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## Research

**Keywords:** VANETs, Highway Routing Protocols, V2V and V2R Communications, IEEE 802.11p.

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# A Novel Highway Routing Protocol in Vehicular Ad hoc Networks

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**Abstract:** The Vehicular Ad hoc Networks (VANETs) are an example of mobile networks which utilizes Dedicated Short Range Communication (DSRC) to establish a wireless connection between cars and their primary purpose is to provide more security and comfort for passengers. These networks utilize wireless communications and vehicular technology to collect and disseminate traffic information, and it is required to be delivered to all vehicles on the network reliably and quickly. One of the major challenges raised in VANETs is that the communication path between the source and destination nodes is disconnected due to the dynamic nature of the nodes in this network, and the reconnection process of nodes through the new path reduces the performance of network. This paper presents a highway routing protocol to overcome some of the challenges of these networks including cost, delay, packet delivery rate, and overhead. The NS2 is used for simulation and the performance of the proposed protocol is compared with the VMaSC-LTE and DBA-MAC protocols. The results of the simulation indicated that the proposed protocol performs better than the mentioned protocols.

**Keywords:** VANETs, Highway Routing Protocols, V2V and V2R Communications, IEEE 802.11p.

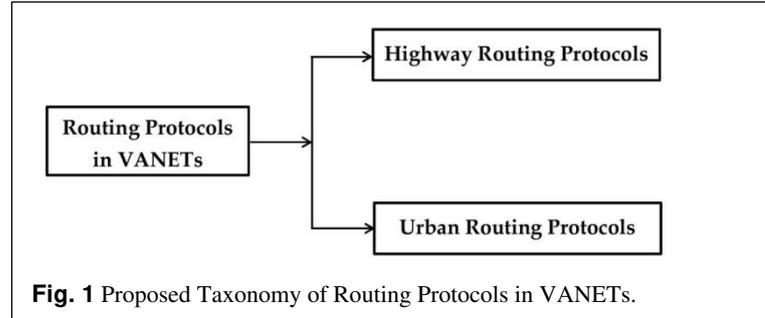
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## 1. Introduction

Vehicular ad hoc network is a wireless network in which the vehicles equipped with wireless interface can communicate with each other or fixed roadside equipment [1] (Fig.1). These networks create wireless communication among moving vehicles by means of dedicated short-range communications (DSRC) [2]. DSRC is, in fact, a version of IEEE 802.11a, improved as IEEE 802.11p for operations with low overhead [3]. VANETs characteristics are mainly similar to mobile ad hoc networks (MANET) which means both of them are self-organizing and self-management, have low bandwidth and stay in the same position in case of sharing radio transmission. However, the biggest operational obstacle for VANETs (versus MANET) is its high speed and the mobility of mobile nodes, alongside the routes, indicating that the appropriate design of routing protocols requires the improvement of MANET structure so that it can match itself to the rapid mobility of VANETs nodes in an efficient way [4]. Vehicular ad hoc networks provide the context for diverse applications like security and welfare applications in a wide range for intelligent transportation systems [ITS] [5]. Thus, the development of appropriate routing protocols has always been a challenge for researchers. For example, in communication environments, most routing protocols focus on urban environments and less on highways. Other challenges to consider include: Dynamic topology and high mobility, Alternative network disconnection, prediction and modeling of traffic path, diverse communication environments, Sufficient energy and memory, distribution networks, security, and confidentiality [6,7,8,9,10,11,12,13]. In this paper, a highway routing protocol called "Greedy Highway Routing Protocol (GHRP)" is presented which contributes to solve or minimize any of the issues raised above. In the proposed method, it is attempted to minimize the number of fixed Road-Side Units (RSUs) by identifying accident sites and installing fixed RSUs in those locations, minimizing the cost of purchasing and installing equipment, and cover the entire route using mobile RSUs which are public transport equipment. The packet delivery rate increases and end-to-end delay decreases when covering the entire route with fixed and mobile RSUs. Ultimately, the main purpose of VANETs, i.e. security and comfort of users, is obtained by collecting the entire information of route and distributing it between cars. The next sections are organized as follows: Section 2 provides DBA-MAC and VMaSC-LTE protocols. Section 3 examines the proposed protocol. Section 4 elaborates discussion, comparison, and simulation of the proposed protocol with other highway routing protocols. Finally, conclusion, challenges, and future works are reported in Section 5.

## 2. Related work

Since one of the main goals of inter-vehicle networks is to maintain the safety and comfort of occupants of cars [4,12,14], and most of the casualties occur in highways, attempts have been made to divide the inter-vehicle routing protocols into urban routing protocols and highway routing protocols (Figure 1), and focus more on highway routing protocols, which are less considered.



**Fig. 1** Proposed Taxonomy of Routing Protocols in VANETs.

The highway routing protocols can also be divided into different categories depending on how the message is delivered, communication of cars with each other and the infrastructure, the use of fixed and mobile RSUs, and the like. Since the proposed protocol is a highway routing protocol, fixed and mobile RSUs are used and simulations are performed on the MAC layer, and both DBA-MAC [15] and VMaSC-LTE [16] protocols are highway routing protocols and used fixed and mobile RSUs and simulations are performed in the MAC layer, these two protocols are examined, and the proposed protocol is compared with them.

### 2.1. DBA-MAC Routing Protocol

In 2009, Bononi et al. introduced the DBA-MAC protocol [16]. The DBA-MAC is presented for a multi-lane highway scenario which is bidirectional. The vehicles are assumed to be equipped with GPS, and any emergency messages include dissemination direction, time to live (TTL), and risk zone, and only nodes in the risk zone are allowed to relay the message. The DBA-MAC protocol defines two priority classes to improve the access to channel: Normal vehicles and Backbone Member (BM) where BMs are in higher priority. A node selects itself as BM to create a Backbone, and then broadcasts a beacon message which selects itself as BM. Vehicles which receive the beacon message calculate the remaining time the message can be disseminated (be released). Then, a car with a longer residual time than a threshold is selected as BM. When a  $BM_{N+1}$  receives a message from the  $BM_N$ , immediately approves it and disseminates it with a SIFS delay for  $BM_{N+2}$ . If a Backbone needs to be repaired, the DBA-MAC will immediately replace a refresh Backbone. Further, the protocol uses infrastructure to avoid possible interruption of communication due to the low number of vehicles, in addition to vehicle-to-vehicle communication, where the locations of these infrastructure must be carefully selected.

### 2.2. VMaSC-LTE Routing Protocol

In 2016, Ucar et al. introduced the VMaSC-LTE protocol [17]. This protocol is a cluster-based technique which uses the IEEE 802.11p standard and selects the cluster head with relative mobility metric, which is calculated using the average relative speed of neighboring vehicles. The average relative speed is obtained from  $AVGREL\_SPEED_i = \frac{\sum_{j=1}^{N(i)} |S_i - S_{i_j}|}{N(i)}$  where  $N(i)$  is the number of neighbors having the same direction of cluster head for vehicle  $i$ ,  $i_j$  is the id of node  $j$ , the neighbor of vehicle  $i$  and  $S_i$  is the speed of vehicle  $i$ . Other features of this protocol include periodically dissemination of the information of cluster members in hello packets, direct connection to the cluster with minimal overhead instead of multi-step connection and reactive clustering to maintain the structure of cluster without over using the network. In the cluster maintenance phase, a timer is used to control the communication between the cluster head and the other cluster members. If the cluster head does not receive any packets from its members in the same cluster at a predefined time, it assumes that the node is lost.

## 3. Proposed Algorithm

In this paper, a new routing algorithm is presented to improve the weaknesses of previous methods such as delay, overhead, packet delivery rate, and the like. The routing mode uses both fixed and mobile RSUs. First,

the accident sites are identified and fixed RSUs installed where it is intended to deploy the inter-vehicle network. However, as known, the whole route cannot be well-covered just by using fixed RSUs installed at accident sites. Therefore, in the proposed protocol a combination of fixed and mobile RSUs are used. As it was mentioned, fixed RSUs are used at accident sites and mobile RSUs at other locations on the route. Public transit vehicles are used as mobile RSUs by installing RSUs. In the proposed protocol, each vehicle can use fixed and mobile RSUs to reduce the number of sending steps and delay in order to send packets and warning signals to other vehicles. The routing steps are as follows:

- If there is a direct route from the source to the destination, i.e. the destination is within the coverage radius of the source, the package is sent directly to the destination.

- If there is no vehicle or RSU (fixed or mobile) near the source, the source vehicle transports the data packet to the first vehicle within its radius and then sends it.

- If there is an RSU (fixed or mobile) near the source and destination, the source sends the packet to the RSU (fixed or mobile). After receiving the packet, the RSU near the source sends it to nearest RSU to destination and then it is sent to the destination.

- If there is more than one vehicle near the source, but none of them are fixed or mobile RSUs, the source vehicle sends the packet to the farthest vehicle within its radius and the shortest distance with the fixed or mobile RSUs. After the arrival of packet to the RSU, the RSU sends it to the nearest RSU to the destination and then it is sent to the destination.

- If there is more than one route to send the data packet, a route with fewer steps and a longer route life is selected.

