ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

# IMPACT OF INTER-VEHICULAR COMMUNICATION PERFORMANCE ON DIFFERENT TRAFFIC MOBILITY MODELS: A CASE STUDY OF AD HOC ON-DEMAND DISTANCE VECTOR ROUTING PROTOCOL

**M.Sc. THESIS**

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**JUNE 2017**

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**Taofeek Abiodun Olasunkanmi YUSUF**
**(504121557)**

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**Thesis Advisor: Assoc. Prof. Dr. D. Turgay ALTILAR**

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ**

# Farklı Trafik Hareketlilik Modeli Üzerinde Araç İçi İletişim Performansına Etkiler: İsteğe Bağlı İsteğe Bağlı Mesafe Vektör Yönlendirme Protokolü Üzerine Bir Vaka Çalışması

**YÜKSEK LİSANS TEZİ**

**Taofeek Abiodun Olasunkanmi YUSUF**
**(504121557)**

**Bilgisayar Mühendisliği Anabilim Dalı**

**Bilgisayar Mühendisliği Programı**

**Tez Danışmanı: Doç. Dr. D. Turgay ALTILAR**

**HAZIRAN 2017**

**Taofeek Abiodun Olasunkanmi YUSUF**, a M.Sc. student of Istanbul Technical University; ITU, Graduate School of Science Engineering and Technology with student ID **504121557**, successfully defended the thesis entitled "**IMPACT OF INTER-VEHICULAR COMMUNICATION PERFORMANCE ON DIFFERENT TRAFFIC MOBILITY MODELS: A CASE STUDY OF AD HOC ON DEMAND DISTANCE ROUTING PROTOCOL**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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|---|---|---|
| **Thesis Advisor :** | **Assoc. Prof. Dr. Turgay D. ALTILAR**<br>Istanbul Technical University | ............................. |
| **Jury Members :** | **Assoc. Prof. Dr. Berk Canberk**<br>Istanbul Technical University | ............................. |
| | **Asst. Prof. Dr. Muhammed Ali Aydın**<br>Istanbul University | ............................. |

**Date of Submission : 5th May 2017**
**Date of Defense : 14th June 2017**

***To My Mother, Late Father, and Departed Brothers,***

**FOREWORD**

Since the inception of my research and studies in general, the effort, advice, and guidance of Associate Professor Deniz Turgay Altilar, can not be over-emphasized towards the success and completion of this Thesis. He always ensured all 'i's are dotted and all 't's are crossed. I am honored to have had him as my school guardian, counselor, and adviser.

My immense appreciation also goes to a special brother, Husam Alzaq, for all his academic, moral and psychological support throughout my stay in school. I wish him great success in his endeavors.

My gratitudes won't be complete without thanking my entire family for their patience and faith in me; most especially my Wife, Rukayat Adebimpe Adeyemo-Yusuf, for her exceptional prayers, patience, and endurance throughout the course of my studies.

June 2017

Taofeek Abiodun O. YUSUF
(Computer Engineer)

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## ABBREVIATIONS

**ITS:** Intelligent Transport Systems

**IVC:** Inter-Vehicular Communication

**VANETs:** Vehicular Ad Hoc Networks

**MANETs:** Mobile Ad Hoc Networks

**AODV:** Ad Hoc On-Demand Distance Vector Routing Protocol

**DSR:** Dynamic Source Routing Protocol

**DSDV:** Destination Sequence Distance Vector Routing Protocol

**RSU:** Road-Side Unit

**OBU:** On-Board Unit

**GPS:** Global Positioning System

**GSM:** Global System for Mobile Communication

**GPRS:** General Packet Radio Service

**UMTS:** Universal Mobile Telecommunication

**WiMax:** World Interoperability Microwave Access

**4G:** 4th Generation of Mobile Telecom Technology

**PDA:** Personal Digital Assistance

**V2V:** Vehicle to vehicle communication

**V2R:** Vehicle to Road-Side Unit

**R2V:** Road-Side Unit to Vehicle

**R2R:** RSU to RSU communication

**NS2:** Network Simulation 2 (Version 2.35)

## SYMBOLS AND UNITS

**P:** Packets

**TIL:** Traffic Interval Length

**ms:** Milliseconds

**$ms^{-1}$:** Meter per seconds

**m:** Meters

**secs:** Seconds

**sq m:** Square meters

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**IMPACT OF INTER-VEHICULAR COMMUNICATION PERFORMANCE ON DIFFERENT TRAFFIC MOBILITY MODELS: A CASE STUDY OF AD HOC ON-DEMAND DISTANCE VECTOR ROUTING PROTOCOL**

## SUMMARY

With the integration of vehicles as an active communication and computational agents of road management into Intelligent Transport System (ITS), interest in Wireless technology and Vehicle Ad Hoc Network (VANET) studies and research have taken a drastic turn. Many studies and researches have been done and are still being carried out with a concentrated interest in regards to 'Safety Precautions of Vehicles' and how to further enhance the infotainment system therein.

The twenty-first-century technological advancements in vehicles, in general, has called for and as well demanded better and improved measures on the part of vehicle owners and also for safety on the road, as one of the paramount aspects of Inter-vehicular communication and mobility, in such a way that, people want to be mobile and nurse great interest in traveling safely to their various destinations. And in order for this to be achieved, there is the need for wireless inter-vehicle communication between vehicles plying the roads.

