehicle.

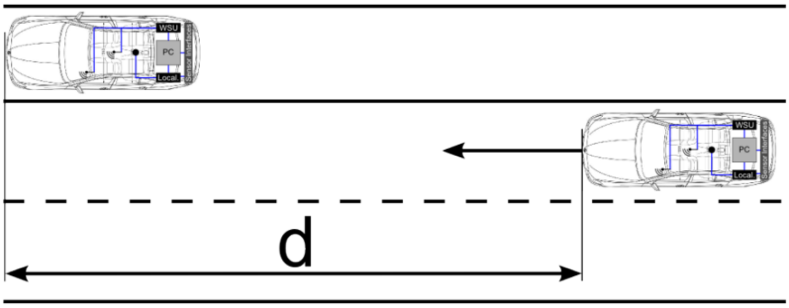

Figure 2. Car Distances [7].

Shown in figure 2, in this Vehicle matrix, distance is also modulated as d, we consider the vehicle distance for further development in reliability analysis.

The other factors, including the size of one packet sends, the amount of computing power required for a package is randomized, while the handover costs of computing and transmission rate is modulated by different protocols:

$$d_p = rand[4.5\,,5.5]\ (Kb) \tag{2}$$

$$c_p\ =\ rand[0.49\,,0.51]\ (GHz) \tag{3}$$

Where d_p (2) shows the data amount per one package, and c_p (3)shows the amount of computing rate required for one package, and the handover costs of computing and transmission rate is modulated by different protocols.

Table 2. Protocol Reference [2].

Handover type	Data size (KB)	Computing rate (MHz)
LTE (d_{LTE})	2-4	200-400
V2X (d_{V2X})	4-8	400-800

Dividing the system into three areas, the computing power and transmission rate required can be considered as the sum of these three independent areas. Where the transmission rate and computing power of the first, second, and third area can be represented by d1, d2, d3, and c1, c2, c3. However, in part three, due to the presence of receivers, an extra flow of rate must be considered. Including the vehicle matrix, the final equation we get is:

$$D_n = \sum_{i=0}^{d_a} M_c[i] * d_p + n * M_c[i] * d_{(LTE|V2X)} + n_c * d_r \tag{4}$$

$$C_p = \sum_{i=0}^{d_a} M_c[i] * c_p + n * M_c[i] * c_{(LTE|V2X)} \tag{5}$$

Where in the equation (4), D_n is the data rate in the system considered as a whole, while C_p in the equation (5) represent the total computing power required for the system. In the equation (4), $n_c * d_r$ is the number of vehicles multiplies the data size of one package. This will give the amount of data received by the system (passing through area three). By having the total number of received rate and computing power, data is send through area three which can be furthermore modulated. Therefore, hypothesizing the replacement of interstation fiber can be tested.

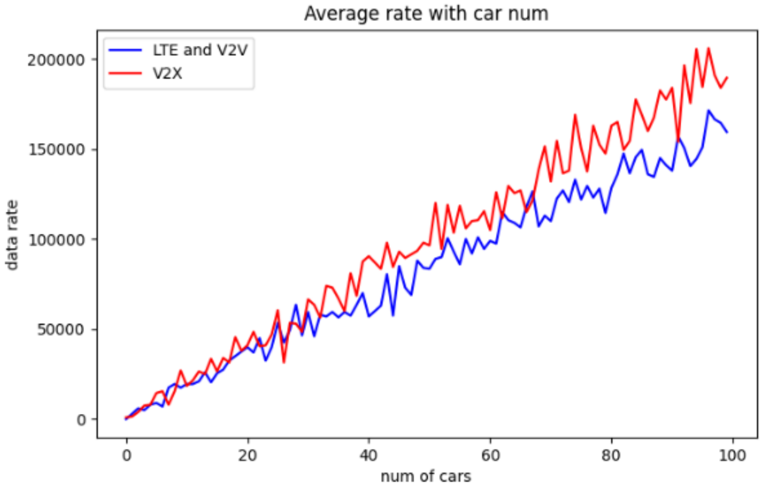

Figure 3. Average data rate for the car matrix.

