Spectrum Sensing: An integrated approach for 6G VANETs

By

Umair Riaz

Fall 2019-MS(EE-DSSP-11)-00000320653

Supervisor

Dr. Huma Ghafoor

Department of Electrical Engineering

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering (MS EE)

In

School of Electrical Engineering and Computer Science,

National University of Sciences and Technology (NUST),

Islamabad, Pakistan.

(January 2023)

THESIS ACCEPTANCE CERTIFICATE

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Signature: ____________________________

Name of Advisor: Dr. Huma Ghafoor

Date: 29-Jan-2023

HoD/Associate Dean: ________________________

Date: ____________________________________

Signature (Dean/Principal): ________________

Date: ____________________________________

Approval

It is certified that the contents and form of the thesis entitled "Spectrum Sensing: An integrated approach for 6G VANETS" submitted by UMAIR RIAZ have been found satisfactory for the requirement of the degree

Advisor : Dr. Huma Ghafoor

Signature: ________________________

Date: 29-Jan-2023

Committee Member 1:Dr. Mohaira Ahmad

Signature:

26-Jan-2023

Committee Member 2:Dr. Syed Ali Hassan

Signature: ________________________

Date: 26-Jan-2023

Signature: ________________________

Date: ________________________

Dedication

I dedicate this thesis to my parents, my brother, my sister, and my friends.

Certificate of Originality

I hereby declare that this submission titled "Spectrum Sensing: An integrated approach for 6G VANETS" is my own work. To the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics, which has been acknowledged. I also verified the originality of contents through plagiarism software.

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Student Signature: ______________

Acknowledgment

First, I would like to thank Allah Almighty, who gave me the courage, strength, motivation and above all, the ability to complete this research-based Master's thesis. It is my firm belief that nothing could have been possible without His guidance and blessings.

Secondly, I would sincerely express my gratitude to my supervisor Dr. Huma Ghafoor from SEECS, NUST, Pakistan, who helped me with full determination to complete this research work. I have been extremely fortunate to work under her worthy supervision. I believe that her guidance in choosing the topic, timely feedback, and constructive comments on every step kept me going throughout this journey. Most importantly, she has set an unforgettable example for me to pursue my career in the road of good researchers.

Finally, I want to say a special thanks to my colleague Muhammad Rafid who helped me finalize this thesis, as without his guidance, I would not have been able to achieve this.

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List of Abbreviations

6G	6^{th} Generation Wireless Technology
5G	5^{th} Generations Wireless Technology
VANETs	Vehicular Ad-Hoc Networks
CRN	Cognitive Radio Networks
mmWave	Millimeter Wave
GHz	Gigahertz
THz	Terahertz
DSRC	Dedicated Short Range Communication
RSU	Road Side Unit
PDR	Packet Delivery Ratio
SDN	Software Defined Networking
SDVN	Software Defined Vehicular Networking

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Abstract

To fulfill the needs of exponentially growing automobiles' users and to provide services with efficient paths among different bands on demand for these proliferated users, an integrated approach for software-defined vehicular network (SDVN) is proposed in this thesis. Due to this huge increase, DSRC has already been considered insufficient to fulfill the modern needs. Hence, to enhance the network performance and to fulfill the growing needs of users in SDVN environment, we implement cognitive technology by integrating DSRC, sub-6GHZ, and THz bands to find stable paths among different nodes. SDN controller is considered as the main controller (MC) for keeping the global state of all the nodes in the network. Channel sensing is done individually for each technology, and these sensing results representing the number of available bands for secondary communications is updated periodically to the MC. Consequently, the MC is managing these bands by switching between DSRC, sub-6GHz, and THz, and providing stable paths between source and destination. The switching decision is taken by considering the distance and availability of channels among these three technologies. This cognitive integration of bands in SDVN improves the network performance in terms of packet delivery ratio, network delay, and overhead ratio.

Chapter 1

Introduction

This chapter gives a general review of the wireless technologies, software-defined networking (SDN), cognitive technology, and vehicular ad hoc networks (VANETs) that are used in this thesis. The problem statement and project objectives are also covered at the chapter's conclusion.

1.1 VANETs

Vehicular ad-hoc network (VANET) is a significant component of intelligent transportation system (ITS), which was purposely developed to control and monitor transportation issues, provide safety to users, reduce traffic accidents, enhance network stability, and many more. Recently, smart cities have been introduced under the umbrella of ITS, where different applications are provided to different users by considering vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), vehicle-to-drone (V2D), vehicle-to-ship (V2S), and vehicle-to-everything (V2X) communications [1].

To enhance the performance of these smart cities, various technologies like software-defined networking (SDN), artificial intelligence (AI), and network function virtualization (NFV) have been integrated with vehicular networks to gather, handle, and analyse a large set of data for network management. But, considering the increasing amount of this vehicular data, the dedicated band for automobile communications assigned by FCC in 1997, was found to be insufficient to fulfil the demands of increasing number of users in a smart city [2]. Among these seven channels of 75MHz band, the one was solely dedicated for the exchange of control messages, while the remaining six channels, each with a bandwidth of 10MHz, were exclusively used for the exchange of data messages. Various cognitive radio (CR) schemes for vehicular environment have been proposed in literature to overcome this spectrum scarcity issues [3] [4] [5]. But, to deal with an upsurge in number along with their services and to maintain network stability along with bands availability, a new integrated approach is required.

1.2 Cognitive Radio networks

Spectrum sensing is used to find nearby available bands based on the distance from the road-side unit (RSU) for establishing a stable link between different users. To find the optimal band among different available bands and to switch frequently between different frequencies, various detection schemes are used in literature [6]. Since spectrum is one of the most expensive and scarce resources, researchers are attempting to utilise it effectively and efficiently to fulfill the increasing demands of all users around the world. [7]. Both vehicles and RSUs sense the spectrum and exchange the sensing results to update each other about the availability of free bands at the specific locations. Hence, cooperation among nodes is required to keep updated with the current state. SDN controller is considered as the best entity to manage the locally updated data by keeping the global state of the whole network. The controller is also responsible for taking switching decisions between different wireless technologies.

1.3 THz band for vehicular communication in 6G Wireless Technology

Moving towards 6^{th} generation, the services offered by modern vehicles require ample amount of bandwidth with high data rates and less delay in near future [8]. The THz band, above the frequency range of 90 GHz, operates in the range of 0.1THz - 10THz, has a maximum data rate of 1T bit/sec with extremely low latency of about 0.1 m/s, which is more than ten times less in latency over 5G networks. Therefore, we consider THz band as one of the three technologies to meet the current needs of vehicular data. This latest requirement involves high data rates and throughput to process the videos and vehicular data properly among vehicular users [9]. Moreover, integration of vehicular networks in health-related and other intensive applications also require exceedingly low latency to operate correctly [10]. Similarly, to expedite communications among nano-empowered vehicular networks, this band play a vital role in providing stable connections [11]. Consequently, THz band is the best candidate which has provision to fulfill the highly demanding traffic needs.

1.4 Problem Statement

Vehicles in the upcoming 6G wireless technology will be equipped with many smart and advance devices which will require alot of bandwidth and data rates for efficient communication between them. In terms of data speeds and bandwidth, 5th generation wireless technology performed very well with mm-Waves, but in near future around 2030 the this mm-wave band will also get short in terms of bandwidth. A novel infrastructure for vehicular communication is required for 6G wireless technology to make the efficient use of spectrum s it is considered as one of the important and costly resource round the globe.