### *3.1. Assumptions*

The following assumptions were made:

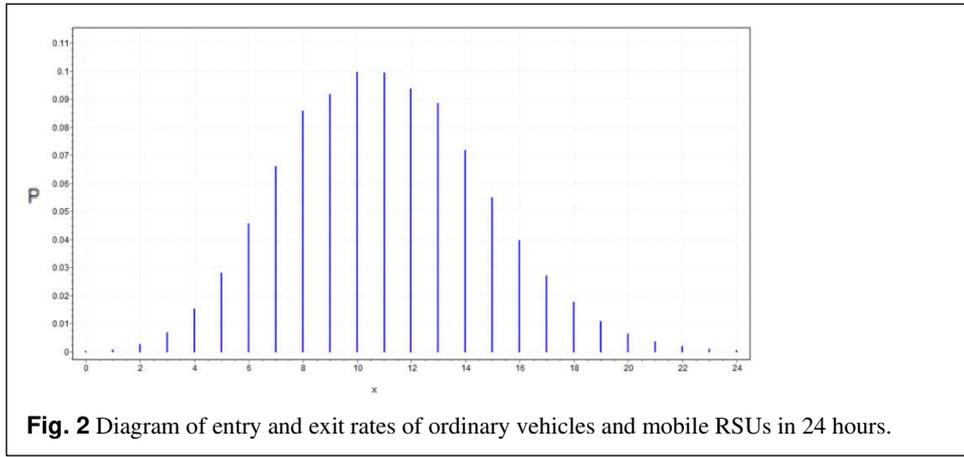
- Each vehicle using its GPS obtains its location, the location of neighboring nodes, the location and direction of destination, road information (such as traffic), as well as a map of its intended environment. This information is periodically transmitted as a Hello message to nearby vehicles within its range.

- A digital map with the conditions of road traffic load is installed on the vehicle.

- The On-Board Unit (OBU) in any vehicle which is used as a mobile RSU has an IEEE 802.11p and a 3G interface. The IEEE 802.11p interface is used to communicate with ordinary cars and the 3G interface is used to communicate with RSUs (fixed and mobile).

- 20% of the nodes in the network are considered as fixed and mobile RSUs and the number of fixed and mobile RSUs is considered to be equal.

In addition, it is assumed that the entry and exit rate of ordinary vehicles and the mobile RSUs on the road follows the Poisson distribution (Figure 2), and distribution function of the vehicles and mobile RSUs is uniform along the entire road. It should be noted the Poisson distribution is used here since the normal distribution is not suitable for  $n$  nodes larger than 20 and here  $n$  is the number of vehicles which is much more than 20. Figure 2 presents the diagram of entry and exit rates of ordinary vehicles and mobile RSUs in 24 hours with the number of vehicles per hour on the road which can be used to estimate the number of steps and the arrival time to the accident site.



### 3.2. Estimating the number of steps and transmission time

As mentioned before, one of the features of the proposed algorithm is to reduce delay by minimizing the number of steps between source and destination. For this purpose, if there are several routes between the source and destination, the shortest route is selected by estimating the number of steps. In order to estimate the number of steps, the required parameters are defined as follows (Table 1):

**Table 1.** Parameters used in the proposed protocol.

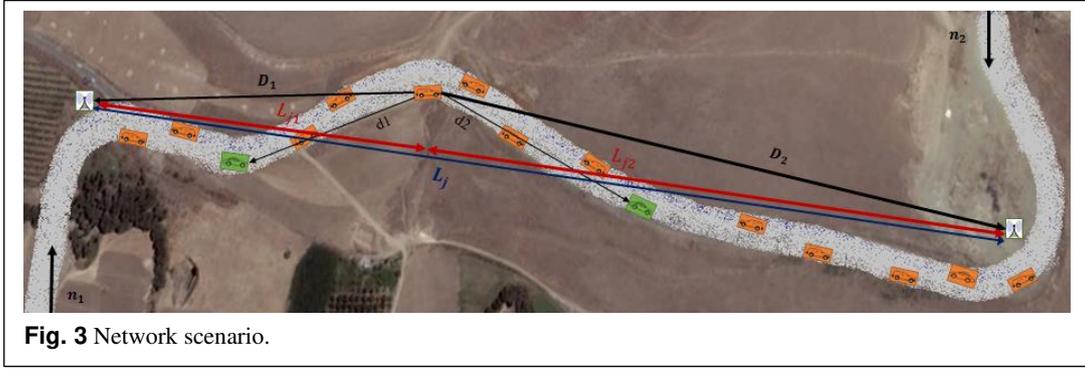
Description	Name
The coverage radius of each vehicle	R
Packet delivery time between two source and destination vehicles	T
Delivery time between two vehicles	$t_d$
Speed of vehicle i	$V_i$
Speed of vehicle j	$V_j$
The distance between two vehicles i and j	$d_{ij}$
The whole length of the route	$X_i$
Total number of mobile RSUs in 24 hours	N
The number of mobile RSUs moving to the right of the road at a specific time	$n_1$
The number of mobile RSUs moving to the left of the road at a specific time	$n_2$
Total number of mobile RSUs at a specific time on the road	$n=n_1+n_2$
Total number of ordinary vehicles in 24 hours	M
The number of vehicles moving to the right of the road at a specific time	$m_1$
The number of vehicles moving to the left of the road at a specific time	$m_2$
Total number of ordinary vehicles at a specific time on the road	$m=m_1+m_2$
Poisson probability at a particular moment	P
The length of section j	$L_j$

Considering that the entry and exit rate of ordinary vehicles and mobile RSUs on the road follows the Poisson distribution, first the number of vehicles and RSUs on the road is calculated from the following equation 1,2:

$$n = N \times P \times 10 \quad (1)$$

$$m = M \times P \times 10 \quad (2)$$

In the above case, it is multiplied by 10 because the probability is 1 at the best. Since the Poisson distribution is considered for  $\lambda = 13$ , and the maximum value is approximately 0.1 as shown in the graph, so it is multiplied by 10 to get 1.



**Fig. 3** Network scenario.

Since fixed and mobile RSUs are used and fixed RSUs are installed at the accident sites in the proposed algorithm, the route is divided into several sections (Figure 3). Then, we have (Eq. 3,4):

$$N_{jk} = n_k \times \frac{L_j}{X_i} \quad k = 1,2 \quad (3)$$

$$M_{jk} = m_k \times \frac{L_j}{X_i} \quad k = 1,2 \quad (4)$$

where  $N_{jk}$  indicates the number of mobile RSUs and  $M_{jk}$  shows the number of ordinary vehicles in section  $j$  of the road.

It is assumed that the source vehicle is in section  $j$  of the road and wants to send a packet. Since it can send the packet in the direction or in the opposite direction of itself, the  $j$ th part of the road is divided into two parts of  $j_1$  and  $j_2$ . The distance from the source vehicle to the fixed RSU behind it is called  $D_1$  and the distance from the source vehicle to the fixed forward RSU is  $D_2$ . Now, if  $D_2 > D_1$ ,  $D_2$  is selected for sending the packet because there is a higher probability of more mobile RSUs in this area, then we have (Eq. 5,6,7,8):

$$N'_{j_2k} = n_k \times \frac{L_j}{D_2} = n_k \times \frac{L_j}{X_i D_2} \quad k = 1,2 \quad (5)$$

where  $N'_{j_2k}$  is the number of RSU in  $L_{j_2}$  section.

$$d = \frac{D_2}{N'_{j_2k}} = \frac{D_2^2 \times X_i}{n_k \times L_j} \quad (6)$$

where  $d$  is the distance from the source to the first RSU.

$$M'_{j_2k} = m_k \times \frac{L_j}{d_2} = m_k \times \frac{L_j}{X_i d_2} \quad k = 1,2 \quad (7)$$

where  $M'_{j_2k}$  is the number of ordinary vehicles between the origin and the first RSU.

$$d' = \frac{d_2}{M'_{j_2k}} = \frac{d_2^2 \times X_i}{m_k \times L_j} \quad k = 1,2 \quad (8)$$

where  $d'$  is the average distance between ordinary cars from the origin to the first RSU.

In order to calculate the number of steps to get to the nearest fixed or mobile RSU:

A. If  $d' \leq R$ . Then, we have (Eq. 9,10):

$$C_j = \frac{L_j}{N'_{j_2k} \times R} \quad (9)$$

$$T = C_j \times t_d \quad (10)$$

where  $C_j$  is the number of steps to reach the nearest fixed or mobile RSU and  $T$  is the time to reach the nearest fixed or mobile RSU.

B. If  $d' > R$ . Then, we have (Eq. 11,12):

$$C_j = M'_{j_2k} - 1 \quad (11)$$

$$T = \left( \sum_{i=1}^{M'_{j2k}-1} \frac{V_i}{d_{ij}} \right) + (C_j \times t_d) \quad (12)$$

If  $D_1 = D_2$ , since the number of steps will be equal, a route with the longest lifespan will be selected among the available routes.

### 3.3. Calculating the lifetime of the route

The lifespan is calculated as follows:

A. Both vehicles should be in the same direction and the speed of the front vehicle should be more. In this case, the lifetime of the path is calculated by the following equation 13:

$$\text{LifeTime}_{\text{link}} = \frac{R - |d_{ij}|}{|V_i - V_j|} \quad (13)$$

B. Both vehicles should be in the same direction and the speed of the front vehicle must be less. In this case, the lifetime of the route is calculated by the following equation 14:

$$\text{LifeTime}_{\text{link}} = \frac{R + |d_{ij}|}{|V_i - V_j|} \quad (14)$$

C. Vehicles move in the opposite direction. In this case, the lifetime of the route is calculated by the following equation 15:

$$\text{LifeTime}_{\text{link}} = \frac{R + |d_{ij}|}{V_i + V_j} \quad (15)$$

where  $R$  is the transmission range between the vehicles,  $d_{ij}$  represents the distance between vehicle  $i$  and  $j$ ,  $V_i$  is the speed of vehicle  $i$  and  $V_j$  is the speed of vehicle  $j$ .

## 4. Result and discussion

In this section, the performance of the proposed protocol is compared through various factors. NS2 simulator is used to simulate the proposed protocol and compare its performance parameters with other protocols [17]. Table 2 gives the parameters used in the simulation.