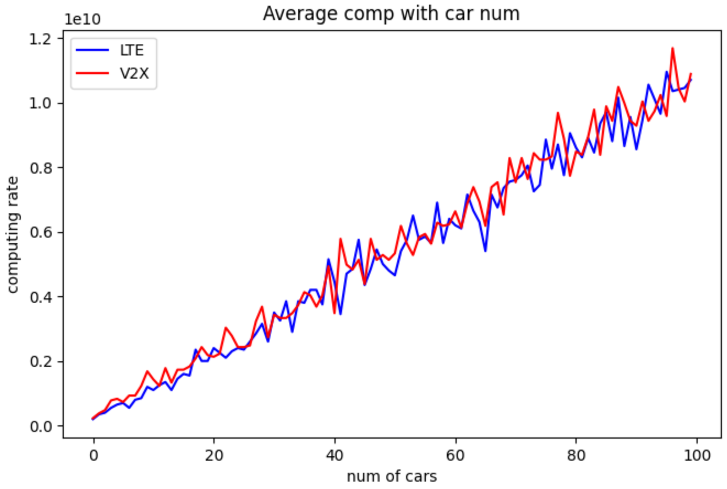

Figure 4. Average computing rate with the vehicle matrix.

In Figure 3 and Figure 4 data rate and computing rate is modulated in the present of randomized variables, but there is still a noticeable difference in LTE and V2V compared with V2X. V2X requires more capacity in communication due to its advanced protocols compared with simple protocols performed in LTE and V2X

4. Simulation Result

In our simulation, system delay and a overall reliability of communication are the main focuses. By system delay, we refer to the time it takes for the task(s) to travel from sender cars to receiver cars, and reliability is the test of whether our system, being a relatively complicated communication network, can operate without significant error rate and data loss.

In this section, we will first explain how our analysis of system delay is arranged, and show corresponding simulation results afterwards. This part is simulated under the assumption of a high-speed fiber presenting between the two edge servers to achieve fast information exchange. Then by further digging into the actual performance of reliability, we remove the fiber connection to examine if the functioning of the handover region would have had the potential to replace the use of fiber.

4.1. Considerations on Delay

As included in the basic model in Section II:

$$total\ delay\ = transmission\ delay\ +\ computational\ delay$$

To be noticed, while the method to calculate computational delay stays the same, that of transmission delay slightly differs. In our handover model, it is assumed that receivers care for all the information from all the senders in front of them. That is saying as a receiver, it may not only receive packages from senders which share the same base station with themselves, but from senders serviced by another base station as well. This implies that the transmission path of tasks are not unique:

$$path\ (a){:}\ sender\ in\ b.s.A \rightarrow b.s.A\ or\ worker\ in\ bsA \rightarrow receiver\ in\ b.s.A$$

$$path\ (b){:}\ sender\ in\ b.s.A \rightarrow b.s.A\ or\ worker\ in\ bsA \rightarrow b.s.B \rightarrow receiver\ in\ b.s.B$$

$$path\ (c){:}\ sender\ in\ b.s.A \rightarrow b.s.A\ or\ worker\ in\ bsA \rightarrow cars\ in\ handover\ region \rightarrow receiver\ in\ b.s.B$$

(b.s. is short for base station)

All the above indicate that the new transmission delay should include the transfer of processed data and consideration of multi-path communication.

In order to acquire a comprehensive analysis on the delay performance of our model, we focus mainly on four influencing factors: car density, tasks rate, the area of the handover region and the ratio of vehicles on the road that support the protocol used (i.e. V2V & LTE, V2X) or simply v2v penetration. Among them, v2v penetration is the most difficult one to control in practice if VMC is finally utilized in real life. It takes time for car industry to trust such technology and equip their car with V2V or V2X ability. Further, there’s the process of replacing cars in the society with new VMC-supported cars. As a result, the performance trend of VMC system over different level of v2v penetration is a crucial concern. To conform this point, we investigate the delay v.s. v2v penetration under the impact of all remaining factors.

Moreover, as delay sometimes is not representative enough, we put concerns on the amount of delay by each extra introduction of the task and define the reciprocal of it to be the transmission quality factor. Larger values of the quality factor indicates an overall higher communication efficiency within the system under that specific condition. In other sense, larger quality factor means the system supports higher task rate at certain delay constraint.