1.5 Thesis Contribution

In terms of data speeds and bandwidth, 5^{th} generation wireless technology also performed well with mm-Waves, but it requires directional antennas and a direct line of sight (LOS) between the transmitter and the receiver in order to achieve maximum performance. While sub-6GHz, also known as Frequency Range 1 (FR1) in 5^{th} generation wireless technology, has an excellent coverage that also ensures best network performance. However, mm-Wave communications also require an additional beam forming as well as directional antennas to expand the coverage of any communication network [12].

Therefore, considering the special requirements of using mm-Wave band in vehicular networks and to get benefit from the wide communication range of sub-6GHz band, we prefer sub-6GHz over mm-Wave band in this proposed scheme. Accordingly, in addition to THz and sub-6GHz bands, we also consider DSRC band which is the dedicated spectrum for automobile communications. Hence, in this proposed scheme a vehicular node can only establish a connection with any of its current neighbor if it finds a free channel among any of these three technologies.

1.5.1 Key Contributions

The following are the key contributions of the thesis:

(*i*) A novel scheme for 6G cognitive radio software-defined vehicular networks (CR-SDVN) is proposed for a city scenario in this thesis to find a stable path between source and destination. The communication between two nodes is dependant on the number of available free channels that are provided to each link forming a stable path. These free channels are sensed by the energy detector scheme which is implemented solely for each wireless technology. Three different technologies, DSRC, sub-6GHz, and THz are used to meet the needs of growing number of vehicular users. The SDN controller is responsible for keeping the updated data and for switching among these three technologies.

(*ii*) After finding the available channels, the two communicating nodes are allowed to transfer the data among each other. Hence, considering the free channels and the link status, the final step is to find an optimal path among different available paths between source and destination. This path is a combination of different wireless technologies; thereby providing a heterogeneous stable path for modern vehicles in a city environment.

The rest of this thesis is organized as follows. Section 2 provides a quick summary and explanation of the related work in the literature. Our proposed model and methodology is presented in Section 3 while Section 4 presents the simulation results. Finally, the last Section 5 concludes the thesis.

Chapter 2

Background and Literature Review

Several cognitive schemes in integration with vehicular networks have been proposed in literature to overcome the problems of spectrum scarcity. Due to an unexpected surge in the number of mobile users, the ample amount of bandwidth with high data rates is an urge for these networks to fulfil the growing demands of users. To serve these growing users, another important factor is the provision of a stable path between two communicating source and destination nodes in such a highly dynamic environment like VANETs. Several solutions to overcome this scarcity problem by considering the stability of the network and providing the optimal paths between different sources and destinations have been contemplated for a decade [13]. Recently, various emerging technologies like sub-6GHz, mmWave, and THz have been introduced to VANETs to overcome the issues of spectrum scarcity and to support the demands of emerging services in VANETs [14] [15] [16]. We will discuss in this section the contribution of each technology generally to 6^{th} generation and specifically to VANETs.

The concept of integrating these emerging technologies was considered for V2X communications in [17]. The authors considered a linear vehicular network in a small lane where clusters are formed to ensure mmWave communications within a cluster and sub-6G is used for inter-cluster communications. A new MAC protocol is proposed to consider the V2X communications which achieves high throughput and low latency in such an integrated environment. Yi *et al*. [15] considered both urban and highway scenarios for THz V2I channel to explore various parameters under different weather conditions. This channel characterization can be used to enable THz-based communications in 6G vehicular networks. Likewise, a multi-band network scheme for vehicular communications was proposed in [14] to ensure LOS transmission in mmWave communicating links. This is a scheduling-based link prediction scheme which considered multi-bands i.e., DSRC, mmWave, and sub-6GHz for communications. A hierarchy is first maintained depending on the distance among vehicles and then relevant bands of frequency are assigned to the network to achieve the higher performance under various conditions.

Another scheme for multicast mmWave vehicular communications was proposed in [18] to achieve high throughput by coordinating through control messages on sub-6GHz band between relays. The highway scenario is considered to measure the positions of vehicles by using beamwidth-aware scheduling. Their results showed that a single transmission can cover up to four receivers. A low THz band which operates in the spectrum of very high frequencies, i.e., between 300 GHz and 1 THz, for vehicular environment in single-lane and multi-lanes was proposed in [19] to ensure that the communication for this band is dependent on distance between transmitter and receiver. Their results indicate that the THz wave's trajectory has a significant impact on both the penetration and propagation losses. The authors also compared some metrics with mmWave vehicular solutions and made the conclusion that THz band outperforms the mmWave. A recent study in [20] considered the use of 6^{th} generation technology to fulfill the demands of next-generation V2X communications. The authors reveals the use of machine learning (ML)-based technologies and algorithms specifically for efficient vehicular communications. They also discussed the challenges faced by vehicular networks for integrating into next-generation vehicular communications.

The protocols discussed above only consider multi band vehicular communications for different conditions. None of these protocols have been implemented the spectrum-aware vehicular communications by using these different wireless bands. In [21], authors investigated the use of the THz spectrum for automotive communication. With the increase in the world's population, the number of automobiles is also growing every day, which raises the need for faster data rates and huge bandwidth. The authors also discussed the difficulties with THz vehicular communications along with potential solutions. To overcome the issues of bandwidth utilization for vehicular communications, a novel skip network coding (SNC) multipath algorithm was proposed in [22] to reduce the number of packet re-transmissions after going through the limitations of traditional multipath techniques. Their simulation results shows a significant improvement in terms of packet loss, reliability, and bandwidth utilization. Another energy and spectrum-aware MAC protocol was proposed to access channel in nanosensor devices [23]. A distance-based decision is taken for THz bandwidth. To maintain the infinite lifetime, the authors assign optimal sleeping and transmission times among these devices. Another novel THz spectrum-aware scheme named compression and reconstruction network (CRNet) for vehicular communications was proposed in [24] to improve accuracy of channel sensing by reducing the spectrum complexity. Blind spectrum reconstruction was used in this scheme without considering the location of vehicles and other channel characteristics. The algorithm showed better results.

Considering cognitive technology for integration of different wireless bands as mentioned above have increased the overall delay, since finding an optimal channel to make a stable connection between each pair of communicating nodes is a time consuming procedure. Therefore, a central controller is needed to handle the spectrum availability among different wireless technologies and to enable switching between these wireless bands. Hu *et al.* [12] were the first to consider the integration of sub-6Ghz, DSRC, and mmWave bands with mobile edge computing (MEC) in vehicular environment. To distribute larger files among vehicles, MEC and fog computing are used to handle this integration among different bands. The sub-6GHz band is used for making connections between gateway nodes, mmWave is used for gateway to vehicular communications, and DSRC is used for V2V communications. The simulated results showed better performance in comparison to previous scheme for different network conditions. Likewise, the first work that simultaneously considered spectrum sensing and routing for CR-SDVN was proposed in [25] to provide stable paths between source and destination.

A dynamic switching between mmWave and THz bands for SDVN to access a small cell tower was taken into consideration in [26]. The controller is responsible for taking the switching decision between two aforementioned bands based on distance, channel characteristics, and contact times. An actual end-to-end connection between two towers of the Boston city was considered to show the benefits of proposed scheme. Another CR-SDVN routing scheme was proposed in [27] to enable switching between mmWave and THz bands. Clusters are used to divide the whole network into subnetworks where THZ band is dedicated for communication between vehicle and the roadside unit. However, for vehicle to vehicle communication, mmwave is used. A fuzzy inference-based system was used to find the optimal path between source and destination in mmWave communication, whereas, in THz communication, the improved fruit fly (IFF) method based on genetic algorithm (GA) was considered for path selection. Their results showed better performance in comparison to typical routing for vehicular networks in terms of delivery ratio, delay, and overhead.

