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METHOD ARTICLE

Dynamic spectrum management using frequency selection at licensed and unlicensed bands for efficient vehicle-to-vehicle communication [version 1; peer review: 1 approved with reservations, 1 not approved]

Keshvinder Singh Randhava, Mardeni Roslee , Zubaida Yusoff

Centre for Wireless Technology, Faculty of Engineering., Multimedia University, Cyberjaya, Selangor, 63100, Malaysia

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Abstract

Background: The exponential increase in pattern of vehicles on the roads demands a need to develop a vehicular infrastructure that may not only ease congestions and provide a better experience but also pivot the levels of safety among users. The development of wireless technology has made it convenient for machines, devices and vehicles to interact with one another. The efficacy of this wireless communications relies on utilising current and available technology to enable information to be shared efficiently. In the wake of the available advancement in wireless technology, a new dynamic spectrum management (DSM) in vehicle-to-vehicle (V2V) communication that coexists with the existing Long-Term Evolution (LTE) network to increase the throughput in V2V communication is proposed. This will provide some solutions to enable a more efficient vehicular infrastructure.

Methods: This paper focuses on the utilization of DSM in V2V communications by selecting an appropriate frequency band through the selection of available licensed and unlicensed frequency bands for vehicles. Further investigations are done to identify the effect of interference in the dynamic spectrum by observing the path loss, SINR, and the throughput with various interfering users.

Results: The results show that the performance of the proposed DSM augments a significant improvement in the overall throughput and the signal-to-interference-plus-noise ratio (SINR) value is reduced by up to 60% when compared to the fixed spectrum allocation.

Conclusions: Although the dynamic spectrum is still affected by the interference from the existing cellular users, the throughput of the dynamic spectrum remains sufficient to transmit the information to other vehicles.

Open Peer Review

Approval Status ? X

	1	2
version 1		
22 Dec 2021	view	view

1. Muhammad Waqas , University of Bahrain, Bahrain, Bahrain

2. Mustafa Maad Hamdi , Al-Maarif University College, Ramadi, Iraq

Any reports and responses or comments on the article can be found at the end of the article.

Keywords

Vehicle-to-vehicle (V2V), dynamic spectrum, the fifth-generation technology standard(5G), Long Term Evolution (LTE), throughput, interference.

This article is included in the **Research Synergy** Foundation gateway.

Corresponding author: Zubaida Yusoff (zubaida@mmu.edu.my)

Author roles: **Randhava KS:** Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft Preparation; **Roslee M:** Conceptualization, Methodology, Project Administration, Resources, Supervision, Writing – Review & Editing; **Yusoff Z:** Conceptualization, Project Administration, Supervision, Writing – Review & Editing

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Introduction

Vehicle-to-vehicle (V2V) communication allows vehicles to interact and trade data or information directly with one another without the need of accessing a base station. This may involve data exchange with regards to speed, position and traffic environment.¹ This method of communication correspondingly benefits users to avoid collisions, reduce traffic congestions and subsequently improves road safety.² As the current wireless network technology moves from the fourth generation (4G) towards the fifth generation (5G),^{3,4} there lies a promising future for V2V communication in terms of improved latency, throughput and connections^{5,6} between vehicles. This enhancement in wireless network technology compels researchers to identify in detail the improvements to be made.

Literature review

V2V communication is initially utilised in dedicated short-range communications (DSRC) through the exchange of information with each other.⁷ The DSRC generally works on the 5.9 GHz band⁸ of the radio frequency range and is powerful and efficient for vehicle communication that involves short to medium distance coverage. However, this technology does not offer high-speed communication.

Due to the innovations driven by the 3rd Generation Partnership Project (3GPP), the most recent vehicle-to-everything are utilising the cellular networks. This network is known as Cellular V2X (C-V2X) to separate it from the wireless local area network (WLAN)-based vehicle technology.⁹ The 3GPP began to normalise work regarding cellular vehicular communication in 2014 during Release 14.¹⁰ This technology is known as Long-Term Evolution (LTE)-V2X since the functionalities of this technology relies on LTE networks. The C-V2X functionalities are extended to help 5G technology in the 3GPP Release 15.¹¹

Each technology has its assigned spectrum band where the users operate on the listened spectrum. Due to the expanding number of various kinds of wireless services and the number of vehicles on the road, the current fixed spectrum allocation policy such as dedicated short-range communications (DSRC) and LTE-V2X cannot cope with the growing demands of the wireless networks.¹² Hence, the Federal Communications Commission (FCC) has proposed the usage of the underutilised spectrum and spectrum portions that are not in use by the user. The technology that can solve this problem is known as dynamic spectrum management (DSM) where it can combine a few bands in a wireless service.

