Traffic Mobility Models (TMMs) for Vehicular Ad Hoc Networks (VANETs)

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***Abstract*--Vehicular Ad Hoc Networks (VANETs) is a sub-category of Mobile Ad Hoc Networks (MANETs) which can play a vital role as a part of Intelligent Transport System (ITS). VANETs have become a topic of great interest for the researchers because of this recent attainment of increasing popularity. A great amount of research activity in this field has been conducted over the years with a view to enhancing the quality of ITS. Thus it becomes evident to give structure and develop mobility models for the perfect evaluation of a vehicular network so that the realistic mobility characteristics of the moving nodes can be captured accurately. In this paper, we have discussed the major components of VANTE along with the communication categories that exist in VANETs. Then we analyzed and represented a comparative study among the types of Topology based VANET routing protocols. In the later part of this study we have explored the patterns of traffic mobility by conducting MATLAB simulation works with respect to three probable traffic scenarios regarding VANETs: V2V communication between two vehicle nodes crossing two parallel roads and the intersection point of two roads, V2I communication for a single vehicle node passing a single RSU, and V2I communication for a single vehicle node passing across two RSUs. Based on this exploration we have proposed more sustainable models regarding traffic mobility for two different scenarios: a V2I communication model for a single vehicle passing across a complete path having multiple (>2) RSUs and a combined V2V and V2I communication model for two passing vehicles passing across two parallel paths having multiple (>2) RSUs.**

***Index Terms*—ITS, I2I, MANET, RSU, VANET, V2V, V2I.**

I. Introduction

VANET stands for Vehicular Ad Hoc Network. VANETs fall into the subclass of Mobile Ad Hoc Networks (MANETs) and thus are considered as an application to MANETs as these networks are formed on the basis of MANET fundamentals [1]. Network formation between moving vehicles takes place depending on demand basis [2, 3]. In a VANET network, the moving vehicle nodes are equipped with communication systems so that they can communicate among themselves and with the road-side infrastructures called RSUs.

One worth mentioning characteristic of this special kind of vehicular networks is that it can easily operate in an infrastructure-less structure that is capable enough to keep pace with the rapid changes of the network topology [4].The main vision of forming VANETs is to create safer surroundings across highways and roads by disseminating real-time dynamic information regarding the high density of vehicles and distance on road [2], [5] and the overall traffic scenario among the participating vehicles in a timely manner. So to ensure the road safety, it is a must to analyze different patterns of traffic mobility within a vehicular network. Along with the safety applications VANETs can also provide valuable information such as weather information, transit systems, internet access, mobile e-commerce, and other multimedia applications to the moving vehicles along the road. The overall strength of a VANET network greatly depends on some key features like routing protocols, privacy, security, amount of delay in terms of delivery of network packets, etc. [6]. VANETs comprise a huge collection of routing protocols to ensure effective autonomous communication between the moving vehicles on the road [3]. However, most of them have come out as results of the long theoretical work that has been conducted in the background of MANETs. Just because of this reason it has to be mentioned as a fact that VANETs are a very specific case of MANETs [1].

In this study, we explore the major components of vehicular networks along with the existing types of communication among the network nodes. Then we conduct a comparative study among the sub-classes of topology based routing protocols. Lastly we propose two unique traffic mobility models for VANETs on the basis of simulating common traffic scenarios.

II. Literature Review

Being a part of an intelligent transport system, VANETs can exhibit significant impact on our daily life as most of us have to travel across places on a daily basis [7]. Thus the overall quality of such vehicular networks needs to be sufficient and also trustworthy so that people can move to places with more security, safety and very less probability of facing any sort of unfortunate vehicular accidents. For the last few years immense amount of research works have been conducted by the researchers in this field for the overall welfare of vehicular networks.

Cloud computing has become one of the emerging research topics as a result of technological advancement in recent years. Md. Wahiduzzaman et al. have presented a survey work along with a novel architectural concept of vehicular cloud in [8] with a view to establishing a linkup between cloud computing and vehicular networks. A comprehensive comparative research work having a survey among the existing wireless communication standards and protocols related to vehicular networks based on different network parameters was conducted by M. Shahid et al. in [9].