Inter-Vehicular Communication (IVC) has attracted considerable attention from the research community and numerous automotive industries which have benefitted the society, as a whole, through providing Intelligent Transport System (ITS) as well as providing beneficial services to drivers and passengers alike.

Hence, Vehicular Ad hoc Networks (VANETs), also known as Autonomous networks, due to the advancement in wireless technology, are emerging as a new class of wireless networks, which are spontaneously formed between moving vehicles manned with wireless interfaces that could have similar or different radio interface technologies, which employs short-range to medium-range network systems. Vehicular ad hoc networks (VANETs) are a pin-pointed architecture to look forward to, for vehicle-to-vehicle communication in the transportation world. The incessant topology change of

VANET has created many problem and challenges to data packet delivery between sources and destination vehicular nodes, causing an effect on end-to-end message dissemination because vehicle speed and velocity in network varies with time**.**

Vehicular ad hoc networks are a subset or subcategory of Mobile Ad hoc Networks (MANET), which provides communications among nearby vehicular nodes (V2V) and between vehicular nodes and a nearby fixed equipment on the roadside (V2R). In inter-vehicle communication, various scenarios of mobility models such as Simple, Highway, Manhattan amongst others, should also be put into consideration, as vehicles tend to communicate in different environmental scenarios and thus, could affect the way the vehicle communicate and may lead to inefficient communication between or amongst vehicles.

Furthermore, designing an efficient routing protocol for stable and efficient communication is highly important due to the fact that, vehicle dwell in different environment, and the need for efficient communication and message dissemination between vehicles in any environment should be ensured without hindrance to inter-vehicular communication, hence, routing protocol of choice should really be put into consideration.

In this thesis, the Impact of Inter-vehicular communication performance on different mobility models is investigated, basing our research on the use of Ad Hoc On-Demand Distance Vector (AODV) Routing protocol, as the protocol of choice, in different mobility scenario as our case study. Inter-vehicular communication is made possible by passing a message from one vehicle to another through using a reliable routing protocol.

The usage of efficient and reliable routing protocol has created many research areas for researchers and has helped to ensure end-to-end packet delivery in recent times, regardless of the incessant changing network topology of vehicles in Vehicle Ad Hoc Network.

Hence, Ad hoc On Demand Distance Vector Routing protocol (AODV) was evaluated against some network performance metrics, such as Packet data loss, Packet delay and throughput using CityMob traffic generator, which is one of the most popular vehicular traffic mobility generators; for generating mobility for the communicating vehicular nodes.

We created some communicating vehicular nodes and tested them in different traffic mobility scenarios, under the same experimental conditions and parameter, using AODV routing protocol as our case study. The results we got were far from being verbose as we simulated close to real life traffic mobility and we showed that AODV routing protocol thrives better in Simple and Highway traffic mobility model as compared to Improved Manhattan traffic mobility model, comparing our results with previous work in this line of research.

We concluded that, no matter how reliable a routing protocol may be, the wireless communication of vehicle has limitations in different environmental scenarios. Though, there are many routing protocols being used in Vehicular Ad Hoc Network (VANET), but, for this research, we have chosen to check the efficiency and reliability of Ad-Hoc On-Demand Distance Vector (AODV) Routing Protocol in different environmental scenarios because it is one of the most widely used routing protocol in vehicle ad hoc networks (VANET).

# ARACI ARACI İLETİŞİM PERFORMANSININ FARKLI TRAFİK UYGULAMALI MODELLER ÜZERİNDE ETKİSİ: AD HOC İSTENEN MESAFELE UZAKTAN VEKTÖR ROTASYON PROTOKOLÜNÜN BİR VAKA ÇALIŞMASI

## ÖZET


Aktif bir iletişim ve Akıllı Ulaşım Sistemine (ITS) yol yönetiminin hesaplama ajanları olarak araçların entegrasyonu ile, Kablosuz teknoloji ve Araç Ad Hoc Ağı'na, araştırmalara ve araştırmalardaki ilgi büyük bir adım attı. Birçok çalışma ve araştırmalar yapılmış ve halen 'Araçların Güvenlik Önlemleri' konusunda yoğun bir ilgi ile ve orada bilgi-eğlence sistemi geliştirmeye nasıl devam edecektir.

Araclardaki yirmi birinci yüzyıl teknolojik gelişmeleri genel olarak araç sahiplerinin parçası olarak daha iyi ve geliştirilmiş tedbirler talep etmiş ve aynı zamanda araçlararası iletişimin en önemli yönlerinden biri olarak yol güvenliği için de talep etmiştir. Ve hareket kabiliyeti, ki insanlar hem hareket halindeyken hem de hemşireye çeşitli yerlerine güvenli bir şekilde seyahat etmek istiyorlar. Ve bunun başarılması için, yollar arasında dolaşan araçlar arasında kablosuz araç içi iletişim için bir ihtiyaç var.

Inter-Vehicular Communication (IVC), araştırma topluluğundan ve Akıllı Ulaşım Sistemi (ITS) sağlanmasının yanı sıra sürücülere ve yolculara faydalı hizmetler sunarak topluma yararlı birçok otomotiv endüstrisinden büyük ilgi gördü.