**Table 2.** Simulation parameters.

Parameters	Value
Simulation Time	1000s
Highway length	8 Km
Vehicles speed (min)	20 m/s
Vehicles speed (max)	33 m/s
Number of Vehicles	25, 50, 100, 200
Data Message Size	512 Bytes
Transmission Range	250 m
Transmission Power	1 mW

### 4.1. Performance parameters

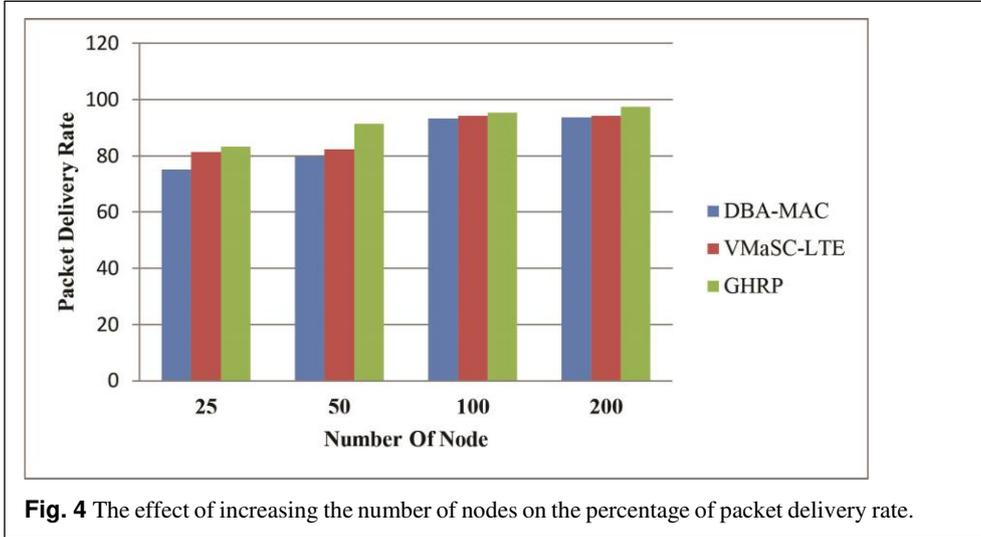
The parameters such as packet delivery rate, overhead, end-to-end delay, and number of dropped packets were used to evaluate the performance of the proposed protocols and compare them with other protocols. In this section, each of these parameters is explained and all three proposed protocols, DBA-MAC and VMaSC-LTE, are compared with each other.

#### 4.4.1. Packet Delivery Rate (PDR)

The ratio of total packets received by the destination node to the total packets sent by the source is obtained using the following equation 16.

$$\text{PDR} = \frac{\text{Number of packets received by destination}}{\text{Number of packets sent by source}} \quad (16)$$

Packet delivery rates gives information on how successful the protocol is in delivering data packets, and the higher PDR means that the protocol has been more efficient in delivering packets.



The breaking of the communication link between nodes due to the high speed of the nodes is regarded as one of the main concerns in inter-vehicle networks is. As observed in Figure 4, the communication links between the nodes are less likely to be broken when the number of nodes increases, resulting in less dropped packets and higher packet delivery rates. Furthermore, it is clear that the proposed protocol performs better than the other two protocols.

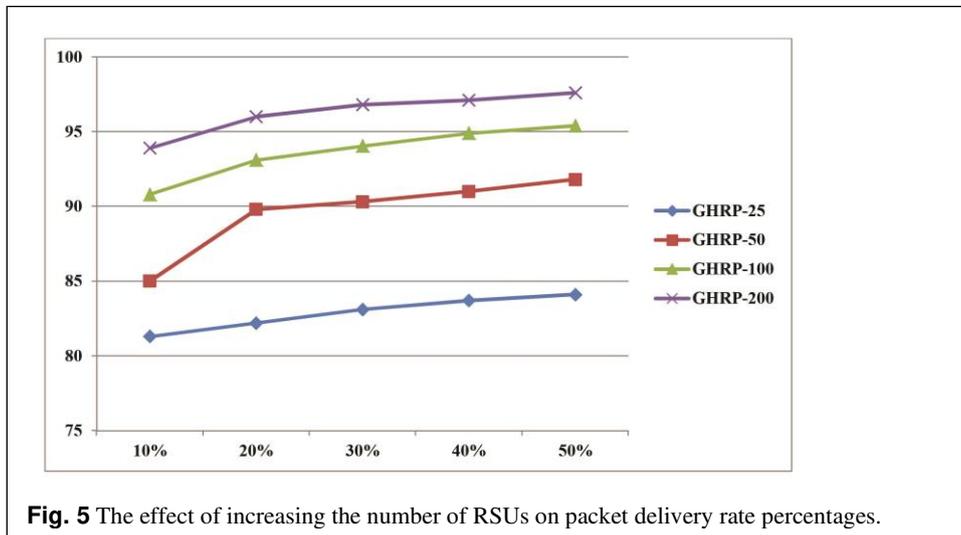


Figure 5 illustrates the effect of increasing the number of RSUs on the packet delivery rate for the proposed protocol in different modes. In the proposed protocol, 20% of the nodes are considered as RSU, but here the packet delivery rate is examined for the modes with 10%, 20%, 30%, 40% and 50% of the total RSU network nodes and for 4 modes with 25, 50, 100 and 200 nodes. As observed, the higher the number of RSUs, the higher is packet delivery rate.

#### 4.4.2. Average End-to-End Delay (AED)

The average end-to-end delay is defined as the average delay in transmission of a packet between two end nodes. This parameter is calculated using the equation 17.

$$AED = \frac{\sum_{i=0}^n ((\text{time of receiving the } i\text{-th packet}) - (\text{time of sending the } i\text{-th packet}))}{\text{Total number of packets received by destination}} \quad (17)$$

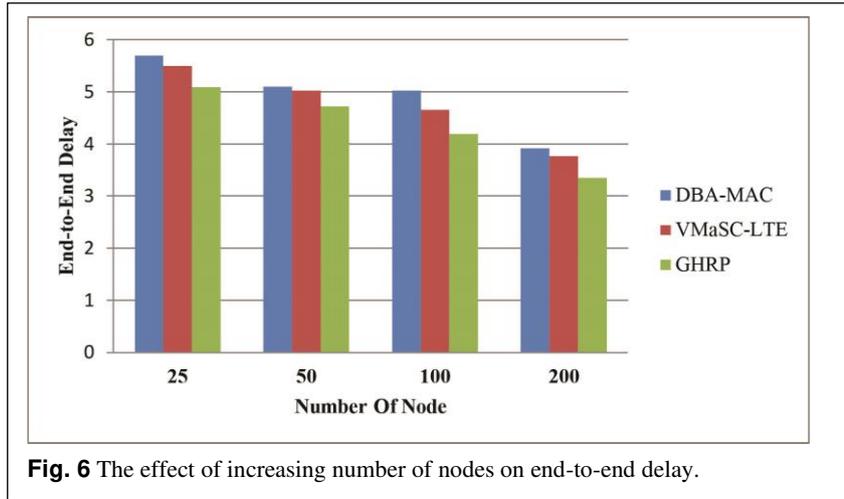
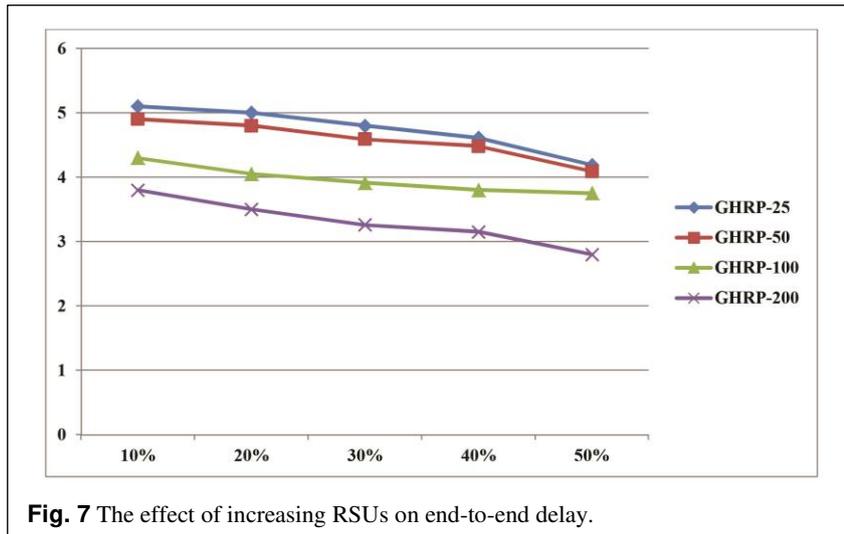


Figure 6 presents the results of the simulation for end-to-end delay where the proposed protocol performs better than the other two protocols.

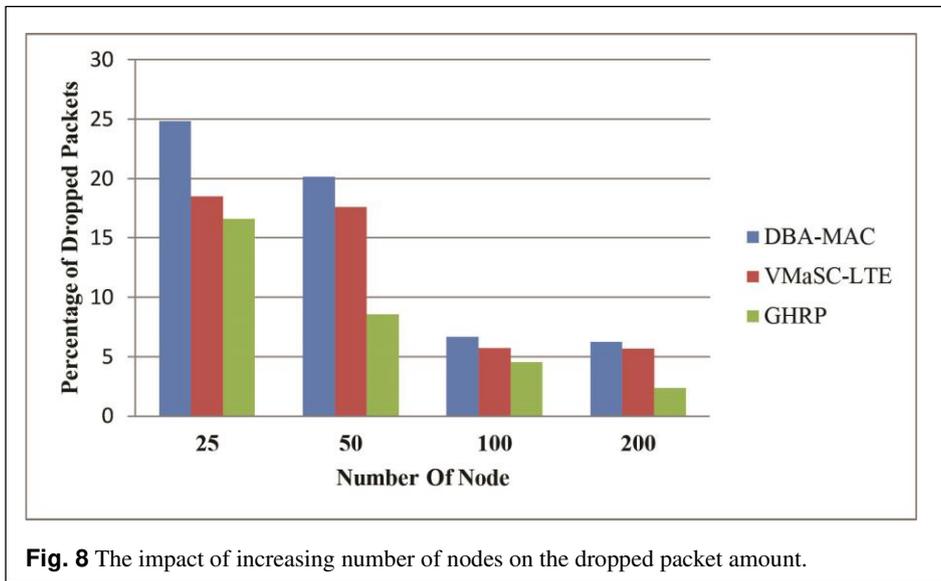


As explained, the use of RSUs in the proposed protocol for inter-vehicle networks reduces the number of routing steps between source and destination. As the number of RSUs shown in Figure 7 increases the number of packet sending steps decreases between source and destination which results in a lower end-to-end delay.