In the context of ad hoc networks, it is a must to follow mobility models in order to evaluate the performance measure of any given network protocol and also to figure out if implemented whether the protocol will come out useful for certain traffic scenarios. In this regard, Tracy Camp et al. have conducted a survey on the existing mobility models that help to simulate different network scenarios [6].

Security is regarded as one of the key issues for a network to be considered as strong. The users of vehicular networks also demand robustness and satisfactory level of network security in case of adversarial situations. Ghassan Samara et al. discussed the existing challenges and security problems that usually occur in vehicular networks [10]. Also they proposed a bunch of solutions to network security problems in this literature. To emphasize the greater concern of secured VANET a similar study was conducted on the security related issues of vehicular networks by Dr. Nirbhay [11].

Application of machine learning tools and techniques is visible in the research field of VANET. In [12] Sara Ftaimi et al. conducted a comparative study of the machine learning algorithms that help in increasing the reliability of vehicular networks by reducing the vulnerabilities that may occur in such networks. Sahil Khatri et al. elucidated the fact that how machine learning algorithms can be implemented to solve various traffic and safety issues related to vehicular networks in [13]. Alia Mohammed et al. explored the usage of machine learning tools in terms of solving various security threats that hamper vehicular networks in [14]. The main focus of this literature was to detect DDoS attacks in VANETs and to provide the corresponding solution. A machine learning based routing scheme for vehicular networks to minimize the end-to-end delay and to establish a perfect network connection was proposed in [15]. Pranav Kumar et al. proposed an advanced machine learning based approach that exhibited the capability for detecting the position falsification attack in VANETs [16]. Application of deep learning technique in the research field of vehicular networks can also be seen [17].

The rest of this article is organized as follows: *Section-III* discusses the major components of VANETs along with the communication categories that usually take place in such a network. *Section-IV* represents a comparative study among the types of topology based routing protocols in tabular format. *Section-V* is comprised of the demonstration of MATLAB simulation works regarding the very basic three traffic scenarios that exist in terms of a VANET network. *Section-VI* proposes two traffic mobility modelswith the corresponding MATLAB simulations based on the simulation works demonstrated in *Section-V*.*Section-VII* discusses the future scope of this study and *Section-VIII* contains the conclusion.

III. VANET COMPONENTS & TYPES OF COMMUNICATION

Now we all know that VANET stands for Vehicular Ad Hoc Network. As the name implies, one of the most major components of a VANET network is the smart vehicles that act as moving nodes of the network [9]. The scope of the mobility of these smart vehicle nodes is confined to the streets only. The network is referred to as an ad hoc network because of the free movement allowance of the nodes. DRSC technology is used for the communication purpose among the vehicle nodes inside VANETs.

Another major component of VANETs is called Road Side Units (RSUs) [18]. These RSUs play the vital role of routing immensely valuable information related to traffic broadcast, safety alert, etc. and providing important services to the moving nodes of the network with the help of internet connectivity.

Each moving vehicle inside VANETs are equipped with TPD and OBU. These components are important for effective communication inside vehicular networks. TPD stands for Tamper-Proof Device which holds all necessary information that can relate to the correct identification of a vehicle [19]. OBU refers to On-Board Unit which is an embedded system. OBUs collect sensor data from the inside of vehicles and output information that infers the vehicular condition. The output data from OBUs are used by TPDs and transmission systems for the purpose of vehicular positioning, monitoring, etc. Fig. 1 represents the connection between TPDs and OBUs.