DSM is a technique subject to the theoretical concept in the communication network created to enhance the performance and proficiency of the network. Various studies have been done to explore the use of DSM by utilising diverse frequency ranges simultaneously in the vehicular network. Research¹³ was conducted in 2016 to demonstrate and analyse the efficiency of dynamic spectrum sharing among DSRC with the support of Wi-Fi systems. The author used the Poisson point process to dynamically construct a vehicular network where DSRC vehicles and Wi-Fi devices coincide and proposed the quality measures on the spectrum efficiency and data rate transmission. Results of this study indicate that dynamic spectrum allocation in the 5.9 GHz band improves the efficiency of the Wi-Fi network without excessively reducing the quality of the DSRC system.

The range optimisation for dynamic spectrum sharing using DSRC and 5G technology in V2V communication links was studied by Elias Alwan.¹⁴ Since DSRC provides a limited capacity for high-speed data, Alwan combined the usage of the 5G network to provide a high data rate in the V2V network. The channel link for this research work uses the free-space path loss model to investigate the link budget of the communication channel. Results from this paper show that the maximum data rate produced by this network model is 27 Mbps with a network coverage up to 500 m.

Haibo Zhou *et al.*¹⁵ developed a dynamic sharing spectrum between 5G and DSRC frequency bands to prepare vehicular communication with massive system capacity while reducing the delay in communication and reducing cost. The idea proposed in this paper meets the developing expectations of vehicular communication services. However, this study does not consider that vehicles have high versatility and due to the heterogeneity of 5G, accomplishing an effective dynamic spectrum sharing is challenging in the real world. Hence, this paper makes realistic studies of the dynamic sharing spectrum of 5G and DSRC for the vivid experience in the vehicular communication network through the usage of available licensed and unlicensed frequency bands available. This paper will study the results of the path loss, signal-to-interference-plus-noise ratio (SINR), and the throughput with various interfering users.

Table 1 shows that the LTE cellular network and mm-Wave technology may offer a high data rate in the vehicular network. Hence, this work will utilize LTE and mm-Wave technology that supports 5G to be used dynamically in the V2V communications to achieve better throughput in the network.

Table 1. Specifications of the technology in vehicular communications.

	Cellular	DSRC	mm-Wave
Standardization	3GPP LTE-A	IEEE 802.11p/WAVE	IEEE 802.11ad
Frequency band	Licensed	5.7-5.92 GHz	30-300 GHz
Mobility support	350 km/h	140 km/h	140 km/h
Data rate	300 Mbps	3-27 Mbps	~ 10 Gbps
Coverage	>4 km	<1 M	<100 m
Method	D2D	Ad hoc	D2D/Ad hoc

Methods

Ethical approval

This study got ethical approval from the Multimedia University Research Ethics Committee with approval number EA2832021.

Dynamic spectrum management using licensed and unlicensed bands

This paper proposes an effective dynamic spectrum by utilising both licensed and unlicensed bands. The user's spectrum selection is determined by the distance between the V2V pairs. Selection is made to determine the most suitable frequency band to be utilised in establishing a V2V communication channel. The proposed dynamic spectrum deals with the distance between the transmitter and receiver of the V2V link and selects either the licensed or unlicensed band that may significantly reduce the overall system interference while boosting the throughput in vehicular communication.

The licensed spectrum with a frequency band of 2.4 GHz is chosen since it is generally used by the LTE network. Similarly, the unlicensed spectrum band that uses the mm-Wave frequency band (5G) of 60 GHz¹⁶ is chosen. Due to the short coverage of 5G, the supporting LTE network is utilized to support a larger coverage area by providing communication between vehicles.¹⁷

Network communication model

The network system is designed in a hexagonal shape with a cell radius of 500 m (Figure 1). The network system is assumed to support both cellular and V2V communication in the network, where there exist n number of the existing cellular users which shall be considered as interfering devices in this paper, denoted as CUEs, and m number of vehicles

Figure 1. Vehicular network setup for dynamic spectrum management (DSM). V2V = vehicle to vehicle; LTE = Long-Term Evolution.

doing local V2V high-capacity data exchange denoted as VUEs. It is assumed that all the vehicle and cellular user equipment is capable of supporting both licensed and unlicensed spectrum communications simultaneously. The value of the vehicle is more than the number of interfering devices, $m \gg n$ in this network setup.