Bu nedenle, kablosuz teknolojinin ilerlemesiyle Özerk ağlar olarak da bilinen Vehicular Ad hoc Networks (VANET'ler), kendiliğinden kablosuz arayüzlerle çalışan ve benzer veya benzer özelliklere sahip olan araçlar arasında oluşturulmuş yeni bir kablosuz ağ sınıfı olarak ortaya çıkıyor. Kısa menzilli ve orta menzilli sistemleri kullanan farklı radyo ara yüzü teknolojileri. Taşıt geçici ağlar (VANET'ler), ulaşım dünyasındaki araç-araç iletişimi için sabırsızlıkla duran, sivri bir mimaridir. VANET'in kesintisiz topoloji değişikliği, kaynakların ve hedef araç kodları arasındaki veri paketi dağıtımında birçok problem ve güçlük yarattı ve dolayısıyla araç hızı ve hızı zamanla değiştiğinden uçtan uca mesaj yayılımı üzerinde bir etkisi var. Araç ad hoc ağları, yakındaki taşıtın düğümleri (V2V) arasında ve taşıt düğümleri ile yol kenarındaki yakın sabit bir ekipman (V2R) arasında iletişim sağlayan, Mobil Ad hoc Ağların (MANET) bir alt kümesidir veya alt kategorisidir.

Araçlararası iletişimde, araçların farklı çevresel senaryolarda iletişim kurma eğilimi gösterdiği ve böylece aracın iletişim kurma biçimini etkileyebileceği gibi, Basit, Karayolu, Manhattan gibi hareketlilik modellerinin çeşitli senaryoları da dikkate alınmalıdır. Araçların arasındaki iletişimin verimsizliği.

Dahası, kararlı ve etkili iletişim için etkin bir yönlendirme protokolü tasarlamak, aracın farklı ortamlarda bulunması ve bu tür ortamlarda veya herhangi bir ortamda araçlar arasında etkili iletişim ve mesaj yaygınlaştırma gereksinimi aralarındaki engel olmaksızın sağlanabilmesi nedeniyle son derece önemlidir Dolayısıyla, yönlendirme protokolünün gerçekten dikkate alınması gerekir.

Bu tezde, farklı hareketlilik modelleri üzerindeki Araçlararası iletişim performansının etkisi araştırılmıştır ve araştırmamız, farklı hareketlilik senaryosunda, seçim protokolü olarak Ad-Hoc On-Demand Mesafe Vektörü (AODV) Yönlendirme protokolünün kullanımına dayanmaktadır. Vaka çalışması. Araçlararası iletişim, güvenilir bir yönlendirme protokolü kullanarak bir araçtan diğerine mesaj göndererek mümkündür.

Etkin ve güvenilir yönlendirme protokolünün kullanımı, araştırmacılar için birçok araştırma alanı oluşturdu ve Vehicle Ad Hoc Network'teki araçların sürekli değişen ağ topolojisi ne olursa olsun, son zamanlarda uçtan uca paket teslimini sağlamaya yardımcı oldu.

Bu nedenle, Adhoc On Demand Mesafe Vektör Yönlendirme protokolü (AODV), en popüler araç trafik hareketliliği jeneratörlerinden biri olan CityMob trafik üreticisini kullanarak Paket veri kaybı, Paket gecikmesi ve verim gibi bazı ağ performans metriklerine karşı değerlendirildi; Iletişim aracı yolları için hareketlilik üretmek için.

Bazı iletişim aracı geçişleri oluşturduk ve bunları örnek çalışmalarımız olarak AODV yönlendirme protokolünü kullanarak aynı deneysel koşullar ve parametreler altında farklı trafik hareketlilik senaryolarında test ettik. Elde ettiğimiz sonuçlar, gerçek hayat trafiğinin hareketliliğini simule ettiğimizden çok uzaktı ve AODV yönlendirme protokolünün, Geliştirilmiş Manhattan trafik hareketlilik modeli ile karşılaştırıldığında Basit ve Otoban trafik hareketlilik modelinde daha iyi geliştiğini ve sonuçlarımızı önceki çalışmalarla karşılaştırarak gösterdiğini gösterdik Bu araştırma dizisi.

Bir yönlendirme protokolünün ne denli güvenilir olursa olsun, aracın kablosuz iletişiminin farklı çevresel senaryolarda sınırlamaları olduğu sonucuna vardık. Vehicular Ad Hoc Network'de (VANET) birçok yönlendirme protokolü kullanılmasına rağmen, ancak bu araştırma için, Ad-Hoc On-Demand Mesafe Vektörü (AODV) Yönlendirme Protokolünün farklı çevre koşullarındaki verimlilik ve güvenilirliğini kontrol etmeyi seçtik Senaryolar, araç geçici ağlardaki (VANET) en yaygın kullanılan yönlendirme protokollerinden biridir.

# 1. INTRODUCTION

Evolving intelligent transport system (ITS) design and development play a major role in improving road safety, traffic monitoring and passengers' comfort in order to minimize accidents and traffic congestion on our roads; and to further serve and satisfy digital needs (infotainment) of vehicle occupants, which includes the drivers and the passengers as well.

In order to achieve these goals, ITSs need to support traffic information delivery accurately, timely and efficiently, to vehicle occupants and traffic/transport authorities. This transmission is ensured through a reliable vehicular wireless protocol and mobile network as a Vehicular Ad Hoc NETwork (VANET).