2.1 Research Gap and Proposed Scheme

None of the protocols discussed above consider simultaneously the spectrum sensing and routing in CR-SDVN to find the number of idle bands available among different wireless technologies. To enhance vehicular communications in the forthcoming 6^{th} generation, we propose a novel scheme to first find the optimal band that are under-utilization among different technologies and then find the optimal path. The sub-6GHz band is a well-known band with far better coverage than mm-wave. Also, it performs well in terms of bandwidth, data, and coverage for vehicular environment. Moreover, it does not require the use of directional antennas, which lowers the network cost and complexity. Similarly, for intelligent transportation system, the THz band alone is sufficient to fulfil the needs of these growing users by providing high capacity, less delay, safety, and stability. But, it is important to sense those under utilized bands to make them available for vehicular communications. Furthermore, THz band outperforms the mmWave band since it offers large bandwidth and high data rates among all the available telecommunication bands discovered up until now. Keeping in view the pros of these wireless technologies, we integrate THz band with the sub-6GHz band in city scenario along with the DSRC. Consequently, this is the first work integrating DSRC, sub-6GHz, and THZ in CR-SDVN that simultaneously considers spectrum sensing and routing for both V2V and V2I communication in a city scenario.

Chapter 3

Spectrum Sensing: An integrated approach in 6G VANETs

We propose a novel cognitive routing protocol that integrates DSRC, sub-6GHz, and THz bands in 6G SDVN. Our goal is to consider spectrum sensing, among these three bands; and routing; simultaneously to find an optimal path between source and destination in a city scenario. The over-utilization of the former and under-utilization of the latter two bands make it compulsive for each vehicle to sense the spectrum in order to find number of free available channels for communication. The energy detector scheme is used individually for each wireless technology to sense the spectrum and then based on the distance of the communicating nodes from the controller, an optimal path is selected. The MC is responsible for keeping the global record of all the idle bands shared by each vehicle as a sensing result periodically. The MC is also responsible for switching among these bands and providing optimal paths to any querying node.

3.1 Assumptions

We consider an integration of DSRC, sub-6GHZ, and THZ bands in 6G cognitive radio software-defined vehicular network with V vehicles, r RSUs, and an MC as shown in Fig. 3.1. The MC communicates directly with the RSUs making it simple for the vehicles to ensure stability. All vehicles and RSUs have three interfaces, each for one wireless technology. Depending on the coverage range of each wireless technology, a vehicle can only form a link with the next relay vehicle moving towards the destination,if both have common free channels within that coverage area. This means that the number of channels are assumed to be same for a specific distance which in our scheme is the coverage range of each technology. That is, for a specific coverage range, the channel state which is presence and absence of primary user (PU) remains same; thereby ensuring stability.

A vehicle moving in a city scenario when looking for a path to the destination, it sends a request message to: i) MC, if it is within the coverage range of the vehicle, ii) any RSU, within the coverage range of a vehicle which then forwards that request directly to MC, iii) any neighboring vehicle, which relays the request until it reaches any fixed node. For above three possibilities, two nodes can only communicate if they both have common free channel. To find these free channels, vehicles need to sense spectrum and update the sensing results with each other and with the MC periodically while moving.

This sensing is done individually for each band using energy detector. In the subsection below, we will explain the spectrum sensing for three different bands in 6G CR-SDVN.

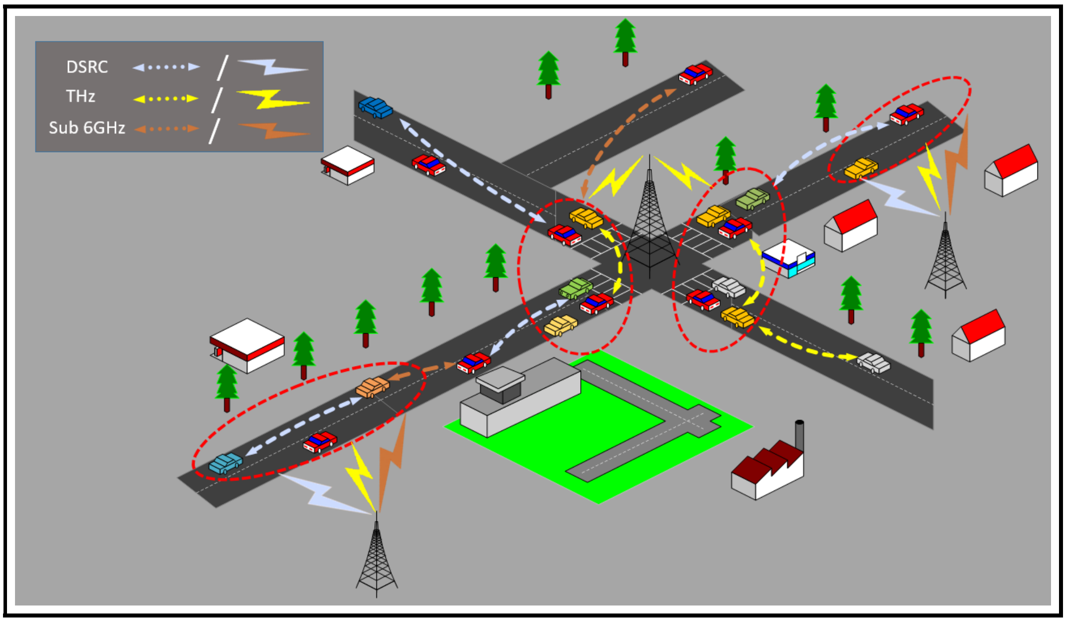


Figure 3.1: CR-SDVN for DSRC, sub-6GHz, and THz communications in a city scenario

3.2 Spectrum Sensing for DSRC, Sub-6GHz, and THz bands

We consider cognitive technology for different bands to allow exchange of data among various nodes in vehicular environment with high data rates, low latency, and less overhead. To fulfil these requirements, we consider a MC in our scheme that is responsible for ensuring stability by providing the optimal bands along with optimal path to any querying node. Each vehicle shares the sensing results (SR_{v_j}) with its neighboring nodes up to the coverage range, C_i of each band; where i represents DSRC, sub-6GHz, or THZ and v_j represents vehicle $j = \{1, 2, ..., V\}$. The range of these bands is shown in Fig. 3.2. These coverage ranges are used to take decision for switching between different technologies. This SR_{v_j} is updated periodically by each vehicle and the list of free channels obtained by each vehicle, LFC_{v_j} is maintained at the global level by the MC as shown in Table 3.1.

Table 3.1: MC Information Table

Vehicle ID	Vehicle Position	Vehicle Speed (m/s)	LFC_{v_j}		
V_1	(x_1, y_1)	25	$Ch_{1,DSRC}$ $Ch_{3,DSRC}$ $Ch_{5,DSRC}$	$Ch_{6,Sub-6GHz}$ $Ch_{9,Sub-6GHz}$	$Ch_{3,THz}$ $Ch_{2,THz}$
V_2	(x_2, y_2)	20	$Ch_{5,DSRC}$	$Ch_{8,sub-6GHz}$	$Ch_{1,THz}$
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
V_V	(x_V, y_V)	30	$Ch_{1,DSRC}$	$Ch_{6,Sub-6GHz}$ $Ch_{9,Sub-6GHz}$ $Ch_{8,Sub-6GHz}$	$Ch_{3,THz}$ $Ch_{1,THz}$ $Ch_{5,THz}$

Thus, each vehicle updates its neighbors with the following entries to find LFC_{v_j}:

$$SR_{v_j} =< C_i, f_i, E_{C_i,f_i}, \eta_{C_i,f_i} > \tag{3.1}$$

where f_i represents one of the M_i channels (M_i is the total number of channels in each wireless technology, i), E_{C_i,f_i} represents the energy of the signal at channel f_i in coverage range C_i, and η_{C_i,f_i} is the number of samples accordingly.