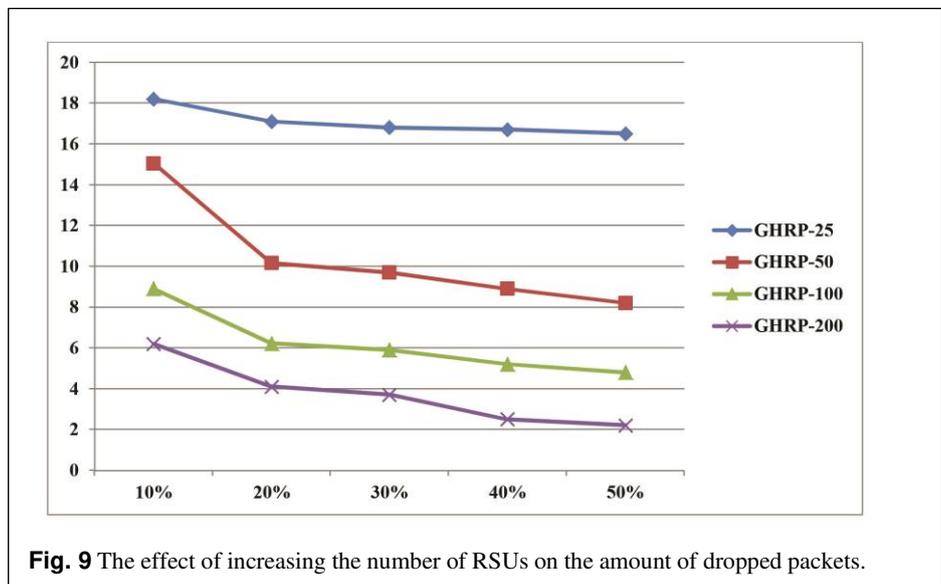
#### 4.4.3. Number of Dropped Packets (NDP)

This parameter indicates the percentage of total packets dropped during the simulation and not reached their destination. The NDP can be calculated by equation 18:

$$NDP = (\text{sent packet} - \text{received packet}) / 100 \quad (18)$$



Increasing the number of nodes makes it less likely for links to break between nodes and thus the number of dropped packets is lower.



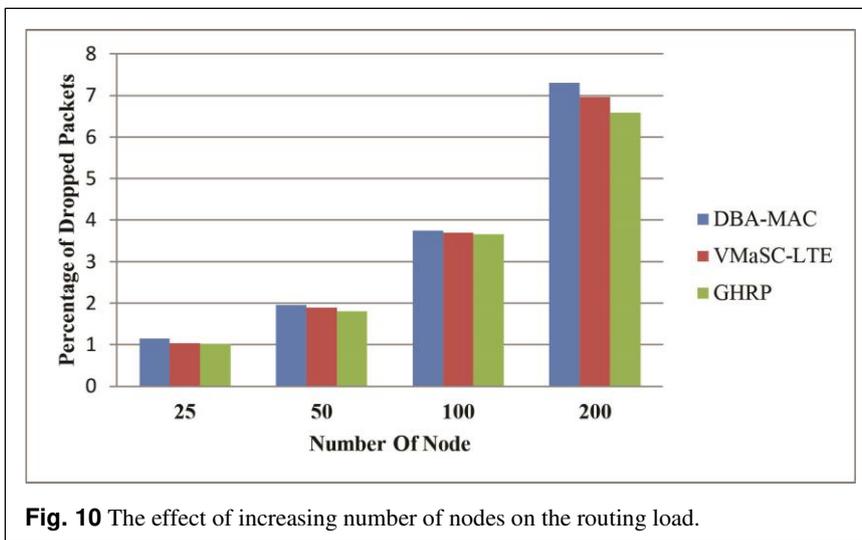
In the section related to packet delivery rates, it was argued that due to the high speed of nodes in inter-vehicle networks, the links are less likely to be broken and thus the packet delivery rate is higher when the number of nodes increases. Since the packet delivery rate and the number of dropped packets in the network are correlated inversely, the number of dropped packets is lower when the packet delivery rate increases. Figures 8 and 9 indicate the obtained results where the number of dropped packets in the network decreases by increasing the number of nodes and RSUs.

#### 4.4.4. Normalized Routing Load (NRL)

This parameter is defined as the ratio of routing packets sent to the number of packets received and can be calculated using equation 19.

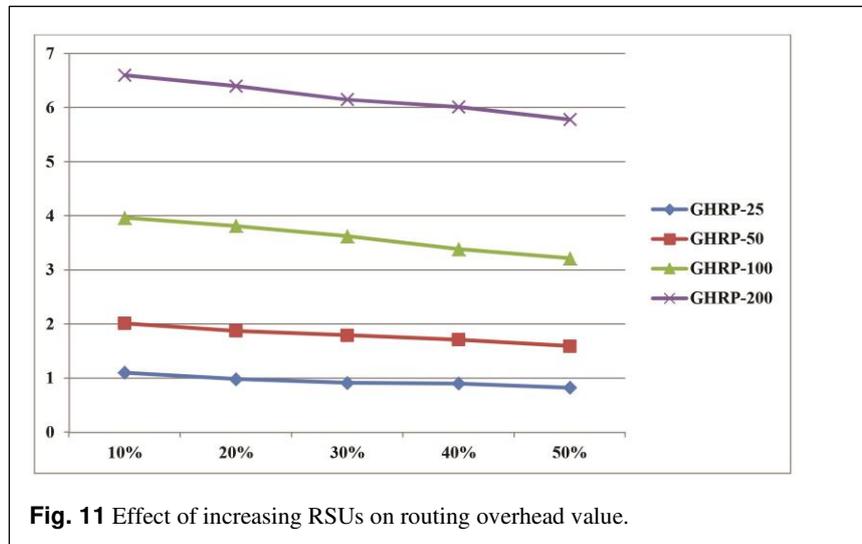
$$NRL = \frac{\text{Number of routing packets sent by source}}{\text{Number of packets received by destination}} \quad (19)$$

The higher the NRL, the lower is the performance and efficiency of protocol.



**Fig. 10** The effect of increasing number of nodes on the routing load.

An increase in the number of nodes leads to an increase in the routing overhead since the operations performed by nodes on packets increase. However, as shown in Figure 10, the routing overhead of the proposed protocol is less than the other two protocols.



**Fig. 11** Effect of increasing RSUs on routing overhead value.

As shown in Figure 10, the overhead increases by increasing the number of nodes and thus the number of operations of the nodes performed on routing packets. However, as illustrated in Figure 11, an increase in the number of RSUs leads to an increase in the number of steps to reach the destination, resulting in less routing operations and eventually lower overhead.

## 5. Conclusion

In this paper, a novel highway routing protocol was introduced in inter-vehicle networks, which can contribute to reduce cost, delay and overhead, and increase the packet delivery rate to achieve the main goal of these networks, which is the comfort and security of the occupants. In the proposed protocol, fixed and mobile RSUs were used for packet routing. The NS2 is used to simulate and compare the proposed protocol with DBA-MAC and VMaSC-LTE protocols, which are highway routing protocols. The results indicated that the proposed protocol can perform better. Future studies can be conducted on implementing proposed protocol in the urban environment, and evaluating security since the exchanged information is important in vehicular ad hoc networks and in some cases even human life. Therefore, it should be resistant to all kinds of attacks including spoofing, denial of service, black holes, and the like. More works can be performed on security dimension of the proposed protocol to make it a secure protocol against all kinds of attacks and deliver the right information to the destination.

## Abbreviations

AED: Average End-to-End Delay; BM: Backbone Member; DSRC: Dedicated Short Range Communication; GHRP: Greedy Highway Routing Protocol; GPS: Global Positioning System; ITS: Intelligent Transportation Systems; MANET: Mobile Ad hoc Network; NDP: Number of Dropped Packets; NRL:

Normalized Routing Load; OBU: On-Board Unit; PDR: Packet Delivery Rate; RSU: Road-Side Unit; TTL: Time To Live; VANETs: Vehicular Ad hoc Networks.

### Competing Interest

The authors declare that they have no competing interests.

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### Authors Contribution

EK conceived of the study, proposed the idea of communication strategies and participated in its design and coordination and helped to draft the manuscript. EZ participated in the design of the study and performed the statistical analysis. All authors have read and approved the manuscript.