VANET **[1]** is regarded as a specific kind of Mobile Ad Hoc NETwork (MANET) which entails a set of mobile nodes (in this case, Vehicles) and fixed nodes knows as roadsides units (RSUs). VANET provides digital data communication between vehicles through inter-vehicular communication (IVC or V2V), and between vehicles and RSUs through vehicle-to-roadside communication (V2R).

VANET has a restricted range of motion in terms of directions and speeds, which makes the vehicle move according to an organized and restricted mobility model with some distinctions between Simple/Rural, Highways or Urban/Manhattan areas. Moreover, a vehicle is equipped with some sort of radio interface called the on-board units (OBU) that enables short-range wireless IVCs and/or V2R along with a Global Positioning System (GPS) integrated into the vehicles to facilitate location-based services.

VANETs can support different types of services such as vehicle safety, automated toll payment, traffic management, enhanced navigation, location-based services. For example, finding the nearest fuel station, hotel or restaurant and as well as infotainment applications, such as Internet-based services and operations alike. Though, many research is continuing being made into how to better enhance the infotainment part of the Vehicular ad hoc network, many researchers are still being welcome to do so.

## 1.1 Problem Definition

Inter-vehicular communication is limited by the restricted and confined topology of the Vehicular network system, that is, the road network on which the vehicles ply. This limitation has brought about a great area of research studies as to investigating the discovery of what and which vehicular wireless network protocol is best suitable for a specific road topology, aiming at its pros, cons, capability, strength and weakness in terms of communication implementation among vehicular nodes and coupled with efficient and secure message dissemination between communicating vehicular nodes (that is, the Source and Destination vehicular nodes).

The availability of several types of mobility model has posed a great problem for researchers in studying different types of vehicular mobility models and protocols that may serve each model better. The different vehicular protocol in use in different vehicles depends on the network protocol system implemented in it, such as DSR, DSDV, AODV and so on.

A vehicular routing protocol is classified either by their characteristics and technique used, such as topology-based, position-based, geocast-based, broadcast, and cluster-based, or according to their network structure, in an array of, hierarchical routing, flat routing, and position-base routing. In some other cases, they can be categorized according to their routing information as geographic-based routing protocol and topology-based routing protocol or in other cases into two classes of protocols as proactive class routing protocol and reactive class routing protocol, details of routing protocol of choice for this thesis is given in Chapter 3 of this thesis work.

The proactive protocol is a subcategory of topology-based routing protocol, that allows a network node to use the routing table to store routes information for all other nodes, with each entry in the table containing the next hop node used on the path to the destination node, regardless of whether the route is needed or not **[2]**. Examples of this type of protocol are Destination Sequence Distance Vector (DSDV) routing protocol, Optimized Link State Routing (OLSR) protocol, Fisheye State Routing (FSR) protocol and many more.

A reactive routing protocol is also a subcategory of topology-based routing protocol, that reduces the network overhead by maintaining routes only when it is required. The source node starts a route discovery process when it needs a non-existing route to a destination node. This route discovery process is achieved by the reactive protocol through flooding the network with route request message. The intended destination node on receiving the message packet sends a route reply back to the sources node using a unicast transmission **[3]**.

Reactive protocol scales considerable with the large size of mobile ad hoc networks, with high mobility and incessant topology change. Examples of reactive protocols include, but not limited to, Ad Hoc On-demand Distance Vector (AODV) routing protocol (which is the main protocol to investigate for this thesis work), Ad Hoc On-demand Multipath Distance Vector (AOMDV) routing protocol, Enhanced AOMDV amongst others. Figure 1.1 shows the different routing protocol categories and classification and pointed out where AODV routing protocol falls in the whole vehicle ad hoc network protocol family.