4.2. *Plots & Analysis*

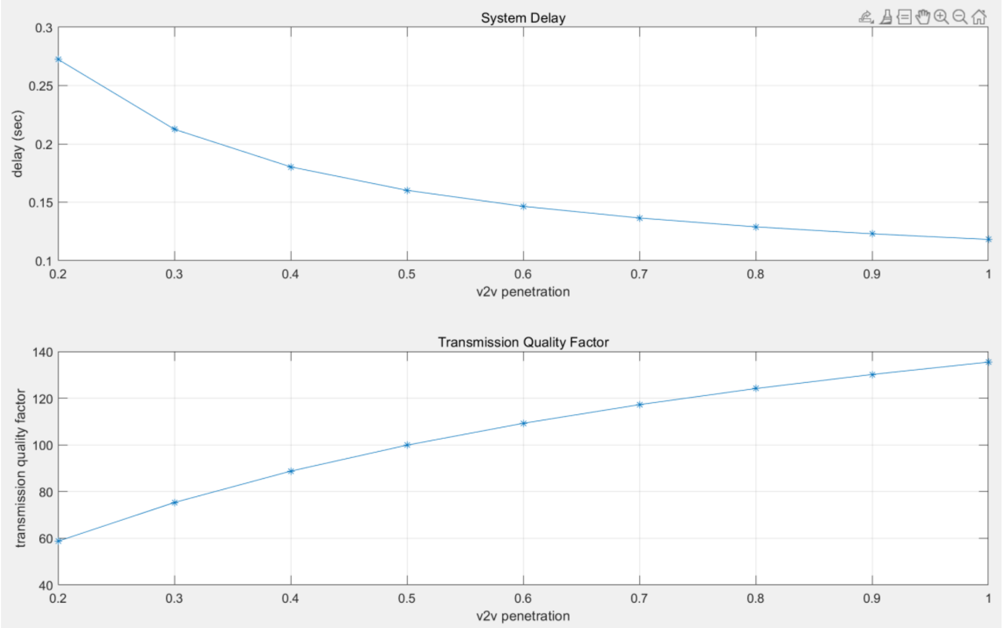

Figure 5. General behavior of delay and transmission quality v.s. v2v penetration.

The general behavior of delay and transmission quality factor along with changing v2v penetration is plotted in Figure 5. It is observed that increasing v2v penetration notably improves system delay, but the extent improvement drops when going to high v2v penetration level. Transmission quality behaves mostly the same as well.

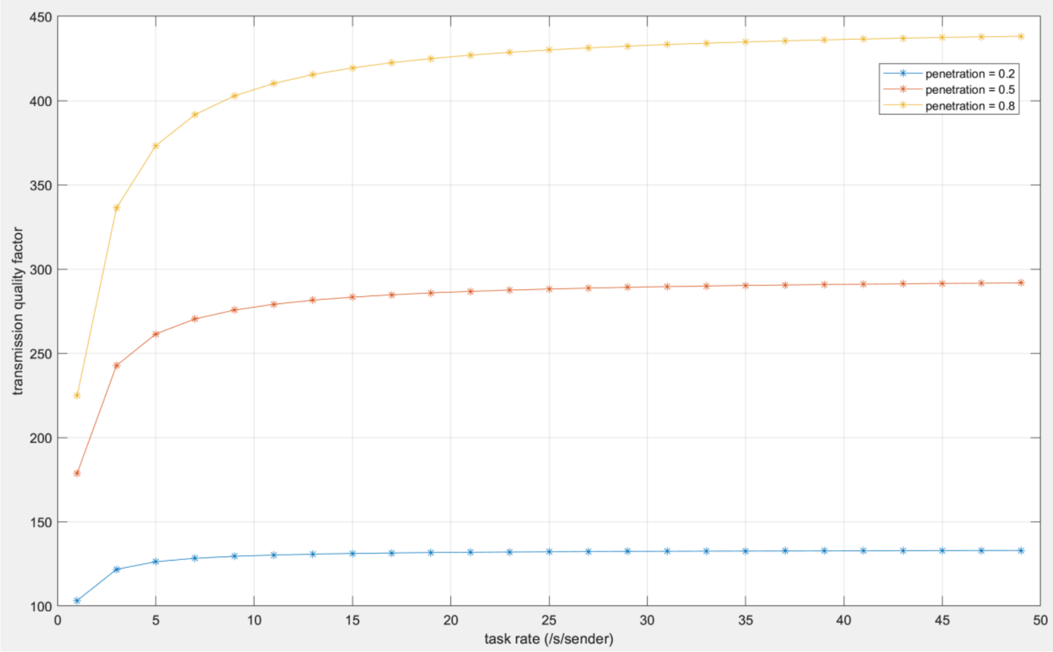

Figure 6. Transmission quality over task rates.