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# Figures

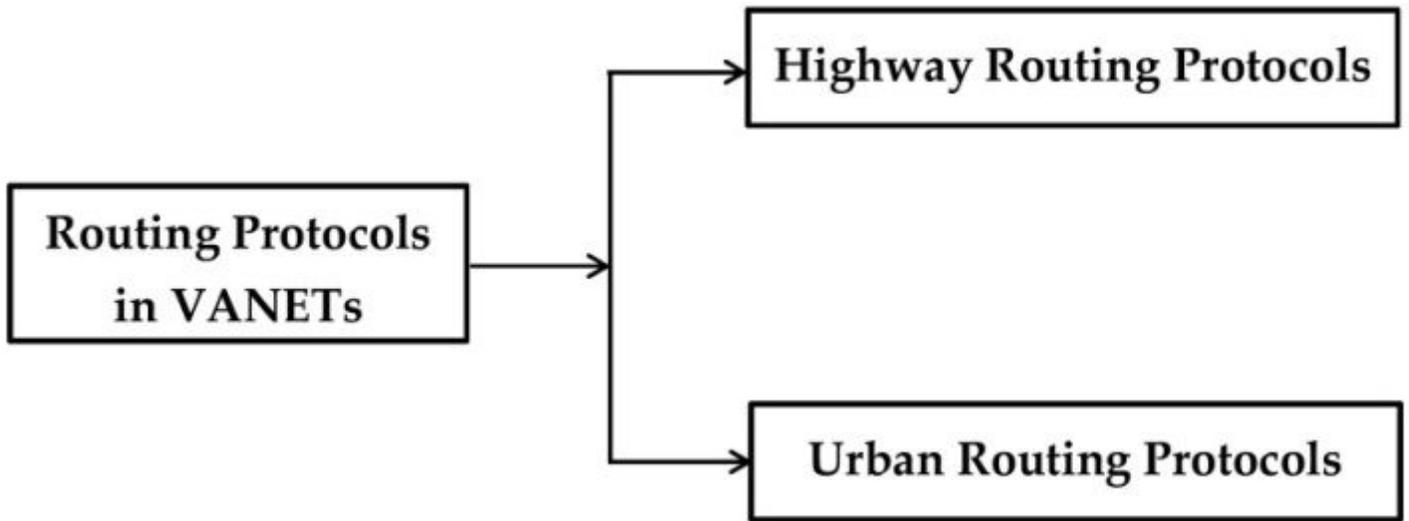


Figure 1

Proposed Taxonomy of Routing Protocols in VANETs.

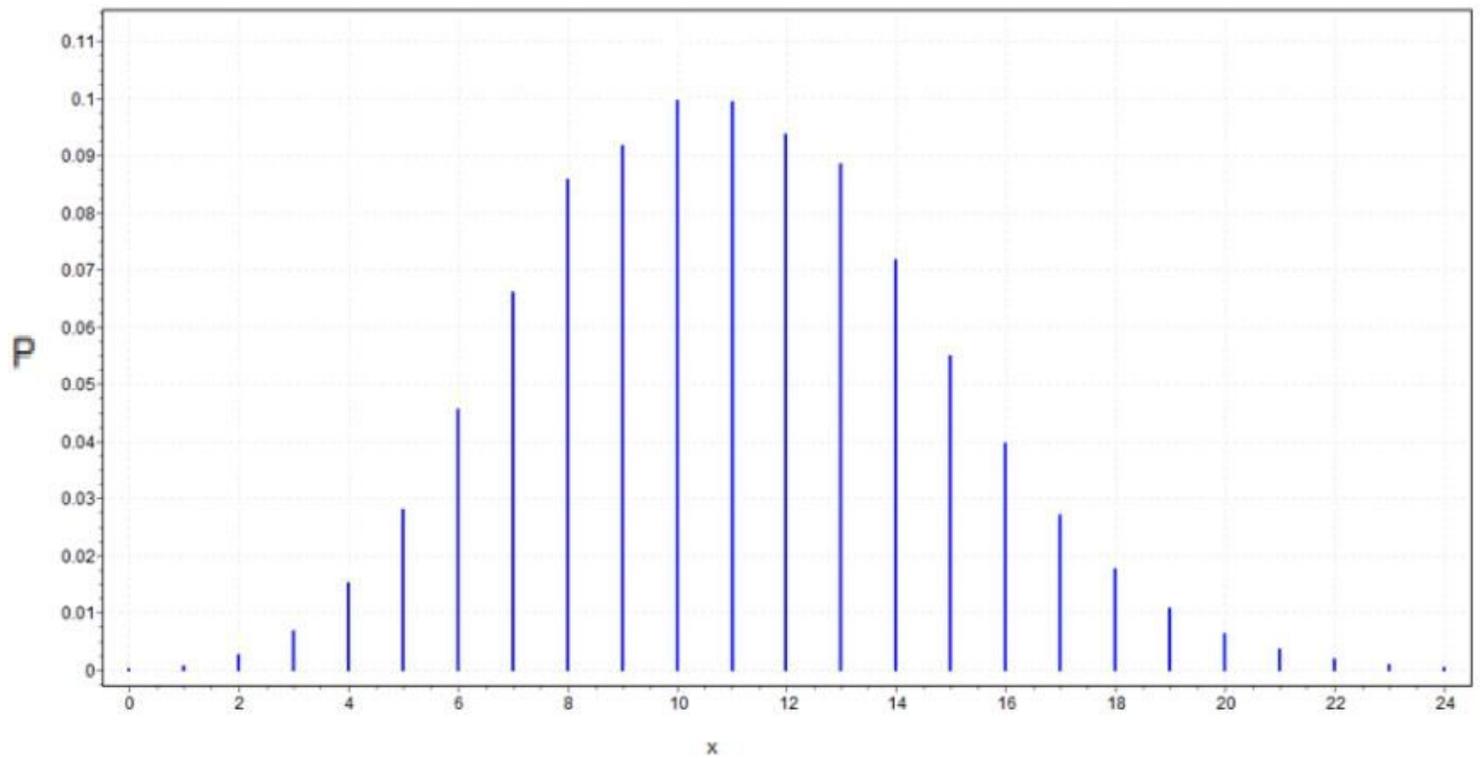


Figure 2

Diagram of entry and exit rates of ordinary vehicles and mobile RSUs in 24 hours.

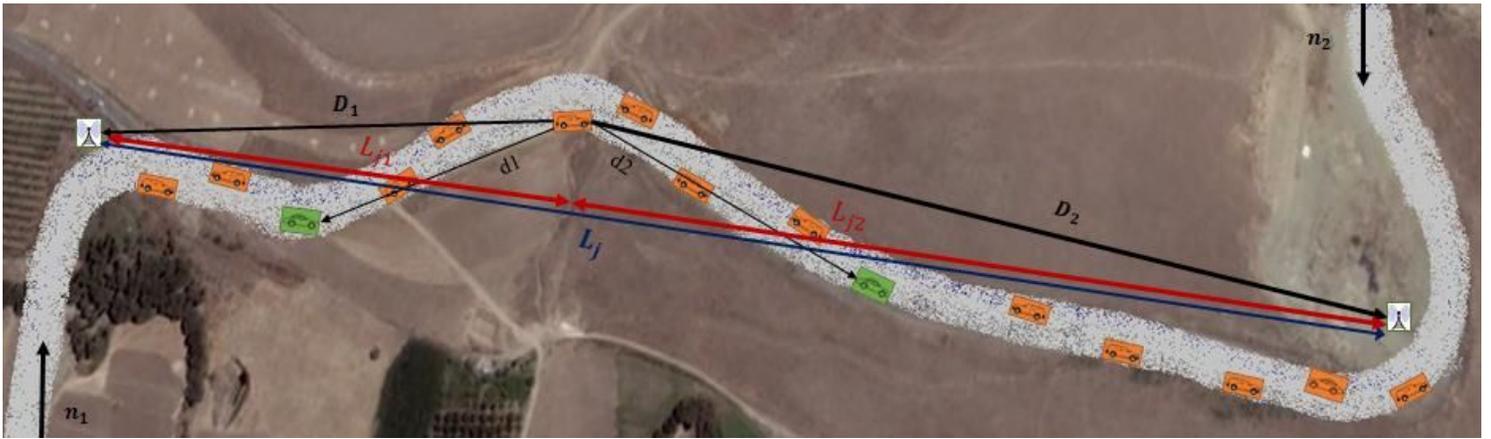


Figure 3

Network scenario.