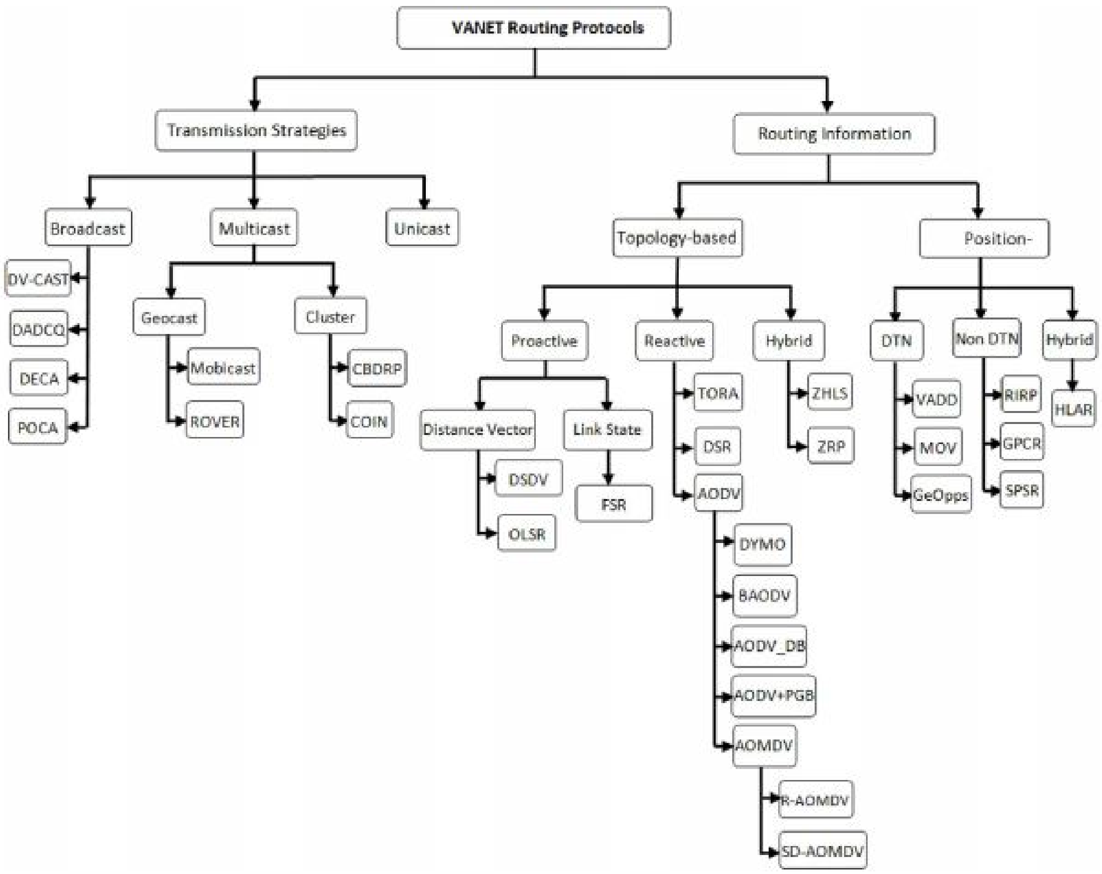


**Figure 1.1:** Categories and Classification of Vehicle routing protocols [2].

Studying how these protocols thrive in various mobility model is one of the major research area in this field, and the main concern of this research study is to investigate, how AODV routing protocol thrives in these traffic mobility scenario, simulating with parameters close to real life mobility scenarios.

### 1.2 Purpose of Thesis

Our main drive for this research was solely based on the experimentations, close to real world scenarios, on how vehicular protocol, in this case, Ad Hoc On-Demand Distance Vector (AODV) routing protocol, thrives and fair in different traffic mobility models. This was achieved through inter-vehicular communication among the vehicular nodes and measuring the vehicular wireless network protocol against different performance metrics, such as throughput, end-to-end delay, and packet loss, under the same experimental scenario conditioned in different vehicular mobility models.

The purpose of this thesis as previously stated, we believe, sets the stage for this research, positively, which eventually made us come to a conclusive end as regards the results and outcomes of the experimentations and simulation altogether.

### 1.3 Thesis Contribution

In this thesis, we demonstrated how different traffic mobility model could be utilized regardless of the routing protocol being employed. Some preliminary analyses were made as to how this research could help fix some network parameters issues, such as transmission range, in order to advance the communication performance of IVC networks in VANET. This thesis research study contributed through showing the importance of inter-vehicular communications with respect to safety and infotainment utilization in vehicles in general.

Observations were made as regards the low throughput in some vehicular mobility model which may be due to high packet collision rate during the data packet dissemination.

Our research also contributed by recommending Ad Hoc On-Demand Distance Vector (AODV) routing protocol as the routing protocol of choice for some vehicular traffic mobility model scenario due to the way it thrived better in some tested and experimented traffic mobility models of our simulation. Its unique ability to dynamically adjust to node density made it a protocol of choice in this research work.

### 1.4 Thesis Structure

The rest of the thesis are as follows: Chapter 2 gave insight into the related works and literature reviews in the field of VANET and IVC as a subject. It was followed by Chapter 3 where more terminologies were explained and a brief insight into our research was given.

In chapter 4, simulation details on different experimentations carried out are elaborated, and the respective results of the different experiments are given thereafter. Chapter 5 draws our conclusions and possible future projection work as a continuation, possible improvement and further research in the field of Inter-Vehicular Communication (IVC) and Vehicle Ad Hoc Networks (VANETs).

## 2. LITERATURE REVIEW

Intelligent Transport Systems (ITS) combine high tech and improvements in infosystems, sensors, computing devices, distributed databases in order to increase the capacity of transportation systems, and as well to improve the level of services. ITS introduces diverse applications supported in VANET spanning from safety-related to entertainment and infotainment applications.

ITS is currently the center of attention for car industrial manufacturers as well as transportation authorities and communication organizations bringing the basic idea to broaden the range of perception of the driver beyond their field of vision and to further assist the driver with autonomous assistance applications **[4]**.

Embodiment of VANET into ITS architecture **[5]** is a great breakthrough in automobile industries through the cooperative system it summed up to be, which has lessened the problems encountered on roads and highways in reducing number of road accidents and minimizing traffic congestion.

VANETs are a special mobile and wireless networks, characterized by a set of unique properties which make them very distinct, and call for more requirements to develop networking vehicular applications **[1]**.

Studies show that in VANETs, vehicle velocity is the rate of change of the position of mobile vehicular nodes versus time. Vehicle speed may range from zero when vehicles are stuck at a fixed point, in a traffic jam for example, up to over 200km/h on highways **[6]**.

Vehicular Network Architecture as discussed in **[7]** is a very important segment of VANET as vehicular networks can be deployed by network operators and service providers or through integration between operators, providers, and a governmental authority. The advances in wireless technology coupled with the trend in ad hoc networks have allowed a number of deployment architecture for vehicular networks, in simple/rural, highway and city/manhattan environment. Like the architecture depicted in figure 2.1, this is a typical novel example of an architecture of Vehicular ad hoc networks.