To explain how vehicles exchange the sensing results with each other, let us consider an example scenario in Fig. 3.2. As can be seen from the figure, the V_1 in DSRC range wants to communicate with V_2 in THz range. The former senses the spectrum by using energy detector equation as:

$$H_z(C_i, f_i)_{V_j} = \begin{cases} 0, & \text{if } E^{V_j}_{C_i,f_i} \leq \rho \\ 1, & \text{if } E^{V_j}_{C_i,f_i} > \rho \end{cases} \tag{3.2}$$

$$E^{V_j}_{C_i,f_i} = (1-\alpha)E^{V_j}_{C_i,f_i} + \alpha E^{V_{j+1}}_{C_i,f_i} \tag{3.3}$$

$$\alpha = \frac{\eta^{V_{j+1}}_{C_i,f_i}}{\eta^{V_j}_{C_i,f_i} + \eta^{V_{j+1}}_{C_i,f_i}} \tag{3.4}$$

All the available channels for V_1 is shown as:

$LFC_{V_1} = H_0(C_i, f_i)$

Likewise, all the available channels for V_2 is listed as: $LFC_{V_2} = H_0(C_{THz}, f_{THz})$. The common channels between both V_1 and V_2 must be in the THz band, so these vehicles exchange data using one of the common M_{THz} channels. Keeping the global record for the coverage range helps other vehicles to find the available channels for the specific location. When the V_9 reaches the current position of the V_1, it can request the list of free channels from the MC at that position if it is within the range of the MC. Consequently, the coordination of sensing results among vehicles and the management of global updated state by the MC, increases the path stability in such a dynamic environment which will be discussed in the next subsection.

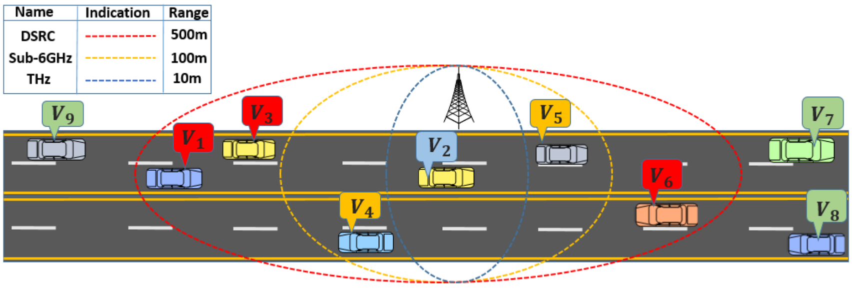


Figure 3.2: Coverage ranges of DSRC, sub-6GHz, and THz bands.

3.3 Path selection between source and destination using DSRC, sub-6GHz and THz bands

This section illustrates how a data packet is transferred from any source node to the destination node in a city scenario using LFC_{v_j} for three different bands. From our previous discussion, it is clear that coverage range is the basic parameter to reach a final decision about the available spectrum. Vehicles exchange control messages using the control channel to exchange information with each other or with the MC. As a result of this information exchange, each vehicle has the following entries in its flow table:

$$< V_j, V_{x,y}, V_{speed}, LFC_{V_j} > \tag{3.5}$$

These entries are used among neighbors to form a stable link between two moving vehicles. When a source node j wants to send data to any destination node k that is not in its communication range, it sends the request $(packet-in)$ message to the MC. For any source node, there are two possibilities; i) the MC is within source coverage range ii) the MC is not in range. If it is the former case, the MC replies the source node with a route to destination in the same manner as presented in [25].

$$route_{v_{jk}} = max(PD_p) \tag{3.6}$$

where PD_p is the path duration for all the available paths between source and destination.

$$PD_p = min(LD_{1,p}, LD_{2,p}, ..., LD_{l,p}) \tag{3.7}$$

$p = \{1, 2, ..., P\}$ is the total number of available paths between source and destination, l is the total number of links for each path between source and destination, and LD is the link duration which is calculated as:

$$LD_{jk} = \frac{R_i \pm d_{jk} + CC_{jk}}{\sqrt{(s_j \cos\theta_j - s_k \cos\theta_k)^2 + (s_j \sin\theta_j - s_k \sin\theta_k)^2}} \tag{3.8}$$

R_i represents the coverage range of each band, s is the speed, θ is the angle, $CC_{jk} = \{LFC_{v_j} \cap LFC_{v_k}\}$, and $d_{jk} = \sqrt{(x_j - x_k)^2 + (y_j - y_k)^2}$.

For the latter case, the source finds the relay node by using (8) to reach the MC. This relay node could be any other vehicle within the source coverage or the RSU. If it is the RSU, the delay from RSU to MC is considered negligible since both are directly connected in our proposed scheme.

Now the question is how these vehicles decide on which band they are going to communicate to ensure stability. The three wireless technologies we use in this proposed scheme have different frequency ranges, bandwidth, data rates, coverage areas, and under-utilized spectrum. In this thesis, we consider the coverage range of DSRC band as 500m, for sub-6GHz 100m, and 10m for THz band as can be seen in Fig. 3.2. These values are taken into consideration by undergoing some literature review about parameter modelling and link budget analysis of different bands [28] [29]. These ranges can vary from environment to environment. In order to explain the decision of communication band including common free channels, the switching between these bands, and the provision of stable path by the MC, we consider five different cases in the city model with the help of an example scenario.

3.3.1 Case i (when source vehicle is in DSRC range)

After exchanging the sensing results with the neighboring vehicles and with the MC, all nodes that act as relay nodes for the source, store that information in their flow tables and updated it periodically. Hence, whenever a source node sends the request message to the MC, the MC calculates its distance with its neighboring nodes based on the current position of the vehicle. If the distance is less than 500m and both nodes have common free channels in the DSRC band, the MC repeats this process for the second relay, and does so until it reaches the destination. For each link, based on the current position of the two communicating nodes and the range in which these nodes lie, these nodes only make stable link for that specific band. In this way, a path between source and destination can be the combination of three different wireless technologies.

3.3.2 Case ii (when source vehicle is in DSRC range but no free common channels are available)

If in the previous case, there is no common channel available in the DSRC band, which has the high possibility to be happened in any vehicular environment; the vehicle checks for other bands. As we have mentioned above, the channel state remains same for a specific coverage range. Since 500m covers both sub-6GHz and THZ ranges, so there is a possibility that the querying vehicle has common free channels in the other bands. In order to forward the packet without causing irrelevant delay, if the source and relay node are 100m or 10m away from each other, and both have same free channels for either case, they form a link. If a source node finds common channels for both sub-6 and THz, then it selects the one randomly for communication.