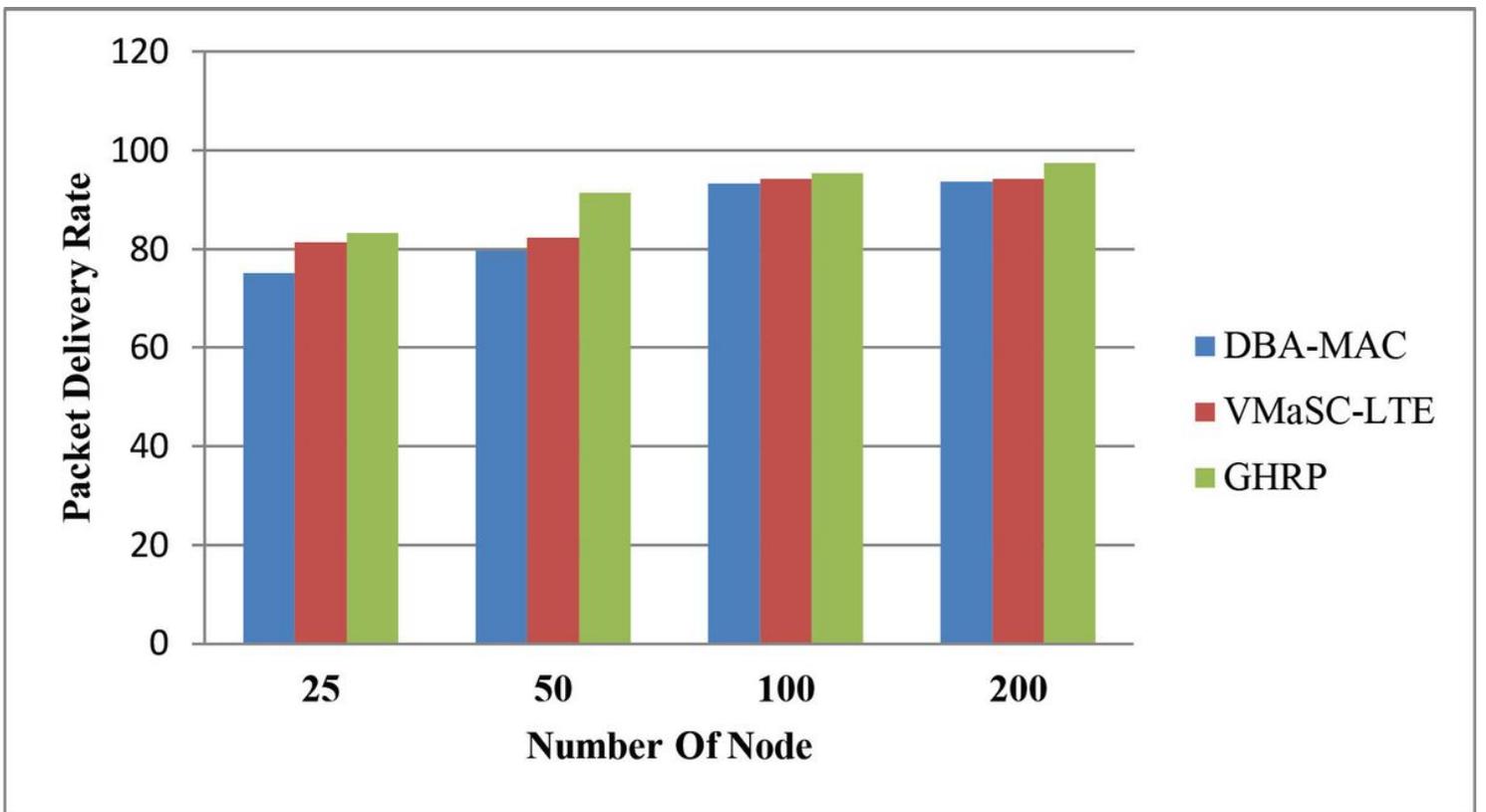


Figure 4

The effect of increasing the number of nodes on the percentage of packet delivery rate.

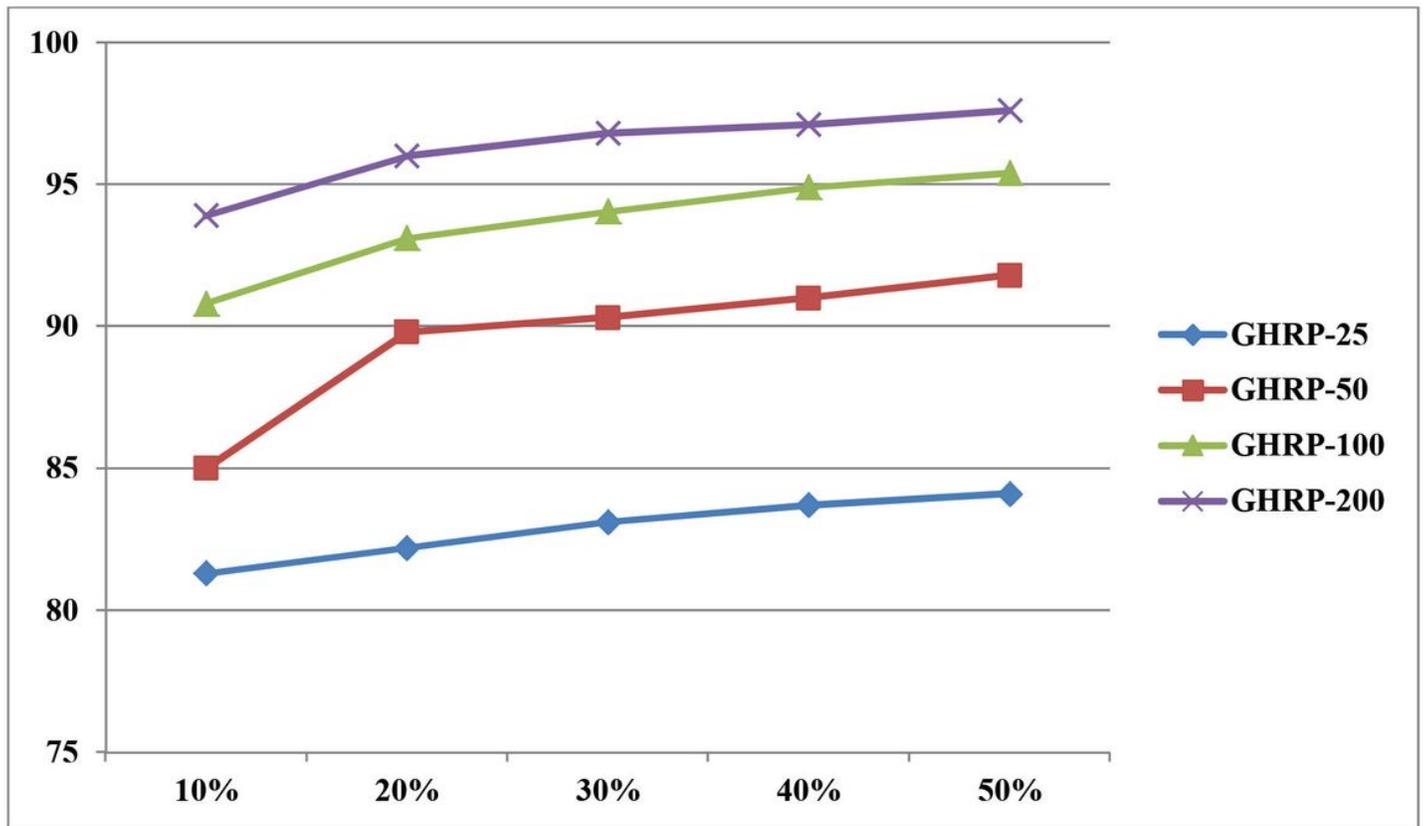


Figure 5

The effect of increasing the number of RSUs on packet delivery rate percentages.

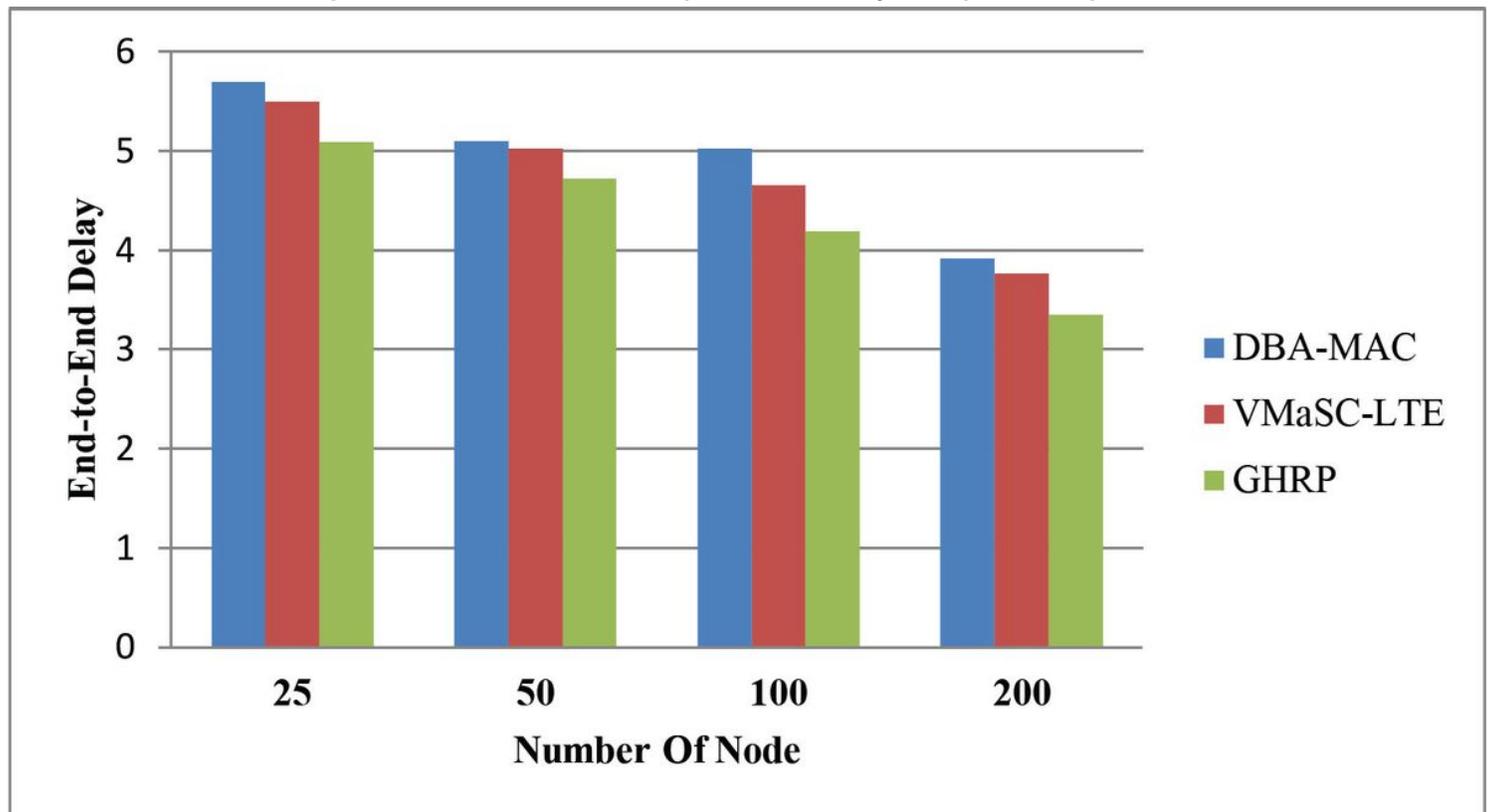


Figure 6

The effect of increasing number of nodes on end-to-end delay.