Regarding task rate, it is expected obviously that delay increases almost linearly with higher task rate, so we pay attention to the communication quality in this part. From Figure 6, we can see that the trend of the curve hurries up quickly at the very start, but settles very fast as well. In fact, we tried increasing the task rate to above 1000, and found out that there might be a difference of no more than 0.5 in quality factor with an increment of 2000 tasks per second. Even if the curve is proved to be divergent finally, it is reasonable to assume an upper bound of information transfer quality according to the performance. This also conforms to the fact that our system bears a capacity under different penetration level.

For the impact of the handover region area, or crossing range of the system, it turns out that increment of crossing range introduces nearly the same result as that of the task rate. This is because of the existence of fiber between the two base stations. With an extremely high-speed connection and not large enough car density (0.2 car density set for normal simulation condition), the cars in handover region, serving as an information-exchange bridge between two server-managed VMC region, cannot overpower the data rate of the fiber so that most of the data exchange is still done by the fiber connection. In addition to that, without a significant amount of receivers, there aren’t too much information needed to be transfer and the time required to do data exchange counts for only a pretty small proportion of the whole delay time. Consequently, the overall behavior of delay v.s. handover area resembles that of delay v.s. task rate very much.

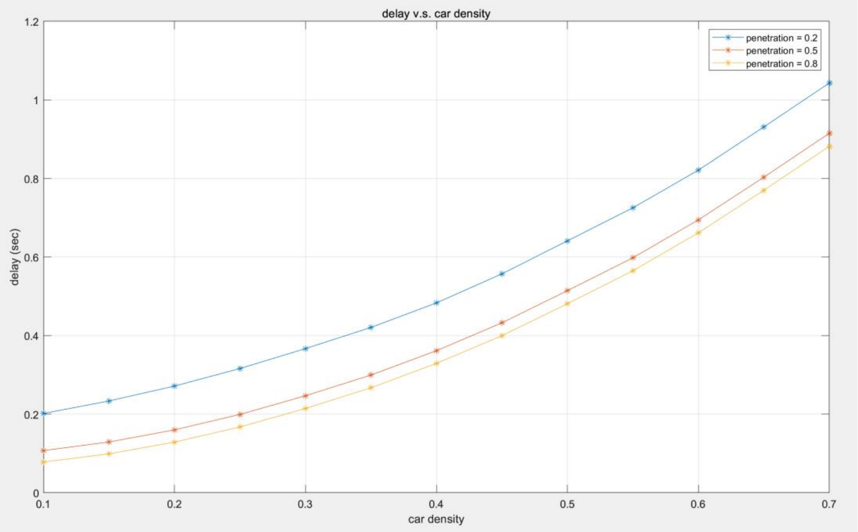

Figure 7. System delay trend over car density.

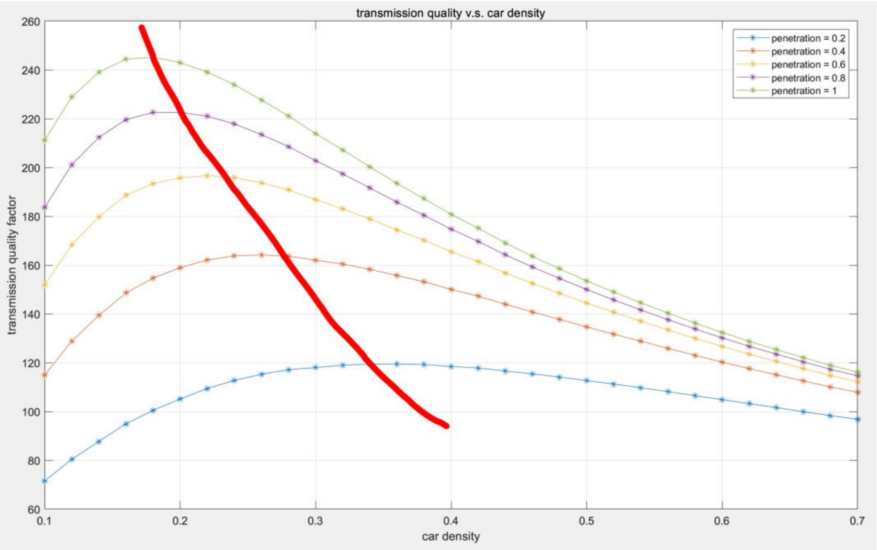

Figure 8. Transmission quality over car density & trend of max quality over different penetration level.