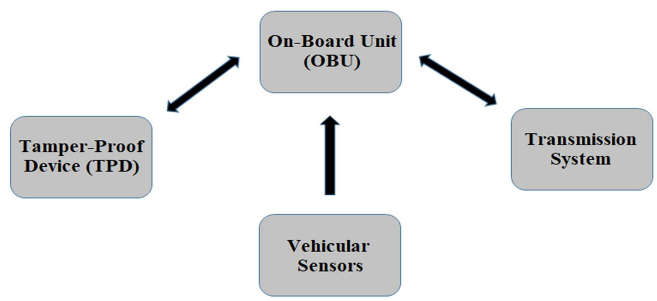

Fig. 1TPD and OBU Components of VANETs

Moving vehicles and the roadside device units are considered as the communicating nodes of a vehicular network. There exist three types of communication in a VANET. Fig. 2 illustrates these three types of VANET communication schemes. When moving vehicles communicate with each other directly, the communication is regarded as V2V communication where V stands for Vehicle. This V2V communication seems to be infrastructure-less, or in other words we can say that V2V is ad hoc in nature. When the communication takes place between a moving vehicle and a road side unit (RSU), the communication is referred to as V2I communication where V indicates Vehicle and I indicates Infrastructure. In this type of communication the RSUs act as access points for the moving vehicles. RSUs also conduct communication among themselves and this type of communication is known as I2I communication where I stands for Infrastructure. All of these communications are of the same importance and need to be dynamic for the overall efficiency and effectiveness of a vehicular network.

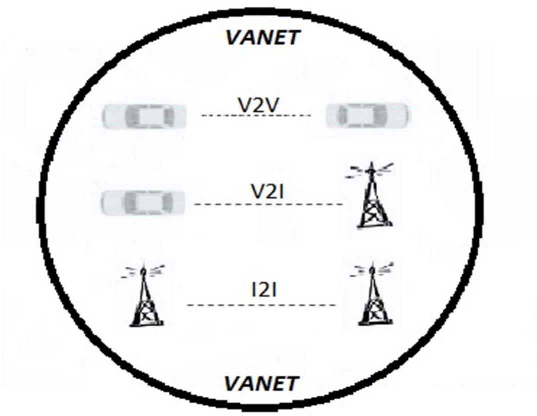

Fig. 2 V2V, V2I and I2I Communication in VANET

IV. Comparative Study On Topology Based VANET Routing Protocols

Routing protocol is considered as one of the most important factors in case of networking. The overall communication strength of a network depends on the efficiency and performance of the routing protocol being followed.

VANETs comprise a massive collection of different types of routing protocols. This collection can be categorized into five classes [20, 22, and 24]. One of the classes is Topology Based Routing Protocol. The main concept of using this routing protocol is that the path must be discovered at first and then be preserved in a routing table prior to the start of information transmission. Some examples of topology based routing protocol are STAR, DSDV, OLSR, CGSR, etc. [25]. Topology based routing protocols are further divided into three sub-classes: Proactive, Reactive and Hybrid [20], [26] – [30].

We represent a comparative analysis of Reactive and Proactive routing protocols below based on the knowledge gathered by exploring the literatures [20] – [30].

TABLE I
Comparison between Proactive and Reactive routing protocols

Proactive Routing Protocols	Reactive Routing Protocols
Proactive routing means that routing information will be maintained irrespective of transmission request.	Reactive routing means that the route will be opened if there is any transmission request. If not, route will not be opened
Familiar as “Table-driven” protocol.	Familiar as “On-demand” protocol.
Periodic updates are always required.	Periodic updates are not required.
Periodical route discovery.	On-demand route discovery.
Don’t face initial route discovery delay.	Face initial route discovery delay.
Average end-to-end delay is constant.	Average end-to-end delay is variable.
Less efficient delivery of packet data.	More efficient delivery of packet data.
Communication overhead is high.	Communication overhead is low.
Bandwidth requirement is high.	Bandwidth requirement is low.
Power requirement is high.	Power requirement is low.
Slower performance.	Faster performance.
Packet size is uniform.	Packet size can be both uniform and non-uniform.

V. Simulation Procedure On Existing Patterns Of Traffic Mobility

We analyze and illustrate three very common and basic traffic mobility scenarios in regards of a vehicular network. We conduct test simulation following step-by-step procedures in order to visualize these scenarios. MATLAB has been used as the platform to conduct the simulation procedures on Windows operating system. We represent the simulation results graphically for each of the basic traffic mobility scenarios and put immense focus on the ins and outs of every possibility regarding every scenario. Fig. 3 – Fig. 7 visualize simple 2D plotting of existing traffic pattern scenarios. Pathways are indicated using solid lines in Fig. 3 – Fig. 4 and using yellow dashed lines in Fig. 5 – Fig. 7. Connectivity is represented using different colored straight lines.