3.3.3 Case iii (when source vehicle is in sub-6GHz range)

For this case, we consider that all relay nodes are within sub-6GHz range only. After calculating the *LD* which includes the free channels in the sub-6GHz range, the MC repeats the process until it reaches the destination, and finally sends the heterogeneous stable path to the source vehicle. The sub-6GHz band, also known as FR1 band, operates between 2400 MHz to

7125 MHz [30]. We consider a chunk of this band known as N78, since it has already been commonly deployed and tested for 5^{th} generation vehicular networks. Furthermore, as discussed in Section 1, it is anticipated that this band will offer relatively high bandwidth and good coverage range than mm-wave [31], if operates at these frequencies. Table 3.2 shows the characteristics of n78 band which can support carriers of multiple bandwidths. We assume one carrier of 30 MHz for our scheme and calculate the total number of channels for sub-6GHz using (3.9).

Table 3.2: Characteristics of n78 band

Name	Ranges
Bandwidth	500 MHz
Channels	620000 to 653333
Duplex Mode	TDD
Frequency	3300 MHz - 3800 MHz
Supported Channel BW	10 15 20 30 40 50 60 70 80 90 100 MHz
No of Vehicles	25, 50, 75, 100

$$\begin{aligned} Channels &= \frac{channel_{max} - channel_{min}}{BW percarrier} \\ Channels &= \frac{653333 - 620000}{30} \\ Channels &= 1111 \end{aligned} \tag{3.9}$$

Among these 1100 channels, we consider a chunk of 110 channels to test the performance of our scheme when there is limited band available for limited coverage ranges of three different wireless technologies.

3.3.4 Case iv (when source vehicle is in sub-6GHz range but no common channel is available)

If in the sub-6GHz range, there is no common channel available for source and relay node, the source vehicle then checks for THz band. Since 100m covers the THZ range, so there is a possibility that the querying vehicle has common free channels in this band. To ensure delivery, if the source and relay node are 10m away from each other, and both have same free channels in the THz band, they will form a link. The THz band performs well in the range from 5m to 30m [32] [33]. Therefore, in this thesis, we consider its range as 10m. This band is discovered as the largest band up till now in the telecommunication domain. Hence, the researchers consider it as the upcoming 6^{th} generation wireless technology [34]. This band operates between the frequency range of 300 GHz to 3 THz and can provide a maximum bandwidth of 500 GHz per carrier, which is significantly higher value than 5^{th} generation.

3.3.5 Case v (when source vehicle is in THz range)

In this case, there are two possibilities: i) when the relay node is only 10 m away from the source vehicle, and similarly all neighboring vehicles are within this range, it means the vehicle must be at the intersection. Thus, at the intersection, source must be within the range of any RSU. In this case, the querying vehicle repeats the previous four cases (to find CC_{jk}) for making a stable connection between itself and the RSU. ii) when a source node does not have any node in 500 m range except the one which is just 10 m away from the source. And this relay might have another node which is 510 m away from the source. In all cases, if source vehicle fails to find any common free channel or any relay node, the vehicle then holds the packet until it finds any free channel or any relay by using store-carry-and forward scheme. A delay might occur using this approach, but this delay is acceptable than dropping the packet. The flow chart summarizing the whole algorithm is shown in Fig. 3.3.

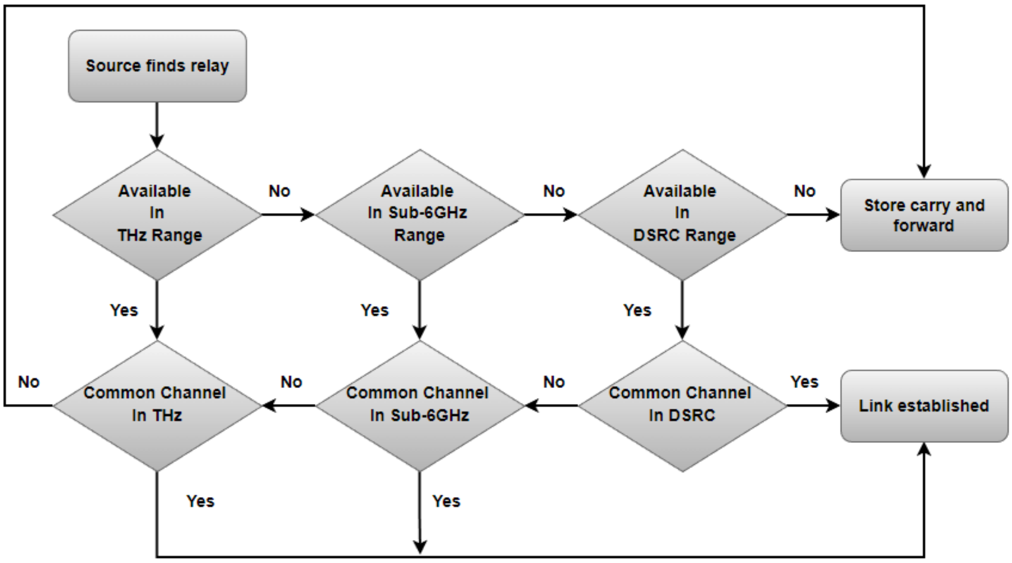


Figure 3.3: A flowchart representing five cases of 6G CR-SDVN.

Chapter 4

Results and Discussions

The section presents the evaluation of proposed scheme in terms of different quality of service (QoS)parameters.

4.1 Simulation environment

The simulation model for the proposed scheme was created by integrating two different simulation environments. An open-source simulation platform, the NS-2, was used to model and analyse the proposed topology. Since the topology only considers the city scenario, the SUMO traffic simulator was used to model the mobility of vehicles in city scenario. SUMO is also an open-source traffic simulation tool which is used to create vast networks for both highway and city scenarios. We consider city scenario in this thesis to test the proposed idea for low speed vehicles. As there are intersections present in the city scenario, therefore in comparison to the speed of vehicles in highway scenario, it is quite simple to handle stability in such a dynamic environment. Moreover, the coverage range of THz band also ensure the stability for the case when there is no other relay node except the one in THz range. We will consider the highway model in the near future. The route file created from SUMO can be reused with NS-2 and many other simulation tools. The versions of software we used include NS-2.35 and SUMO-1.14.1.

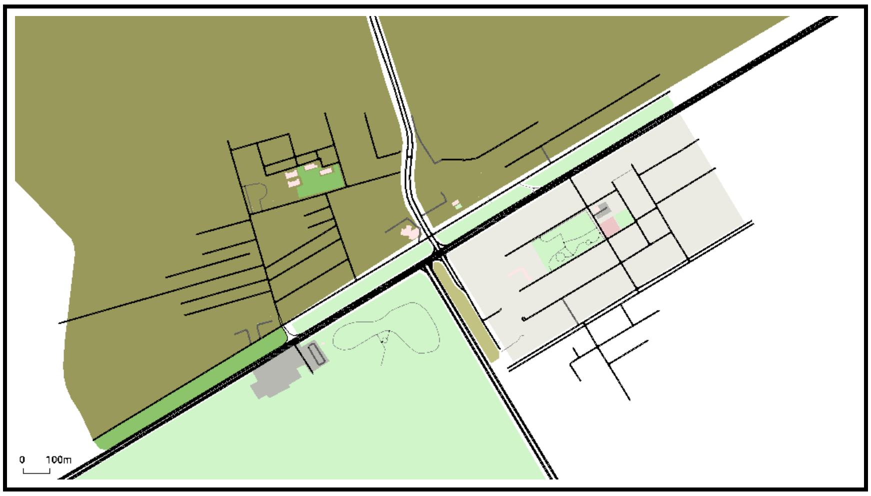


Figure 4.1: Simulation Environment.