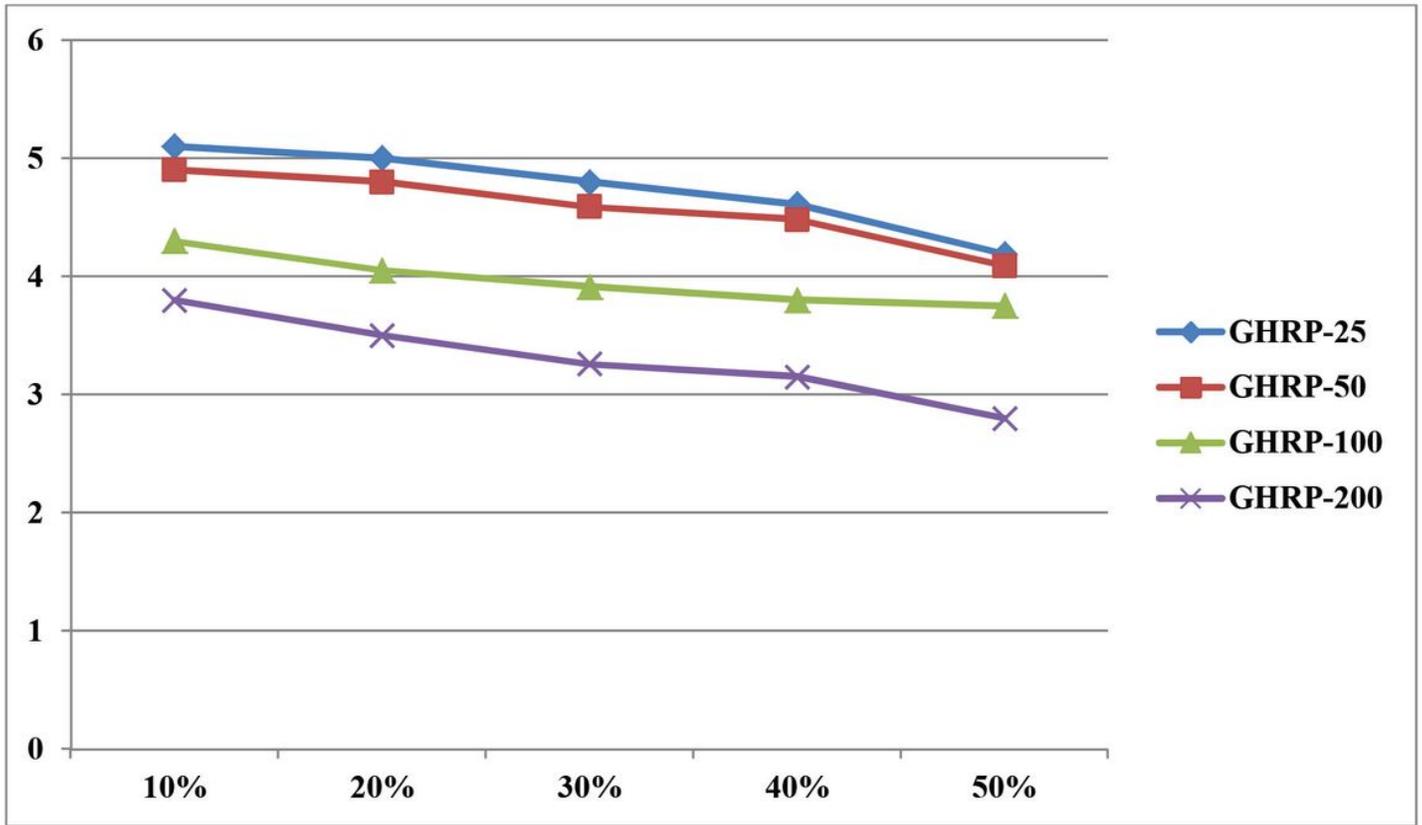


Figure 7

The effect of increasing RSUs on end-to-end delay.

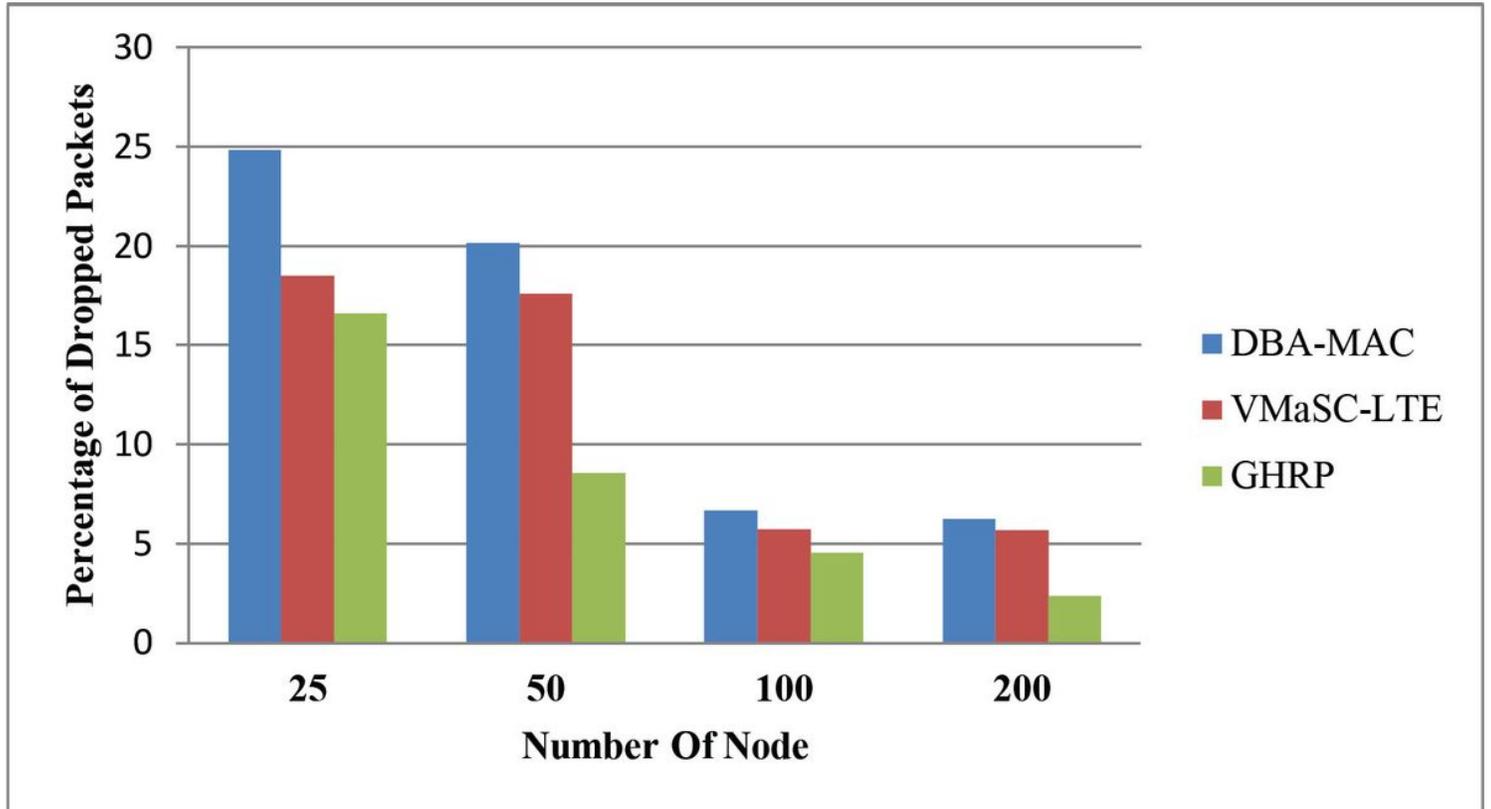


Figure 8

The impact of increasing number of nodes on the dropped packet amount.