A. V2V Communication between Two Vehicle Nodes Crossing Two Parallel Roads and the Intersection Point of Two Roads

The first simulation plots the parallelism of two roads and the second simulation visualizes the intersection of two roads with both simulations having two nodes (* and *) on both sides. The nodes on each section can interact with each other. These simulation scenarios can help us calculate the Doppler effects due to relative motion between the vehicles and can also be used to estimate the window margins for communication between two nodes on Separate roads shows in Fig.3 and Fig.4.

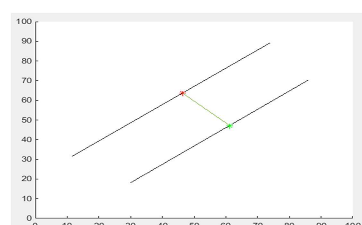

Fig. 3. Two Nodes Passing Two Parallel Roads and having Communication

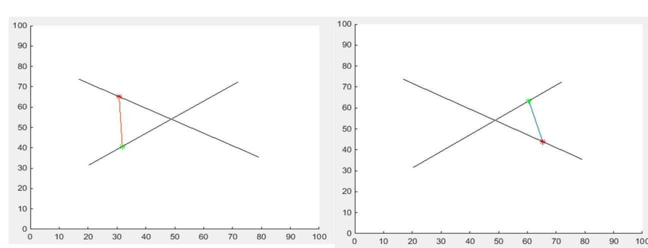

Fig. 4. Two Nodes approaching intersection and leaving intersection

B. V2I Communication between a Single Vehicle and a Single Road Side Unit (RSU)

This simulation marks one of the very basic type of communication in a VANET system which is Vehicle-to-Infrastructure (V2I) communication as illustrated in Fig. 5 and in Fig. 6. This simulation scenario is similar to a cellular base station trying to provide range for traveling mobile node. With the help of this simulation, the user can configure the range of the RSU. Fig. 6 also illustrates the fact that any RSU placed in wrong places can cause void areas. Here is the step by step procedure for this scenario -

Notation:
R = Communication Range of RSU
m = Distance between two points
n = Euclidean Norm
$(x_1, y_1),(x_2, y_2)$, ... = Set of road points
(p,q) = RSU point
Initialization:
Take input of road points and RSU points.
Steps:
S_1: Start looping
S_2: Measure *m* = distance between two points starting with (x_1, y_1) and (x_2, y_2)
S_3: Get *m* number of equidistant points from x_1 to x_2 and y_1 to y_2
S_4: Plot each point
S_5: Get *n* = Euclidean Norm value of each point subtracted from RSU point
S_6: If n_i= *R,* then plot the connecting line from RSU to node

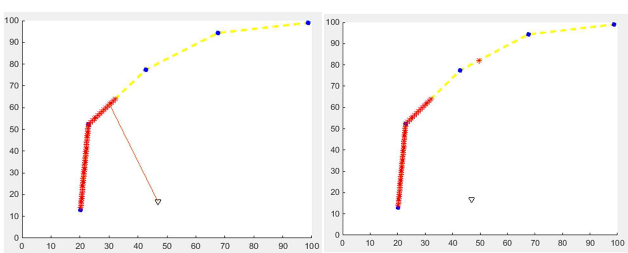

Fig. 5. Two Nodes approaching intersection and leaving intersection

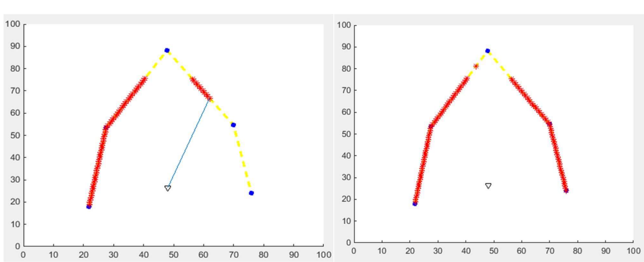

Fig. 6. Node within the range of RSU and node in a void area

C. V2I Communication between a Single Vehicle and Two Road Side Units(RSUs)

This simulation is similar to the cellular phone node transfer from one tower to another. However, there are significant differences. There is no central Mobile Switching Center to coordinate the transfer of mobile VANET node from one RSU to another RSU. This model could be used to study mechanisms that involve continuous connection maintenance over large distances in VANET systems shows in Fig. 7.