The mobility model of vehicles can be seen in Fig. 4.1. We considered the total area of 1500 m x 3000 m. The number of RSUs was $r = 3$, number of channels, M_i for DSRC, sub-6GHz, and THz was 5, 110, and 27; with coverage ranges, R_i = 500 m, 100 m, and 10 m, respectively. Simulations were performed for 25, 50, 75, and 100 vehicles each with average speed 20 m/s, that varies between 10 m/s and 25 m/s for different simulation times (100 s and 150 s). Table 4.1 shows some important simulations parameters in tabular form.

Since this is the first work considering spectrum sensing and routing simultaneously for three different wireless technologies. Therefore, as men-

Table 4.1: Simulation Parameters

Parameters	Values
Area	1500 m x 3000 m
Velocity	10 m/s - 25 m/s
Packet size	64 bytes
Number of RSUs	3
Simulation time	100 s and 150 s
Number of vehicles	25, 50, 75, 100
Coverage area for DSRC	500 m
Coverage area for sub-6GHz	100 m
Coverage area for THz	10 m

tioned in Section I and II, no similar protocol is publicly available for comparison. Hence, we considered three different reference schemes that were implemented individually for each technology to compare our proposed scheme and name them as reference scheme with DSRC [25], reference scheme with sub-6GHz [14], and reference scheme with THz [27]. To make a fair comparison, we implemented the idea of [14] with an integration of SDN and CR technology and consider a cluster as the coverage range of sub-6GHz only for this reference scheme. Also, for reference scheme with THz, we only simulated the THz band by considering the idea of the authors [27]. The same simulation environment and parameters were considered to simulate these reference schemes. Simulations were done to evaluate the performance of our proposed scheme by using the following three metrics.

(i) Packet delivery ratio (PDR): This is the ratio of successfully delivered packets at the destination to the total number of data packets sent from the source. If $sent_n$ is the number of sent packets and $rcvd_n$

represents number of successfully received packets at the destination then PDR is calculated as:

$$PDR = \sum_{n=1}^{m} \left(\frac{rcvd_n}{sent_n}\right) * 100 \tag{4.1}$$

(*ii*) End-to-end delay: It is the total time required by a packet to travel from a source to the destination. This value is calculated as:

$$Delay = Packet\ arrival\ time - packet\ departure\ time \tag{4.2}$$

(*iii*) Routing overhead ratio (ROR): It is the ratio of number of control packets to the number of total packets in the network. If $cntrl_n$ is the number of control packets sent in the network and $total_n$ represents the total number of packets, the overhead is then calculated as:

$$ROR = \sum_{n=1}^{m} \frac{cntrl_n}{total_n} \tag{4.3}$$

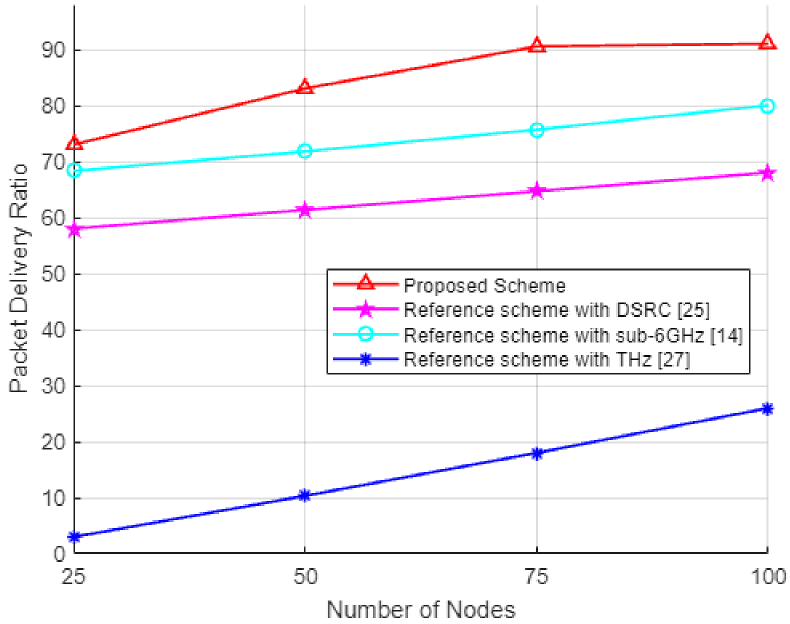
4.2 Result Analysis

The summary of our results based on the comparison of three individual wireless technologies for three parameters are presented in Table 4.2. In this section, we will discuss the results for each parameter in detail.

Table 4.2: Individual comparison of various bands with regard to PDR, end-to-end delay, and ROR

Spectrum band	Drawbacks
DSRC	PDR value is low with high end-to-end delay and overhead ratio. This shows the scarcity of dedicated spectrum for vehicular communications.
Sub-6GHz	All three parameters show quite good performance in comparison to both DSRC and THz bands. This is due to a good number of unused bands and a good coverage area.
THz	All parameters show poor results because of low coverage range.

4.3 Packet delivery ratio



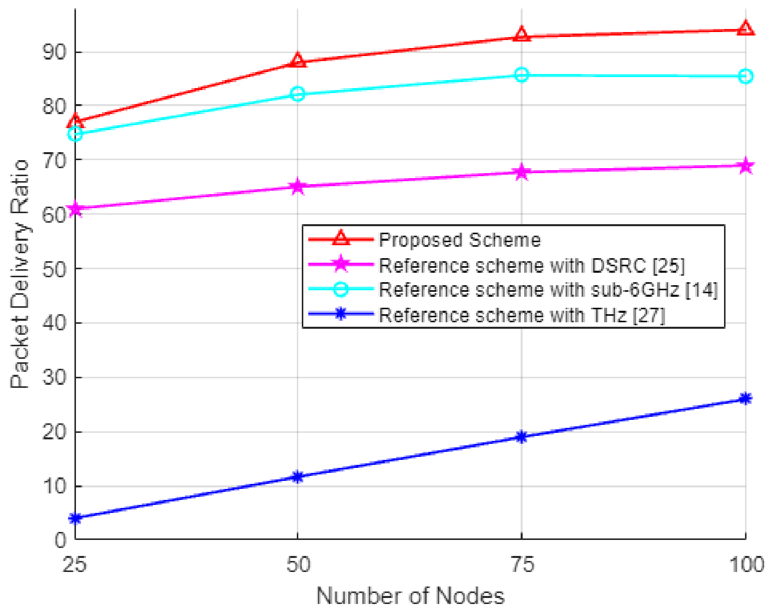


Figure 4.2: Performance comparison of 6G-CR-SDVN in terms of PDR at 100 s and 150 s.

Fig. 4.2 shows the comparison of PDR for our proposed scheme and three different reference schemes for each wireless technology (DSRC, sub-6GHZ, and THz) individually, in city scenario for two different simulation times. The PDR increased with an increase in the number of nodes in the network as well as with an increase in the simulation time. This has proved our objective of maintaining stability in the network for such a highly dynamic and heterogeneous network. By increasing the number of nodes and the simulation time, increases the connectivity in the network as if free bands are available, vehicles can form stable link for long duration. It can be observed from Fig. 4.2 that the proposed scheme achieved high PDR than the other three reference schemes. The reason is simple, by considering the three different technologies in the vehicular network, the proposed scheme increases the number of common free bands. Based on the coverage distance between nodes, if a spectrum is not found in that specific band, there is a high chance that vehicles can still establish a stable link by using any of other available bands within that coverage range. As vehicles periodically sense the spectrum and update the MC with their current state, therefore, MC keeps the global state of the network which is also helpful for any vehicle that joins the network at some later time to keep stable connection with its destination node, as we discussed in the previous section. Thus, both figures show that by calculating the shortest stable path with consideration of both the link duration and the number of common free channels, for three different wireless technologies simultaneously, our scheme outperforms the other three schemes.