The base station is placed in the middle of the network cell. The number of V2V pairs will increase gradually to analyse the algorithm of the network. The V2V pair will consist of one vehicle that will be a transmitter and another vehicle as a receiver. The cellular user and the V2V users are distributed uniformly over a hexagon cell area. In addition, it is assumed that all the devices in the network can support V2V mode and cellular mode in the setup.

The two frequency bands that are supported by the devices to transmit the data in the network are the licensed spectrum (LTE-V2V communication) and the unlicensed spectrum (5G cellular network supported by the mm-Wave technology).⁴ Additionally, the interfering devices that are connected to the vehicle are set to communicate using licensed spectrum, meanwhile, the V2V communication system will use either one of the spectrum bands depending on the best choice at that particular distance.

Channel model setup

The path-loss for the proposed dynamic spectrum is designed by considering the free space, urban, and Line of Sight (LOS) models. It is also designed by considering the mm-Wave propagation models where the heavy oxygen absorption from the environment and heavy attenuation at 60 GHz is considered.¹⁸ The path loss in the transmission link between the V2V pair for long and short distances is modelled as:

$$Pathloss_{V2V_{RX}}^{long} = 20 \log_{10}(distance) + 20 \log_{10}(f_c) + 32.45 \quad (1)$$

$$Pathloss_{V2V_{RX}}^{short} = 12 \log_{10}(distance) + 12 \log_{10}(f_c) + 19.45 \quad (2)$$

Meanwhile, the path loss due to the interfering users, CUE is modelled as:

$$Pathloss_{Int_{RX}}^{long} = 34 \log_{10}(distance) + 34 \log_{10}(f_c) + 64.9 \quad (3)$$

$$Pathloss_{Int_{RX}}^{short} = 20 \log_{10}(distance) + 20 \log_{10}(f_c) + 32.45 \quad (4)$$

For equations (1) to (4), the f_c is in MHz and d is in metres. The constant value represents the shadowing effect of signal power fluctuations due to the surrounding obstacles. This dynamic spectrum V2V model is designed according to a Log-normal shadowing distribution and using a Rayleigh fast fading in the channel link.¹⁹

SINR in V2V communication is obtained in this work to evaluate the performance of the spectrum and to compare the differences between the SINR fixed spectrum allocation of the unlicensed band and licensed band and the dynamic spectrum allocation in vehicular communication.

$$SINR_{V2V}^{long} = \frac{Received\ power, long}{N_o + \sum P_{Interfering}^{long}} \quad (5)$$

$$SINR_{V2V}^{short} = \frac{Received\ power, short}{N_o + \sum P_{Interfering}^{short}} \quad (6)$$

The received power signal is calculated by power transmitted minus path loss in the V2V link. The noise power density is stated as N_o . It has a dimension of power over frequency, which is measured in watts per hertz or equivalent to watt-seconds. Meanwhile, the total power of the interfering devices received by the V2V receiver is label as $\sum P_{Interfering}^{long}$ and $\sum P_{Interfering}^{short}$ for long and short distances, respectively.

The Shannon capacity theorem is considered when calculating the throughput of vehicular communication. It characterises the maximum value of the successful message transmitted or the data capacity which is sent over any channel or communication medium. The system's throughput for long and short distances is through equations below:

$$T_{V2V}^{long} = B_{licensed} \times 10 \log_{10} \left(1 + SINR_{V2V}^{long} \right) \quad (7)$$

$$T_{V2V}^{short} = B_{unlicensed} \times 10 \log_{10} \left(1 + SINR_{V2V}^{short} \right) \quad (8)$$

$B_{licensed}$: bandwidth in Hz in the licensed spectrum.

$B_{unlicensed}$: bandwidth in Hz in the unlicensed spectrum.

$SINR$: received signal power over the total noise power across the channel model.

Flowchart of the dynamic spectrum simulation

The simulation is done using **MATLAB** version R2020a (RRID: SCR 001622) Communications Toolbox 2020 using the algorithm flow chart depicted in **Figure 2**. Alternative software that may be used are GNU Octave and SAGE (Python SageMath). The parameters are based on **Table 2** and the distance between the vehicle transmitter and receiver is calculated. The equations used after this is dependent upon the distances between the two vehicles. When the distance of the link is less than 15 m, the 5G unlicensed band setup is set up for the vehicle to transmit the data where the

Figure 2. Flow chart of the dynamic spectrum simulations.

Table 2. Simulation parameters.