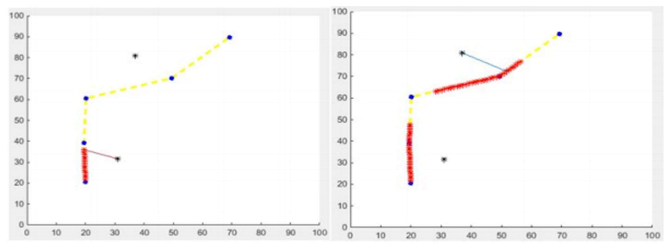

Fig. 7. Communication with the first RSU and the second RSU

VI. Proposed Traffic Mobility Models

We develop and represent two novel mobility models for VANETs based on the concept of the three basic traffic scenarios previously discussed. Among those previously stated common scenarios, the first one doesn't have any RSU, the second one deals with only one RSU, and the last one comprises two RSUs. Our proposed models include the concept of dealing with traffic scenarios having multiple (>2) RSU units. To provide proper 2D visualization of the proposed models, we conduct simulation works and plotting using MATLAB on windows platform (Fig. 8 – Fig. 14). Pathways are indicated using both yellow (Fig. 8 – Fig. 14) and green (Fig. 11 – Fig. 14) dashed lines. Connectivity between nodes and RSUs are illustrated using different colored straight lines. Here is the step by step procedure of the proposed models having multiple RSUs –

Notation:
R = Communication Range of RSU
m = distance between two points
n_1, n_2, ... = Euclidean Norms
$(x_1, y_1), (x_2, y_2)$, ... = Set of road points
$(p_1, q_1), (p_2, q_2)$, ... = RSU points
Initialization:
Take input of road points and RSU points. Plot all of them.
Steps:
S_1: Start looping
S_2: Measure *m* = distance between two points starting with (x_1, y_1) and (x_2, y_2)
S_3: Get *m* number of equidistant points from x_1 to x_2 and y_1 to y_2
S_4: Plot each point
S_5: Get n_1, n_2, ... = Euclidean Norm values of each point subtracted from each RSU point
S_6: Find the lowest of the norm values
S_7: If the lowest value n_i= *R,* then plot the connecting line between those two points

V2I Communication Model for a Single Vehicle Node Moving across a Complete Path having Multiple Road Side Units (RSUs)

The core idea of this proposed model is formed on the basis of the simulation work conducted in Subsection-C of the previous section. Thus the V2I communication of this proposed model is very much similar to the communication scheme between a single vehicle and two RSUs. The novelty of this proposed model is that a single moving vehicle can now get itself connected and communicate with more than two RSUs residing by the side of a complete path.

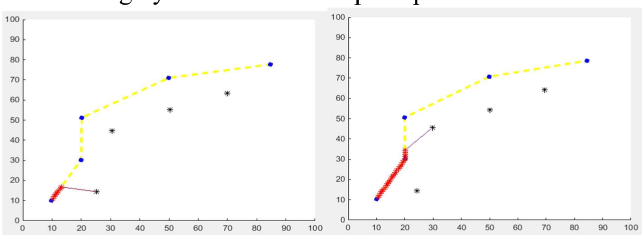

Fig. 8. Communication of the node with the first and the second RSU

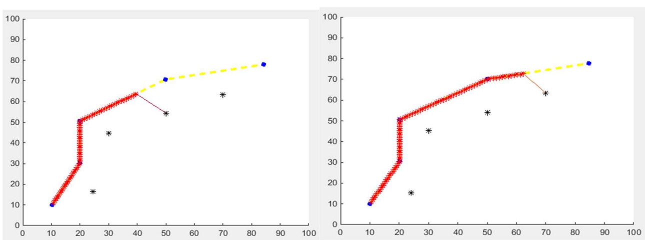

Fig. 9. Communication of the node with the third and the fourth RSU

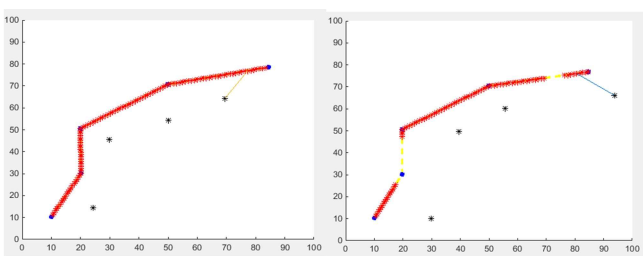

Fig. 10. Node completes the path successfully and RSUs in wrong places cause void areas.