The reference scheme with THz shows poor delivery ratio in comparison to reference scheme with sub-6GHz and DSRC. This is due to the less coverage area of THz band. Ideally, this PDR should be high than other bands as spectrum has large amount of unused bands but, the small coverage range of approximately 10 m degrades the overall performance of this band in vehicular networks. For moving vehicles, it is unusual to maintain a stable connection just for 10 m distance, thereby degrading the performance of this band. It is only possible for this band to maintain stability at intersections, whose benefit is achieved in our proposed scheme as can be seen in all simulation results. For other two schemes, the DSRC band has large coverage range but the spectrum becomes small to fulfil all the demands of vehicular users individually. This limited spectrum of about 75 MHZ makes the performance poor by dropping the packets due to not finding any free common channel, but if bands are available the scheme can outperform the other two reference schemes as it has large coverage range. Likewise, reference scheme with sub-6GHz shows better performance than both DSRC and THz schemes. Because the coverage range is 10 times better than THz band, but it is less than DSRC band, therefore, for vehicular networks, maintaining a stable connection for only 100 m range is difficult but as the spectrum has large number of free bands in comparison to DSRC, it outperforms the both reference schemes. Our proposed scheme achieved a maximum delivery of 94%.

4.4 Delay

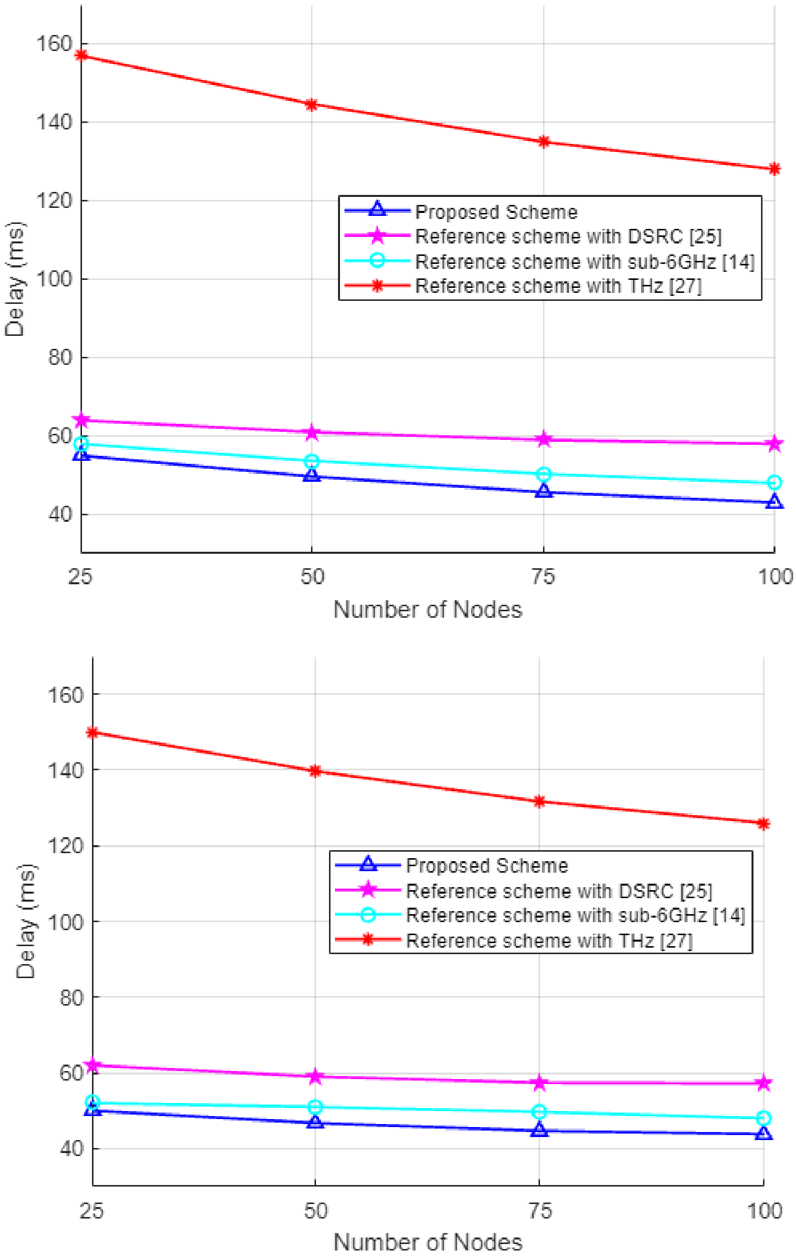


Figure 4.3: Performance comparison of 6G CR-SDVN in terms of end-to-end delay at 100 s and 150 s.

Fig. 4.3 shows the comparison of end-to-end delay for our proposed scheme and three different reference schemes for each wireless technology (DSRC, sub-6GHZ, and THz) individually, in city scenario for two different simulation times. From the figure, it can be seen that increasing the time window increases the network performance because vehicles have more time to establish the stable connections. The overall delay for all the schemes show the same pattern i.e., with increasing the number of vehicles the delay decreases. This is because for less number of vehicles, it is difficult for the vehicles to maintain stability by finding both the relay and the common free channel simultaneously. For each individual scheme, there is a possibility that if a relay is found to make a stable connection the common free channel is not available for that specific scheme, so no connection is established and the network incurs delay in transmitting the packet successfully. However, in our case, if that possibility occurs, we have three different bands available, among those three bands there is a high chance that a common free channel is available for that specific coverage range, thereby increasing the network performance. As MC is responsible for maintaining the global state, therefore in such a scenario, MC provides the stable heterogeneous path that switches between different bands. A vehicle when tries to make connection through DSRC can switch to sub-6GHz and THz band respectively, if DSRC is not available at that time. Moreover, if in sparse network, such a condition occurs that a vehicle does not find a relay and a channel in our scheme, it keeps the packet and forward it as soon as it reaches a node in any coverage range. Considering three different technologies increase the chance for a vehicle to reach the coverage range of a RSU or a relay soon as we have 10 m, 100 m, and 500 m ranges available in our proposed scheme, thereby showing improvement as compared to individual schemes.

However, for each reference scheme, when a vehicle does not find any relay node or a common free channel or both, it will drop the packet which degrades the network performance. As the coverage range of THz band is less, the reference scheme with THz shows high end-to-end delay in comparison to DSRC and sub-6GHz schemes. The reason is same as mentioned above while discussing the PDR i.e., due to less coverage range, it is difficult for vehicles to maintain a connection, thus the packet dropping rate is high in this band even though the number of free channels is large. It takes long for a vehicle to reach destination if 10 m coverage range is used to maintain the connections which is unusual and not possible in case of vehicular networks. Likewise, the reference scheme for DSRC has high coverage range but the number of free bands are congested. We get benefit from this coverage range in our proposed scheme by using any free available bands from either sub-6GHz or THz since both coverage ranges lie within the 500 m, thereby maintaining the stability. Because the sub-6GHz act as the medium band based on the coverage range between DSRC and THz, and it has large number of unused bands, therefore, it shows better performance in comparison to reference scheme with DSRC and THz. We achieved a minimum of 43.8 ms and the maximum of 50.3 ms end-to-end delay for our proposed scheme. For reference schemes, the minimum values are 48 ms, 57.2 ms, 126 ms and maximum of 52 ms, 62 ms, 150 ms were achieved for sub-6GHz, DSRC, and THz, respectively.