Literatures reviewed as regards the density of Vehicle Ad Hoc networks show that VANET density is a particular property which can make a clear distinction between vehicular network and other wireless networks. It is said that, the deployment area of VANET nodes can contain a very high number of nodes which can exceed 250 nodes in the transmission range of only one node, this situation, however, can occur if the vehicular traffic is very congested due to various reasons such as traffic jams and accidents, which is the case for the very high density **[1]**.

Though vehicular ad hoc networks (VANETs) are an extreme case of mobile ad hoc networks (MANET), they should not be confused with each other. The author in **[8]** made a clear distinction between the two terms by emphasizing that, in MANET, nodes communicate with each other in an ad hoc mode, that is, without a fix infrastructure, while, in VANET, nodes communicate in a similar manner but with high speed and with different mobility characteristics, which leads to frequent topology change of the network, other characteristics are as given in Table 2.1.

**Table 2.1:** Main characteristics of mobile and vehicle ad hoc networks [8].

| Characteristics | MANETs | VANETs |
|---|---|---|
| **Topology** | Dynamic | Highly Dynamic |
| **Speed** | Low | High |
| **Mobility** | Unconstrained | Constrained |
| **Power & Buffer Space** | Very limited | Not much limited |
| **Infrastructure** | Not fixed | It may be fixed or not fixed |

In **[9],** the authors studied the performance evaluation of DSDV and AODV, (AODV Routing protocol will be further explained in details in the next chapter) by creating 29 vehicular nodes and simulating their methods using VanetMobisim Traffic generator and NS-2 simulator., in their research, they compared the two protocols against Packet Delivery Ratio, Throughput and Average end to end in a simple traffic scenario, they concluded that DSDV protocol outperformed AODV protocol as affirmed in their paper, (Venkateswarlu and Murali, 2011). Though, their conclusion, to us look a bit shady, hence, the essence of carryung out our experimantal simulations in different traffic mobility model to find out how the protocol fair in them.

Kaur and Verma (2012), did a study of AODV routing protocol by creating different densities of vehicular nodes of 4, 10 and 25 using MOVE and SUMO as their mobility traffic generator and NS-2 to simulate their research findings. They checked throughput metric against all the node densities and concluded that throughput increases with increase in the Vehicular node density **[10]**.

Hamza and Benayad (2015), proposed the use of Hybrid routing protocol for VANET using an ontology., they concluded that the use of ontology in vehicles facilitates the interpretation of the information collected over traffic, and the cluster to reduce the overhead of the delay of the communicated messages between vehicles **[11]**. They emphasized that their approach can significantly reduce the delivery time, optimize routing and as well improve road service performance at the same time.

R. Kumar and Dave (2011), performed a comparative survey on various routing protocols in VANET, and in their conclusion, they emphasized that the use of a routing protocol depends solely on the choice of the implementer **[12]**. That is, it is left for the automobile industries to choose what is best suited for their product.

The author in **[13]** made research into Unicast routing protocols for VANET, making comparison and classification between the protocols, he explained that VANET allows for vehicles to form a self-organized system with no need for permanent infrastructure as an efficient route for structure must be a prerequisite to vehicular node communication which must adapt to the rapidly changing topology of vehicle motion.

Architectures in Vehicular Ad Hoc Networks **[7]** have allowed communication among nearby vehicles and between vehicles and nearby fixed road equipment or infrastructure. It was shown that three (3) alternatives in VANET communication include; (i) a pure wireless vehicle-to-vehicle (V2V) ad hoc network, allowing standalone vehicular communication with no infrastructure support, (ii) a wired backbone with wireless last hop that can be seen as Wireless Local Area Network, WLAN-like vehicular network, (iii) and a hybrid vehicle-to-roadside unit (V2R) architecture that does not rely on a fixed infrastructure in a constant manner, but can exploit it for improved performance and service access when available.

In the latter case, vehicles can communicate with the infrastructure either in a single hop or multihop fashion according to the vehicles' position with respect to the point of attachment with the infrastructure, it is necessary to understand at this point that the V2R architecture implicitly includes the V2V communication **[7]**.

In **[10],** a reference architecture for vehicular networks is proposed within the V2V-VV, distinguishing between three domains as, in-vehicle, ad hoc, and infrastructure domain. Figure 1.1 illustrates this reference architecture further. The in-vehicle domain refers to a local network inside each vehicle logically composed of two types of units: (i) an on-board unit (OBU) and (ii) one or more application unit(s) (AUs).