Fig. 8 - Fig. 10 depict the visual representations of this proposed model where there are four RSUs alongside the pathway. The * symbols used in these figures indicate RSU. The *symbol represents the moving node along the pathway. Here, some gaps in the network can be seen. These gaps can be removed by placing the RSUs in perfect positions or by increasing the range of the RSUs. This fact is illustrated in Fig. 8& Fig. 9.Fig. 10shows that the node completes the path successfully and RSU in wrong places cause void areas. The presence of red zone along the path indicates active connectivity between the moving node and RSUs at the time of passing the pathway. Absence of red zone indicates void area, which means there is no connection in terms of communication between the moving node and RSU for the time being.

A. Combined V2V and V2I Communication Model for Two Moving Vehicles Passing across Two Parallel Pathways both Having Multiple (>2) Road Side Units (RSUs)

This simulation gives us an appropriate and complete visualization of how VANET works. In this proposed combined model of V2V & V2I communication scheme, there are two parallel pathways having two moving nodes and in total four RSUs near them where the distribution of the RSUs is symmetric, that is two RSUs on one side of each pathways. The two moving nodes can have communication between each other and when in range of any RSU, they can also communicate with the RSUs. If out of network of a RSU, they communicate with the next RSU that is close to them just like cellular tower network switching although in the absence of any central control system.

This proposed model is illustrated in Fig. 11 - Fig. 14 where two moving vehicles start a journey together. Fig. 11 shows that at the beginning of the journey, the two nodes are connected to each other and also with two RSUs. Fig. 12.&Fig. 13illustrate the fact that in the midway of the journey, the two nodes are connected to each other and also with multiple (>2) RSUs. Just before the journey ends, the two moving vehicles are connected to each other and also with three RSUs as illustrated in Fig. 14.