4.5 Overhead

Fig. 4.4 shows the comparison of ROR for our proposed scheme and three different reference schemes for each wireless technology (DSRC, sub-6GHz, and THz) individually, in city scenario for two different simulation times. From the figure, it can be observed that ROR increases with an increase in the network density and with the time window as well. To establish a link in any type of communication network, a node needs to exchange control packets to share the local state with its neighboring nodes. In our scheme, a vehicle needs to update the MC as well as its neighboring vehicles about the channel sensing results and other parameters required for routing periodically. This is done by exchanging the control packets among different nodes. The reason that the proposed scheme outperforms the three reference schemes is that it updates the MC periodically about its local state. The global state kept by MC helps any querying vehicle in finding a stable path with less number of exchanging querying messages (that are control messages in any conventional routing scheme), thereby reducing the overall number of control packets in the network. Another reason is that as the proposed scheme is an integration of three different technologies, therefore, the network has less chance to fail in finding any relay node along with common free channel since switching is provided by the MC. Due to this low possibility, the number of control messages exchange is low thus reduces the network burden.

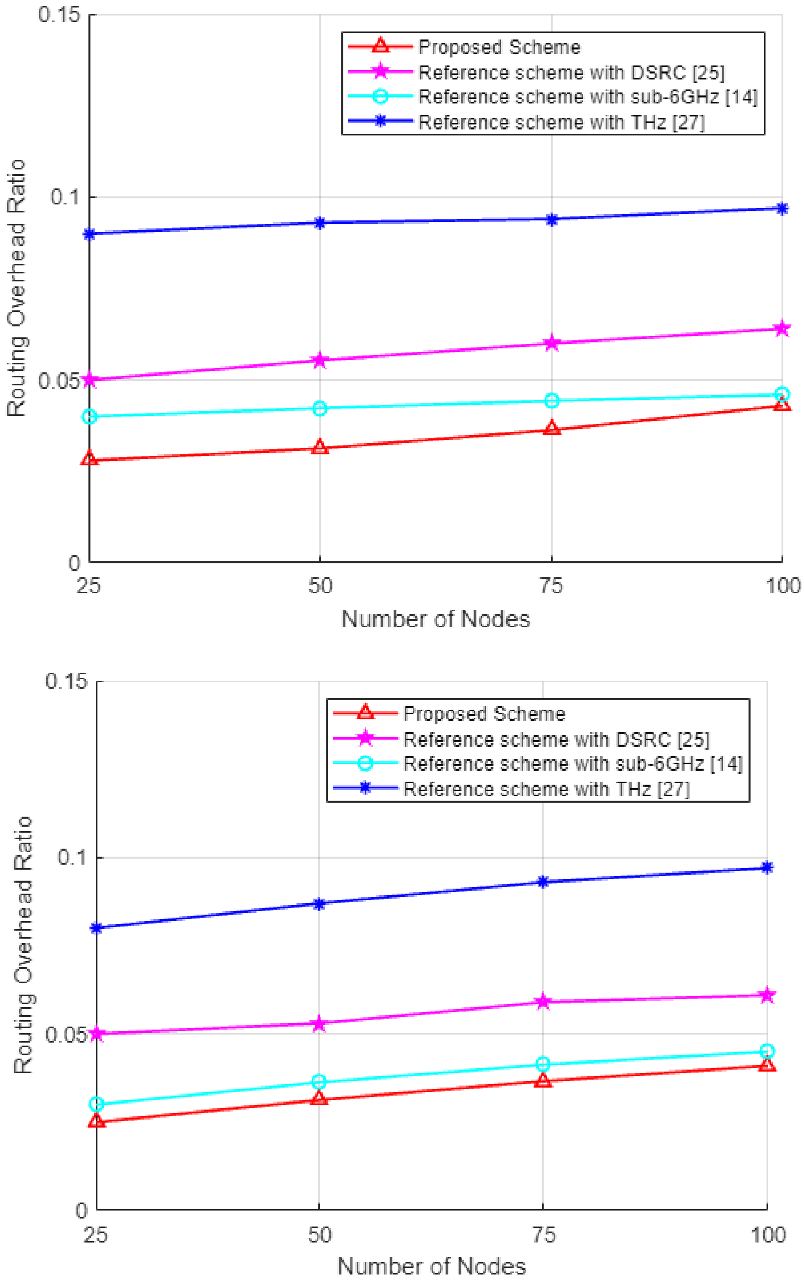


Figure 4.4: Performance comparison of 6G CR-SDVN in terms of ROR at 100 s and 150 s.

As discussed above, the reference scheme with THz shows large overhead in comparison to DSRC and sub-6GHz schemes. The reason is a large number of exchange messages are required when the links among vehicles break frequently due to less coverage area. Therefore, vehicles made several attempts to send control packets periodically in order to connect to the network and build pathways, which causes the overhead ratio to rise. The reference scheme with DSRC shows improvement in comparison to THZ scheme but it has large overhead when compare with sub-6GHz scheme. Because for DSRC, when the free channel is not available, the links are break frequently in the same way as it occurs for THz scheme but the large coverage range of DSRC outperforms the THz scheme. The second best performance in terms of overhead ratio among all the reference schemes was of sub-6GHz band. A good coverage area with sufficient number of channels exchange the less number of control packets when compare with DSRC and THz schemes. For all the schemes we considered in this thesis, there is a tendency that the overhead ratio increases as the number of vehicles increases. But, we can achieve an optimal value by considering the controller as shown in the Fig. 4.4 for the proposed scheme. Consequently, our simulation results demonstrate that our proposed scheme performs better than three reference schemes. Also, these results demonstrate that by integrating different technologies and considering spectrum sensing and routing simultaneously can increase network performance even for such a highly dynamic network.

Chapter 5

Conclusion & Future Works

5.1 Concluding Remarks

In this thesis, we introduced a novel 6G cognitive radio software-defined vehicular network. The idea is to integrate different wireless technologies by combining spectrum sensing, switching, and routing to provide a stable path between source and destination vehicles. The common free channels among DSRC, sub-6GHz, and THz bands, sensed by each moving vehicle using an energy detector method, are considered between communicating vehicles to establish a stable link. A main controller is responsible for keeping the global sate of the network and provides the stable heterogeneous paths on demand to any querying nodes. This routing path is selected by considering common channels, speed, distance, and coverage range of each wireless technology. The controller is also responsible for managing the switching between these bands. By considering the coverage range and the availability of common free channels at a specific location, The switching decision is taken. Therefore, based on the availability of channels, a path between any source and destination is the combination of different wireless bands. Our simulation results show better performance in terms of packet delivery ratio, end-to-end delay, and overhead ratio.

5.2 Future Work

- We assumed the ideal conditions in our proposed work and ignored path losses and the parameter modeling of wireless bands, which can be computed in a forthcoming edition of this study.

- This work can be extended by adding UAV's as dynamic RSU in vehicular ad-hoc networks to enhance the performance of vehicular communication.

- It is possible to suggest beam formation and various antenna designs to expand the THz communication coverage area, which will improve vehicle communication even more.

- To further increase the effectiveness of the proposed effort, we can incorporate other wireless bands, such as TVWs and WiFi, into our proposed strategy.

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