4.3. Reliablility Analysis

Coming to car density, things get a little bit interesting. At a first glance, it is to be noticed that in Figure 7, the general system delay grows, and grows at a higher rate with more and more cars on the road. This is due to the simultaneous increment of a number of senders which produce tasks and number of receivers which thirst for processed information. Then turn to the transmission quality factor performance in Figure 8, it is easy to observe that there is an increasing then decreasing trend. It is a convex curve where a maximum is expected. Furthermore, by plotting various curves of transmission quality over the car density under different penetration (red line in Fig. 4.4), we are able to connect the maximums of all the lines and draw a new curve, named the max-eff curve. Referring back to the start of this session, higher transmission quality tells us that with the same delay the system can attain a higher task rate, so quality factor can also be viewed as the efficiency of the whole system. Regarding that, this curve implies the exact car density value under different v2v penetration to achieve the best performance of delay per task in our system. Although our simulation is somehow restricted without considering some practical issues, this max-eff curve is still meaningful in the various sense if we can expected a max-eff curve for most developed multi-VMC model. Imagine the day when VMC is introduced to the society and being exploited in real life. Like what is illustrated before, cars that supports VMC-related technology would start to be manufactured, but it takes a long time to replace all the cars that cannot join VMC network. At the same time, all kinds of VMC models will be utilized in different districts. To decide which model and what parameters of a model is more suitable to use, we could find the max-eff curve of a model and investigate the v2v penetration of different countries, cities or even smaller regions. Then it is easy to know in a with specific penetration level, what car density reaches the best performance of delay. Max-eff curve of a model would help much on selectively apply different model according to a local situation to achieve a high communication efficiency.

In a brief conclusion, the simulation shows that increasing V2V penetration level improves system delay and transmission quality, but the improvement diminishes at high penetration levels. The impact of task rate, handover region area, and car density on the system's performance is also nicely analyzed. The max-eff curve is found to be a potentially useful tool to identify the optimal car density value under different V2V penetration levels. We expect our work would provide valuable insights for the development and implementation of V2V communication systems, and the max-eff curve can be utilized to optimize system performance in different regions with varying V2V penetration levels.

Impart from the delay that caused system failure such as car crashes, PRR (percentage received rate) is also a crucial factor that cannot be ignored. This PRR directly affects the reliability of the system because the system will not be able to correctly implement the information. This causes a serious problem such as car crashes, which is a topic already overwhelmed with problems needed to be improved. To analyze the performance, data is gathered from experiments [3].

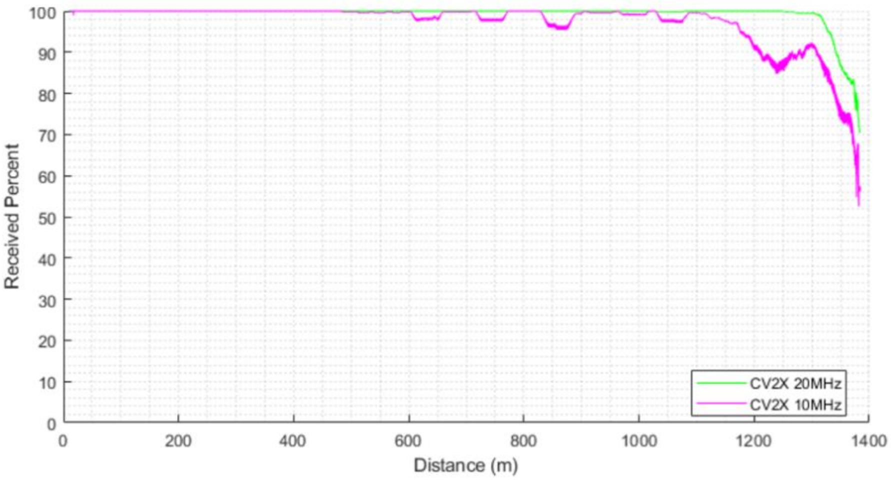

Figure 9. PRR performance with the increase in the distance [7].