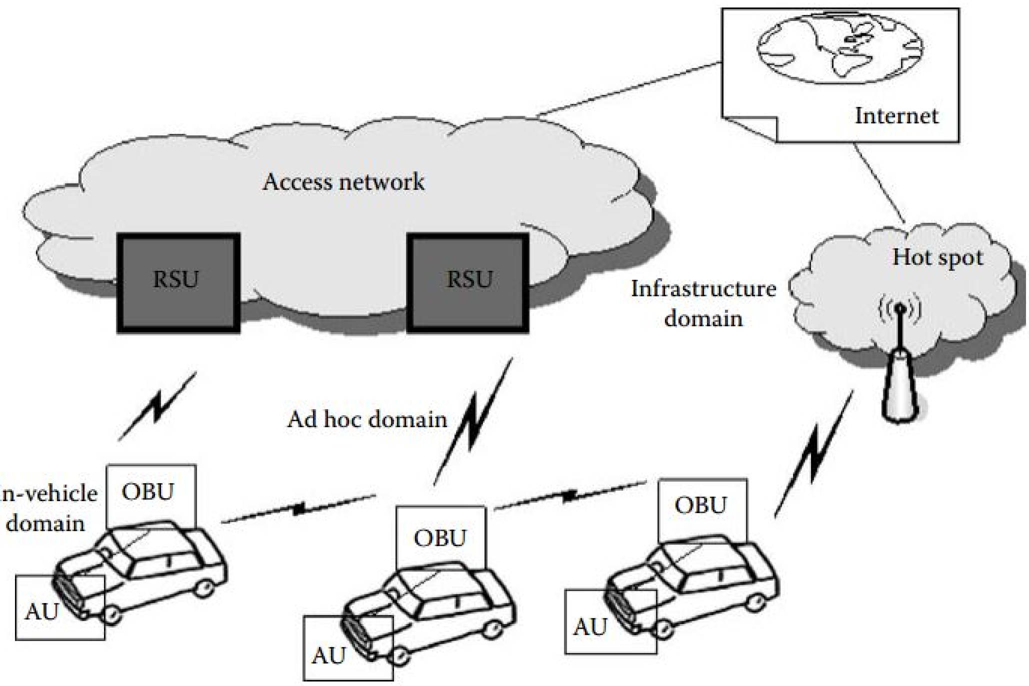


**Figure 2.1:** V2V-VV Reference Architecture [10].

An OBU is a device in the vehicle having communication capabilities (wireless and/or wired), while an AU is a device executing a single set of the application while making use of the OBUs' communication capabilities. An AU can be an integrated part of a vehicle and be permanently connected to an OBU or it can be as a portable device such as a laptop or Personal Digital Device (PDA) that can dynamically attach to (and detach from) an OBU. The AU and OBU are usually connected with a wired connection, while the wireless connection is also possible (using, e.g. Bluetooth and other suitable devices). The distinction between an AU and OBU is logical, and they can also reside in a single physical unit **[7]**.

It was further stated that the ad hoc domain is a network composed of vehicles equipped with OBUs and roadside units (RSU) that are stationed along the road. OBUs of different vehicles constitutes a mobile ad hoc network (MANET), where an OBU is equipped with communication devices, including at least a short-range wireless communication device dedicated for road safety. OBUs and RSUs can be seen as nodes of an ad hoc network, respectively, mobile and static nodes. An RSU can be attached to an infrastructure network, which in turn can be connected to the internet. RSUs can also communicate to each other directly or via multihop, and their primary role is the improvement of road safety, by executing special applications and by sending, receiving or forwarding data in the ad hoc domain **[7]**.

In the review conclusion for the reference architecture, the author stipulated that two (2) types of infrastructure domain access exist: RSU and hot spot. He made it clear that, though, RSUs may allow OBUs to access the infrastructure and, consequently, to be connected to the internet, OBUs can as well communicate with the internet via public, commercial, or private hotspots (Wi-Fi hot spots). And he stated that, in the absence of RSUs and hot spots, OBUs can utilize communication capabilities of cellular radio networks, such as GSM, GPRS, UMTS, WiMax, and 4G, if they are integrated into the OBU **[7]**.

Having reviewed the Vehicular reference architecture, the author in **[15]** continues with details on Inter-vehicular communication (IVC) that, developing IVC is not like developing other civil wireless communication techniques, he laid out the different features of IVS as, (i) requiring more effort to dealing with network delay and hard real-time event under a highly dynamic topology, he further said, network delay and system latency cannot be tolerated in some Intelligent Transport System (ITS) application such as hazard alarming and cooperative driving, (ii) that the size of a vehicular network can be very large in big cities, adding that, a traditional client/server system is not likely to be appropriate and the ability to have a distributed configuration is necessary, (iii) he mentioned that the density of a vehicular network is much more variable, which may become much lower at night and in bad weather, thus an IVC needs to adapt to the density changes and minimize the administrative overhead. And, they concluded by emphasizing that, to develop a real-world IVC technique, these stated features have to be fully considered, that, compared with civil wireless communication techniques, an IVC techniques can utilize two extra network supports such as the Roadside infrastructure support, as known as the RSU, which have been previous explained and the Localization service, which gives geographic information as regards vehicle position and direction **[15]**.

Over the years, the choice of suitable routing protocol for vehicle ad hoc networks have been a great area of research, many routing protocols have been tried but no conclusion have been so far made as to the most suitable routing protocol for VANET. In **[16]**, they investigated the pros and cons of vanet routing protocol in inter-vehicular communication, and amongst the routing protocol they studied was Ad hoc On-demand Distance Vector (AODV) routing protocol, which part of their claims was that AODV has the capability to support large ad hoc networks but more time is needed for connection setup.

In **[17]**, stable routing protocol to support Intelligent Transport System (ITS) was studied, in which they introduced a scheme which enhances the stability of Inter-Vehicular Communication and Road-Vehicle Communication in VANET networks in order to group vehicles according to their moving direction. Their simulation result shows that the protocol's effectiveness in term of high stability, reduced control overhead, and high throughput compared to DSR or any other protocol for vehicular networks.