Parameters	Values
Carrier frequency	60 GHz
Carrier frequency	2.4 GHz
Unlicensed bandwidth	1.5 GHz
Licensed bandwidth	5 MHz
Number of interfering users	20
Number of vehicle users	300
Number of V2V links	1 (increased gradually)
Cell radius	500 m
Noise power density	−174 dBm/Hz
VUE transmitting power	26 dBm
CUE transmitting power	23 dBm

communication link now utilises the equations of $Pathloss V2V_{RX}^{short}$, $SINR_{V2V}^{short}$, $Throughput_{V2V}^{short}$, which are equations (2), (6) and (8), respectively.

As the communication channel is set up using the LTE communication network, equations used to analyse the communication are equations (1), (5) and (7). Table 2 shows the parameter used in the simulation.

The code used in this paper is available from [GitHub](#) and is archived with Zenodo.²¹

Algorithm of the dynamic spectrum

Proposed performance test on the DSMin V2V communication.

- 1: Initialise $CUE = 20$, $VUE = 300$;
- 2: Generate the network setup model
- 3: Calculate the distance between Vtx and Vrx
- 4: if distance > 15 % use licensed parameter
- 5: $f2 = 2.4$ GHz,
- 6: for V2V communication link
- 7: Calculate $Pathloss V2V_{RX}^{long}$
- 8: Calculate *Received power, long*
- 9: For Interference link
- 10: Calculate $Pathloss Int_{RX}^{long}$
- 11: Calculate *Interfering power, long*
- 12: Find $SINR_{V2V}^{long}$
- 13: Calculate T_{V2V}^{long}
- 14: else % if distance less than 15 m
- 15: $f1 = 60$ GHz % use unlicensed parameter
- 16: For V2V communication link
- 17: Calculate $Pathloss V2V_{RX}^{short}$;
- 18: Calculate *Received power, short*
- 19: For Interference link
- 20: Calculate $Pathloss Int_{RX}^{short}$
- 21: Calculate *Interfering power, short*
- 22: Find $SINR_{V2V}^{short}$
- 23: Calculate T_{V2V}^{short}
- 24: end

Results and discussion

Vehicle-to-vehicle network setup

The network communication set up in the proposed DSM in V2V technology is simulated in [Figure 3](#). The network model is designed in a hexagonal shape since it resembles the real-world communication coverage area.²⁰ The radius of this system is set to 500 m. As mentioned previously, the number of vehicle users is set up more than the value of the interfering devices in the cellular network. The V2V receiver is denoted as '●' meanwhile the V2V Transmitter is set as '▶' in [Figure 3](#) where its location is fixed throughout the simulation. The interfering and V2V receivers are distributed uniformly over the network setup and the base station is located at the centre where it is symbolised as 'o'.

[Figure 4](#) shows a significant improvement in the overall throughput in the network. The dynamic spectrum combines the technology of LTE and 5G in the vehicular communication network based on distance. Hence, there is still a throughput

Figure 3. V2V (vehicle-to-vehicle) network setup in the dynamic spectrum allocation.

Figure 4. Throughput of the proposed dynamic algorithm supporting 4G and 5G technologies.

Figure 5. Path loss vs distance.

should the distance be more than 15 m as the proposed dynamic spectrum will utilise the LTE technology to expand the coverage area while maintaining a decent throughput in the channel. If the graph is focused at one point where the distance between the transmitter and receiver is 10 m, it can be observed that the throughput of the proposed dynamic spectrum is 224.5 Kbps, followed by the throughput of the unlicensed spectrum 168.1 Kbps and the licensed spectrum 72.44 Kbps, which denotes that the throughput of the dynamic spectrum suggests an improvement of 67% compared to the throughput in the licensed spectrum.

Figure 5 shows that the static licensed spectrum offers a better path loss interference since the licensed spectrum is initially assigned for licensed users. Hence, the amount of interfering effects to this licensed spectrum is minimised compared to the other spectrum. Observing the point where the unlicensed spectrum is utilised, the unlicensed static spectrum suffered a higher path loss attenuation. The reason for this is because this spectrum was not initially assigned to V2V technology. It is actually an unutilised spectrum that people generally use when conducting experiments in the innovation of wireless communication technology.

Conclusion

In this paper, the DSM is implemented by choosing the more suitable frequency band based on the distance between V2V links to minimise the total system interference while increasing the throughput of the network. A simulation is performed using MATLAB R2020a to prove that the proposed dynamic spectrum guarantees improvement from the existing fixed spectrum allocation. Results show that the SINR of the proposed dynamic system is reduced by up to 60% compared to the unlicensed spectrum. It is also observed that the throughput of the proposed system shows a significant improvement of up to 67% compared to the licensed spectrum allocation. Towards the end of this paper, the effect of interference is studied in the dynamic spectrum. Through the graph, it can be observed that the interference power becomes higher as the distance between the transmitter and receiver is higher and this interference can be influenced by the number of interfering devices. Despite this, it can still provide sufficient throughput for the vehicles to share the information between them.