In Figure 9, it clearly demonstrates the drop of PRR with the increase in the distance. By collecting data from this graph, we can easily simulate the performance of the V2X and LTE system by inserting data into the Vehicle matrix. As the experiment only acquires to analyze the reliability of area three in the system, the PRR is only simulated in area three in the matrix.

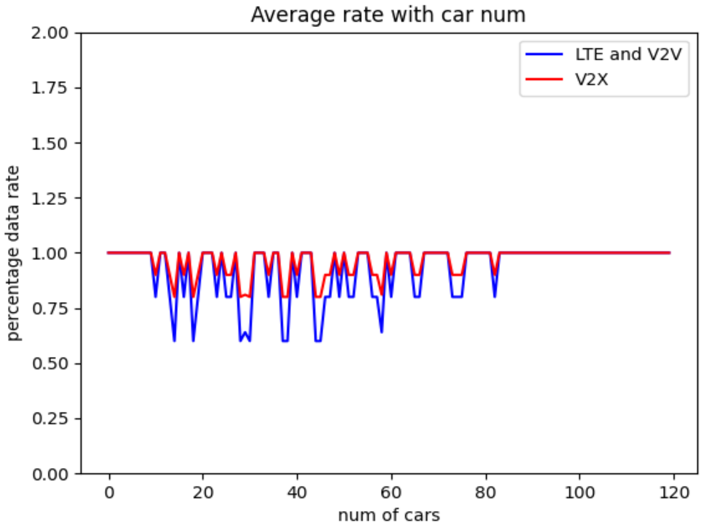

Figure 10. PRR with the increase in number of cars in area three.

Figure 10 shows the relation between the PRR and the number of vehicles. Noticeably, the PRR of the system often drop below 75%, where is a very serious problem considering the accuracy a VMC requires. It can also be observed that the drop of LTE is also much faster than the drop in V2X, which shows the great benefit V2X demonstrates in short-mid distance communications. So, it is urgent to suggest a solution to this problem. Since the drop of PRR is caused by increasing distance between senders and receivers, there are two variables will effectively affect the system is a positive why: decreasing car distances and increasing V2X and LTE penetration. With these two variables considered, a significant change in the diagram is shown.

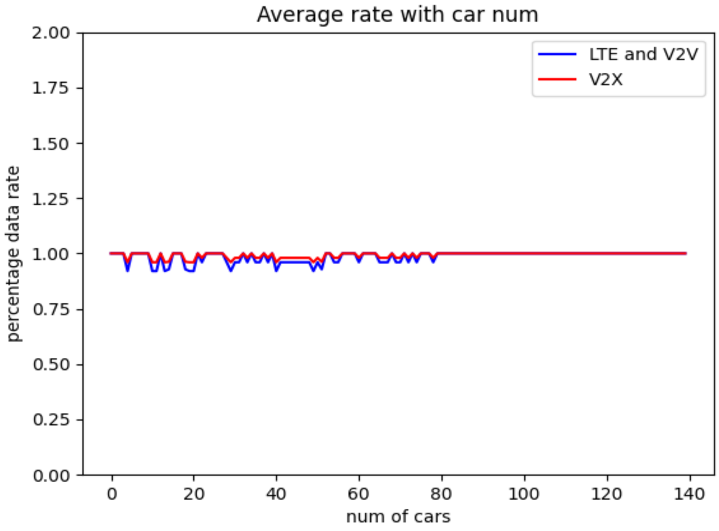

Figure 11. PRR changes after applying a higher penetration.

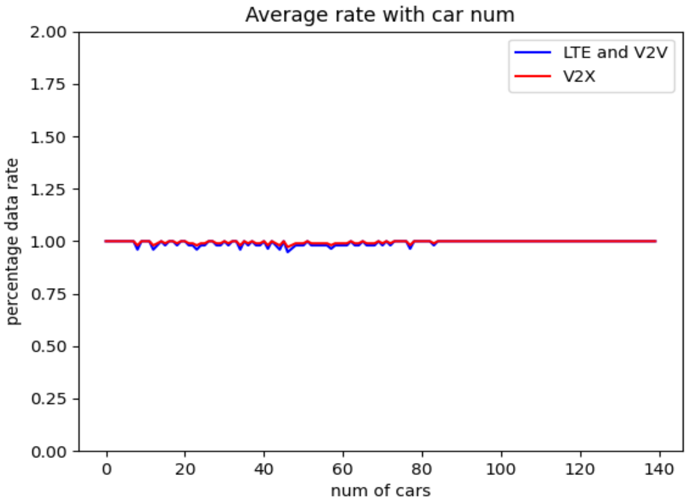

Figure 12. PRR changes after reducing the car distances.