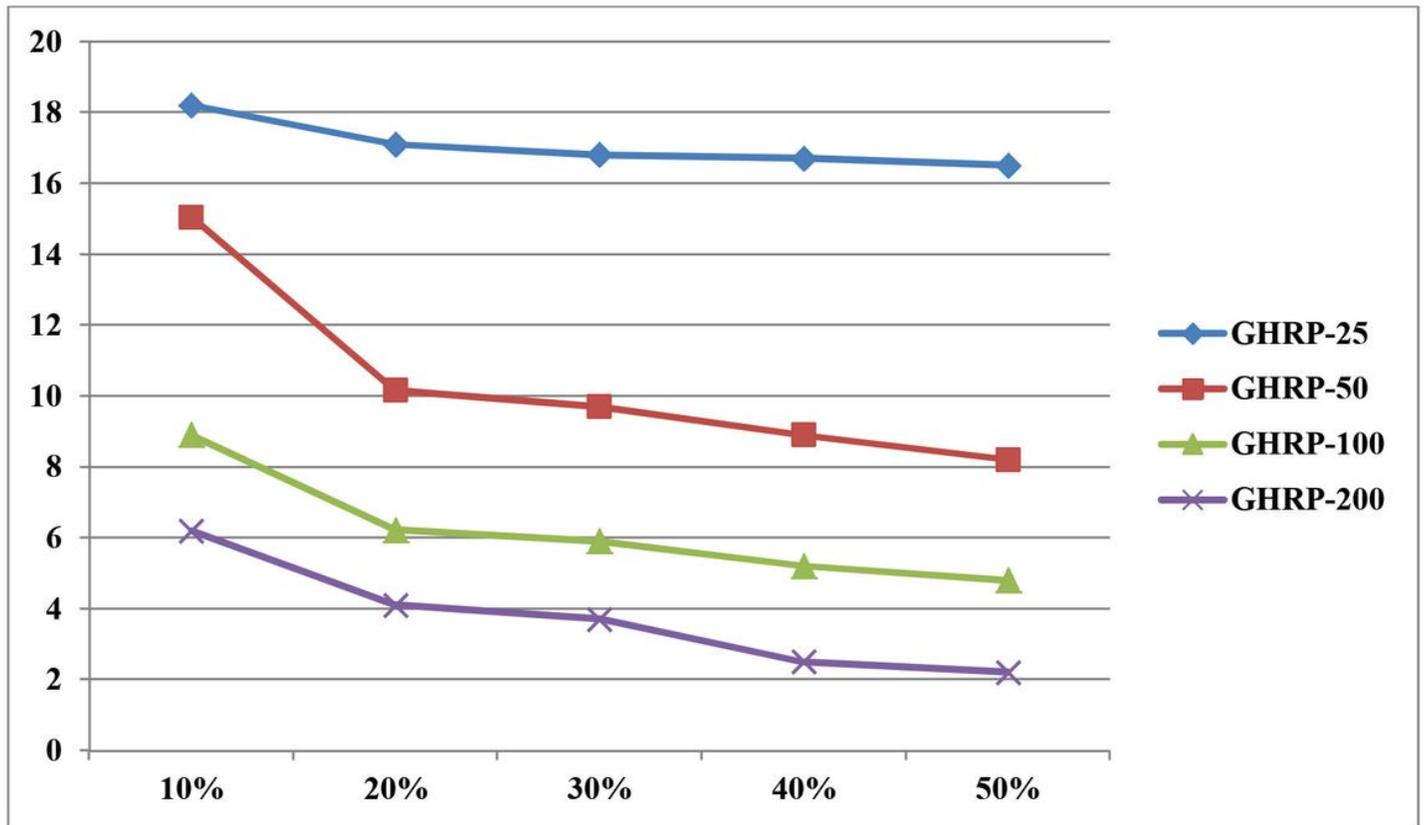


Figure 9

The effect of increasing the number of RSUs on the amount of dropped packets.

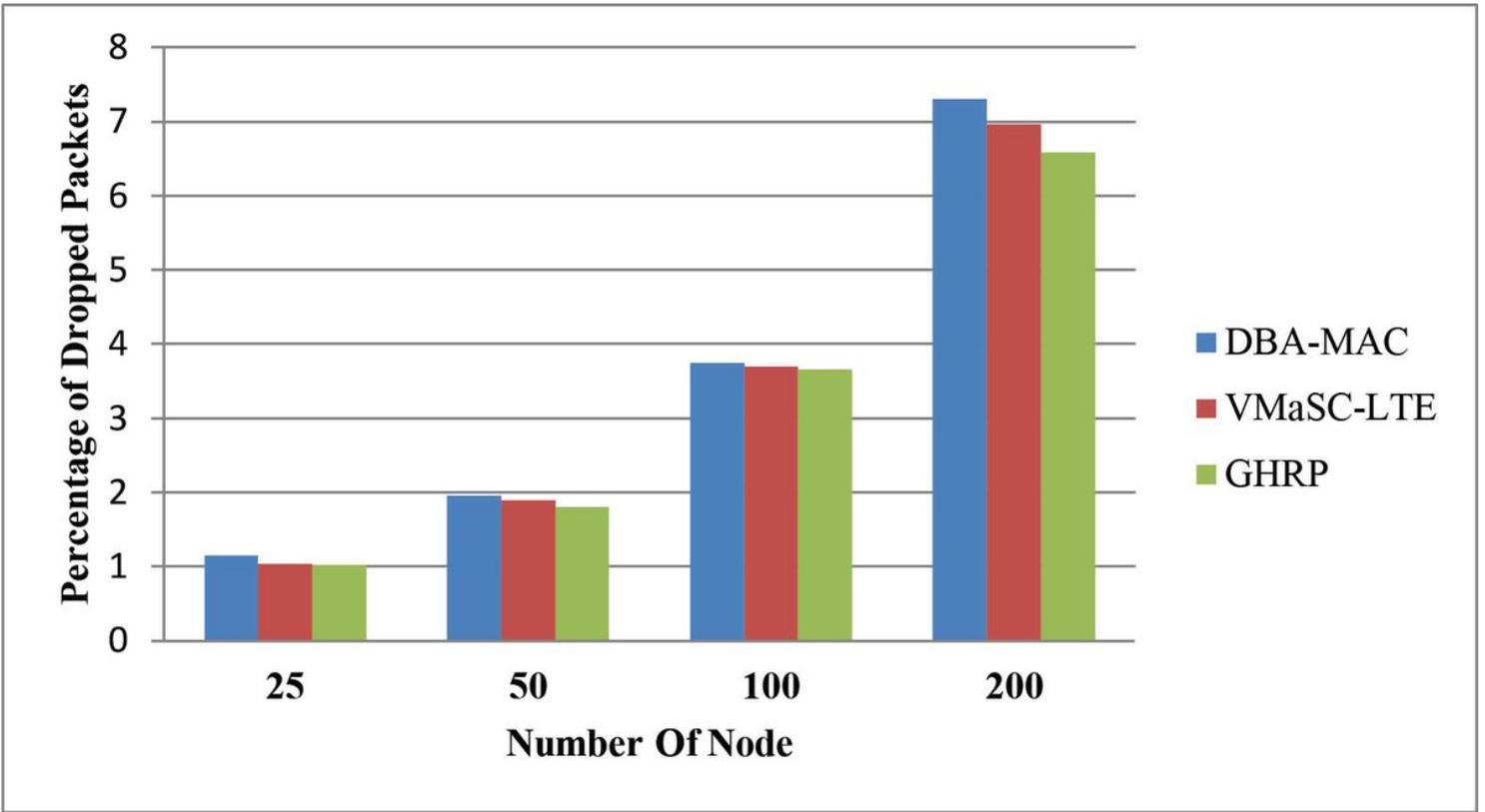


Figure 10

The effect of increasing number of nodes on the routing load.

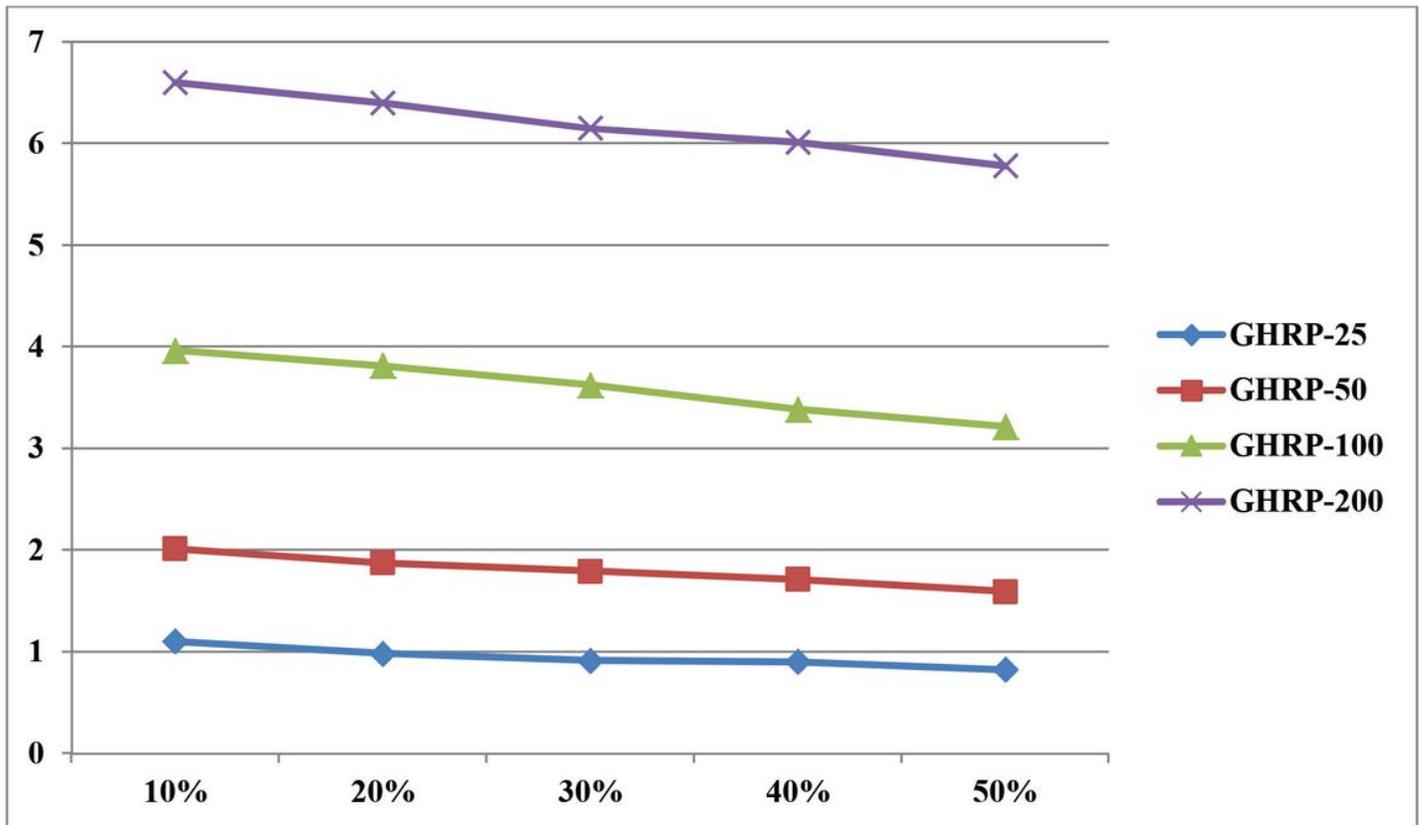


Figure 11

Effect of increasing RSUs on routing overhead value.