Data availability

All data underlying the results are available as part of the article and no additional source data are required.

Software availability

- Source code available from: https://github.com/kesh3141/V2V-Comms_5
- Archived source code at time of publication: <https://doi.org/10.5281/zenodo.5760098>.²¹
- License: The GNU General Public License v3.0

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Open Peer Review

Current Peer Review Status: ? ✖

Version 1

Reviewer Report 03 April 2023

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Mustafa Maad Hamdi

Communications and Computers Engineering, Al-Maarif University College, Ramadi, Iraq

There are some points to improve the article:

Abstract

- Need to mention the issue of this research paper and mention the value of results.
- The abstract needs a rewrite, because the abstract must contain three points like: problem, method and results. Also, there are some problems with the grammar.

Introduction

- Need more explanation in the introduction and mention the current issue and the objective.
- Need to add the figure showing dynamic spectrum management (DSM).

Literature review

- Need to mention the strengths and weaknesses for all studies.
- Need to update all references and use more specific references in five recent years.

Method

- Need to adding more explanation in methods and presented in clearly. Explain the steps of proposed method DSM with V2V) and how observing the path loss, SINR and throughput with various interference user.
- Need to adding flow chart. A flowchart would help make this article very simple to read and understand the proposed method (DSM) step by step.

Results

- Need to compare with benchmark.
- Need to add more explanation in the results. Explain the figure of result in detail and discuss each value.

- All figures in the results need to be redrawn again. They are not clear when the reader wants to see and read in this article.

Conclusion

- The conclusion need to be rewritten and mention the future work. This conclusion must contain the contribution and the value of results. Also there are some problem with the language.

Is the rationale for developing the new method (or application) clearly explained?

Partly

Is the description of the method technically sound?

No

Are sufficient details provided to allow replication of the method development and its use by others?

No

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: VANETS

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 13 March 2023

<https://doi.org/10.5256/f1000research.77135.r159120>

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Muhammad Waqas

Computer Engineering Department, University of Bahrain, Bahrain, 32038, Bahrain

The authors proposed the DSM in V2V communications by selecting an appropriate frequency band by selecting available licensed and unlicensed frequency bands for vehicles. Although the

paper has merit, it requires extensive revision before indexing. My comments are given as follows.

1. In the abstract, the authors should not mention the headings. It should be in a continuous one-paragraph with word limits. No need to mention the headings.
2. The introduction section is not convincing. The authors need to mention the details in the introduction about the work done, the problem statement, the background and the contributions of the work.
3. In the literature, most of the related works are too old, for instance, most of the papers in the literature are from 2010 to 2015. There have been many advancements in this field since 2015. The authors need to update the related work section by citing up-to-date papers from 2020 to 2023. Some of the suggested references to be cited are given below. All the references are related to vehicular networks and are up-to-date:

- Badshah *et al.* (2022)¹
- Haider *et al.* (2023)²
- Ullah *et al.* (2022)³
- Munawar *et al.* (2022)⁴
- Abbas *et al.* (2022)⁵
- Waqas *et al.* (2022)⁶
- Ullah *et al.* (2021)⁷
- Ullah *et al.* (2021)⁸
- Haider *et al.* (2020)⁹
- Waqas *et al.* (2020)¹⁰
- Waqas *et al.* (2020)¹¹

4. The algorithm is not in the standard format. The current format is not professional. I suggest seeing the published paper and taking the idea of how to write the algorithm in the technical papers.
5. All the figures must be revised. The current figures are not clear and don't attract the readers. The figures must be clear, clean and neat, and the text inside the figure should be in the same font and style as the text on the paper.
6. The authors also need to describe each figure clearly. The current version of the explanation is not convincing and doesn't provide the proper meaning of the work done by the authors.
7. More simulation results are needed to claim the work done.
8. It is better to write notations in the equation rather than writing the words.
9. The manuscript also needs an extensive revision to remove all the English mistakes, grammatical issues and typo errors.

The authors need an extensive revision of the paper and I will be happy to see the revise version of the manuscript.

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Is the rationale for developing the new method (or application) clearly explained?

No

Is the description of the method technically sound?

Yes

Are sufficient details provided to allow replication of the method development and its use by others?

Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Wireless Communication, Vehicular Networks

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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