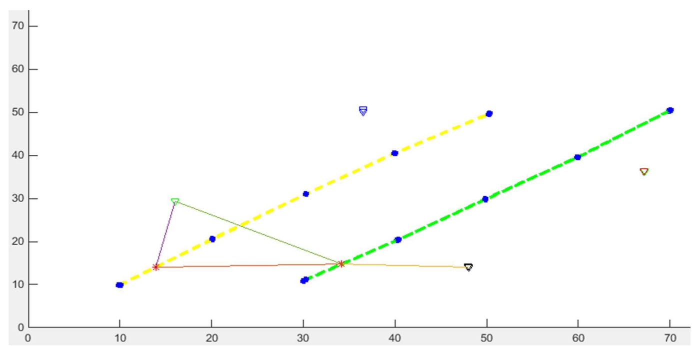

Fig. 11. Two nodes are connected to each other and also with two RSUs

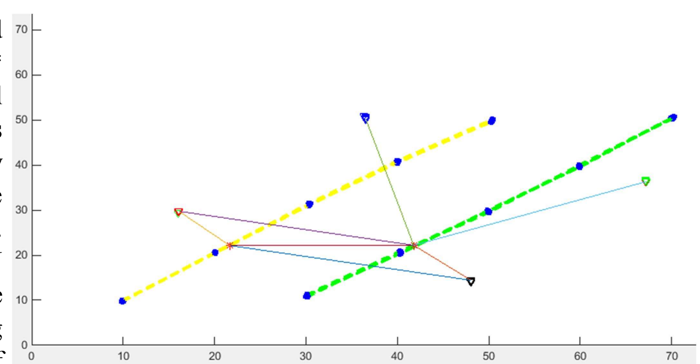

Fig. 12. Two nodes are connected to each other and also with multiple (>2) RSUs

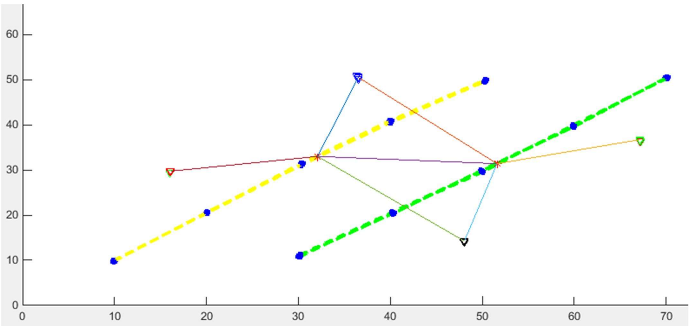

Fig. 13. Two nodes are connected to each other and also with multiple (>2) RSUs

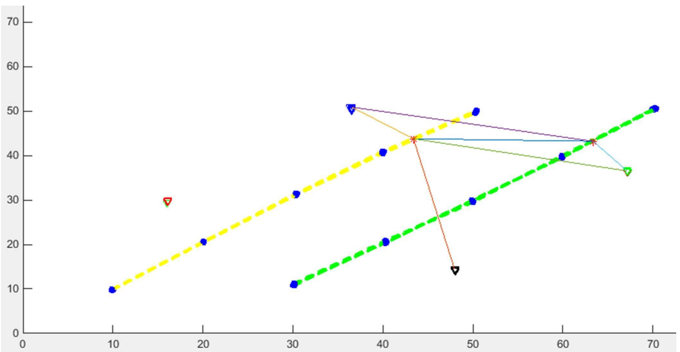

Fig. 14. Two nodes are connected to each other and also with multiple (>2) RSUs

The *symbols used along the pathways indicate moving nodes. RSUs are indicated using ▽ ▽ ▽ ▽ symbols in the figures above.

VII. Future Scope

The performance analysis of the existing protocols is necessary for better routing. These protocols need to be subjected to careful studies, simulations and experimentation. Sometimes the situation becomes much adverse for the routing protocols to spread data because of the high mobility of VANETs. So to design an efficient routing protocol is still an important scope of this research field for the researchers as there is no such VANET protocol that is able to meet the needs for every traffic scenario. VANETs give birth to some technical challenges from some point of views of a network. Security of VANETs is also an important issue because one of the main objectives of a VANET network is to provide safety and security among the users. Existing ways for ensuring a secured network and protecting the network from problematic attacks are still not satisfying enough. So another scope of this research field is to reach a satisfactory level for the sake of safety and security of moving nodes. In future we want to extend our proposed approach with a view to simulate any traffic scenario of a whole city.

VIII. Conclusion

Vehicular Ad Hoc Networks (VANETs) has become one of the most prominent research fields due to the high interest that Intelligent Transportation Systems (ITS) can offer in different sectors of our life through the efficient deployment of vehicular networks. VANET is such an emerging technology that enables a wide range of applications such as road safety, passenger convenience, infotainment, intelligent transportation, etc. It is hopeful that in the near future vehicular networks may offer automated highway applications where the smart vehicles are able to cruise without the help of their drivers. In this paper, we represent the major components that form such vehicular ad hoc networks. Also we discuss the variety of communication types that usually take place in between the communicating nodes of VANETs. Then we provide a comparative analysis among the categories of Topology based routing protocols that sheds light on the differences between proactive and reactive routing protocols. Later we simulate and visualize three common traffic scenarios regarding VANET. The connection patterns of a single vehicular node with a single RSU and two RSUs have been emphasized on the existing simulation works. Lastly we propose two novel approaches for traffic mobility modeling that consist of multiple moving nodes within any traffic region with multiple (>2) RSUs. We conceptualize the proposed models through the extension of the existing simulation scenarios by adding multiple moving nodes with multiple RSUs and visualize them by conducting simulation of such extended scenarios. The novelty of these models illustrate the connection pattern among multiple nodes and multiple RSUs and thus can be helpful for the simulation of any real-time traffic scenario for a whole city.

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