Figure 11 shows the reliability change after changing the penetration from 0.3 to 0.7, a great improve can be seen. The lowest point is about 90%, an ideal PRR for a VMC system in most scenarios. While Figure 12 shows an even more astonishing result when decreasing the car distances from 30 meters to 3 meters. This is performed by changing the distance matrix. There is no significant peak in the range of 20 – 60 cars.

The first implementation of the problem is high in costs and will not be valid for many years due to technology spread, but the second approach is worth trying because it is very often observed. To have a car distance around 3 meters, the system just needs to be installed in areas like cities and main roads, which also met the use of large amount of transmission rate from V2X systems.

5. Conclusion

In conclusion, this article presents a VMC system model that utilizes vehicular micro clouds computing to enhance communication reliability and efficiency in highly dynamic and dense traffic environments. The proposed model considers multi-station scenarios and incorporates various parameters and performance indicators to ensure the success of the vehicle sensing system. The research results demonstrate the potential of V2X communication in becoming an alternative to fiber-optic transmission, offering more efficient and reliable vehicular communication for intelligent transportation systems. However, limitations and areas for improvement are acknowledged, including the need to consider real-world factors and address cost and deployment challenges. Future directions should explore the impact of real-world factors on V2X communication, integrate it with other wireless technologies like 5G, and leverage its potential for enhancing safety, autonomous driving, and advanced applications. Overall, this study provides valuable insights for the development of vehicular communication technologies and offers new ideas for future research.

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References

[1] Kwon, Seong, MA, et al. “Driving Behavior Classification and Sharing System Using CNN-LSTM Approaches and V2X Communication.” Applied Sciences, vol. 11, no. 21, MDPI, Nov. 2021, p. 10420. https://doi.org/10.3390/app112110420.

[2] E. Krijestorac, A. Memedi, T. Higuchi, S. Ucar, O. Altintas and D. Cabric, "Hybrid Vehicular and Cloud Distributed Computing: A Case for Cooperative Perception," GLOBECOM 2020 - 2020 IEEE Global Communications Conference, Taipei, Taiwan, 2020, pp. 1-6, doi: 10.1109/GLOBECOM42002.2020.9322247.

[3] Ye, Hao, et al. “Machine Learning for Vehicular Networks: Recent Advances and Application Examples.” IEEE Vehicular Technology Magazine, vol. 13, no. 2, Institute of Electrical and Electronics Engineers, Apr. 2018, pp. 94–101. https://doi.org/10.1109/mvt.2018.2811185.

[4] Identification and Evaluation of the Effective Criteria for Detection of Congestion in a Smart City.” Iet Communications, vol. 16, no. 5, Institution of Engineering and Technology, Feb. 2022, pp. 560–70. https://doi.org/10.1049/cmu2.12344.

[5] Do, Dinh-Thuan, et al. “Two-Way Transmission for Low-Latency and High-Reliability 5G Cellular V2X Communications.” Sensors, vol. 20, no. 2, MDPI, Jan. 2020, p. 386. https://doi.org/10.3390/s20020386.

[6] C. R. Storck and F. Duarte-Figueiredo, "A Survey of 5G Technology Evolution, Standards, and Infrastructure Associated With Vehicle-to-Everything Communications by Internet of Vehicles," in IEEE Access, vol. 8, pp. 117593-117614, 2020, doi: 10.1109/ACCESS.2020.3004779.

[7] 5GAA., " Addendum to V2X Functional and Performance Test Report; Test Procedures and Results for 20-MHz Deployment in CH183" (2019). 5GAA_190606_TR_V2X_RF-Test-Report_Addendum_20MHz-v2.
Retrieved from https://5gaa.org/content/uploads/2019/06/5GAA_190606_TR_V2X_RF-Test- Report_Addendum_20MHz-v2.pdf