Routing protocol and the search for suitable protocol in vanet is of immense importance, the search for the most suitable protocol have paved way for more research into different routing protocols for vanet, hence, in **[2, 18, 19]** survey were conducted in experimenting different routing protocol for Vehicle Ad Hoc Networks, they concluded that position-based routing and geo-casting are more promising than any other protocol.

In **[20-24]**, performance analysis and comparison of Ad hoc on-demand distance vector (AODV) routing protocol with other vehicular routing protocols were investigated, analyzed and comparison was inferred using performance metrics, such as Packet Delivery Ratio, Packet End-to-End Delay, Traffic Rate, Throughput e.t.c.

The author in **[22]** concluded that increase in the vehicle pause time increases both the packet loss and average end-to-end delay but decreases the packet delivery fraction. AODV routing protocol was compared with Optimized Link State Routing, OLSR, protocol in **[21]** using Urban mobility scenario as a case study, the simulation was done under a controlled experimental procedures and near real life parameters, and they concluded that OLSR routing protocol outperforms AODV in Urban/Improved Manhattan traffic mobility model, claiming that, OLSR has smaller routing overhead, end-to-end delay and route lengths.

Position-based routing protocol as a suitable protocol for vanet was investigated in **[20]** and they concluded that it is a promising routing protocol for vanet in that, it will improve the traffic control management and provide information to concern authorities and drivers in a timely manner. In **[23, 24]**, AODV routing protocol was investigated and affirmed a worthy protocol of VANET, though they claimed that, as the vehicular node density and velocity increases, the protocols' performance may reduce or decrease.

In **[25]**, analysis of routing protocol for highway traffic mobility model without using roadside unit and cluster was studied, they proposed a new routing model concept for VANET routing protocols without the use of cluster that uses the standard 802.11p, and they concluded that, the proposed routing protocol with 802.11p yields better performance compare to the normal 802.11 and that it also gives better efficiency.

GeoSpray, a new multiple-copy geographical routing protocol was researched in **[26]**, this protocol was designed for Vehicular Delay-Tolerant Networks (VDTNs). It exploits mobility of vehicles and location information provided by GPS in order to assist routing in accordance to store, carry, and forward paradigm. They concluded that the protocol performed better in terms of delivery probability, average delivery delay, the number of initiated transmission bundles, the number of packets dropped bundles and overhead ratio. Current trends in VANET were discussed in **[27]** and emphasis was made to massive and different ongoing researches in VANET, listed as part of the trends are the IEEE 802.11p and WAVE suite recently released for use and the research into the development of efficient broadcasting and security algorithms were also mentioned.

With regards to the new trends in VANET, a new interference aware on-demand routing protocol for Vehicular networks was investigated in **[28]** named, Signal-to-Interference Ratio Ad hoc On-demand Distance Vector routing protocol, SIRAODV, which is based on the traditional signaling scheme of AODV routing protocol and as well takes the advantages of DSRC spectrum, in order to reduce interference levels among mobile nodes. Their simulation result showed that there are good enhancements in terms of throughput and packet delivery ratio.

In **[29]**, CoRoute, a cognitive ad hoc vehicular routing protocol was proposed which utilizes geographical location and sensed channel information. With regards to their simulation results, CoRoute demonstrates efficiency and robustness to mobility and external interference.

Survey and challenges in routing and data dissemination was carried out in **[30]** by Wai Chen et al (2008), where they highlighted that, dissemination types are structured as Geocast or Broadcast, Multicast, and Unicast, and affirming that, despite majority body of research on data dissemination in regards to inter-vehicular communication in VANET, data dissemination amongst vehicular nodes continues to be a challenge, hence, creating a wide area of research to researchers alike.

Owing to data dissemination in VANET, an evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces was investigated in **[31]**, they stated that, for few traces of node movement in realistic scenario for ad hoc networks, car traffic simulator used by city planner and civil engineers is the best choice to obtain mobility information. In their work, they modeled the irregular radio channel behavior by the probability shadowing signal propagation model. In conclusion, they stated that VANETs provide an integrating and challenging environment for ad hoc networks.

# 3. RESEARCH MOTIVATION AND METHODOLOGY

## 3.1 Research Motivation

The motivation behind this research is not far fetched. it is known that the application of wireless network technology to road traffic scenarios is to optimize driving with respect to safety, which has long been one of the main drivers of vehicular communication, and efficiency.

It was revealed in past research statistics that, at the end of $20^{th}$ century, when bigger research activities started in North America as well as in Europe and Japan, the global number of injuries caused by road traffic accidents was close to 40 million people and the number of fatalities was almost 1.2 million people., (this fact was gotten from a study carried out in 1998 titled; "**Injury: A leading cause of the global burden of disease**", published by the World Health Organization (WHO) in the year 2000).

This thesis research study was borne out of the need for having safer and efficient Inter-vehicular communication amongst the vehicles plying the roads, in order to ensure safety and reduce road accident and as well to investigate how the routing protocol(s) meant to achieve these goals (efficient message dissemination between vehicles and so on) thrive(s) in different mobility model scenarios.

## 3.2 Research Methodology

The methodology we implemented in this research are novel, carried out through series of experimental simulation with the use of Ad Hoc On-Demand Distance Vector (AODV) routing protocol in different traffic mobility model scenarios. The essence of doing this was to test, how efficient, messages are being disseminated in communicating vehicular nodes and the limitation of this routing protocol in this different mobility models. The following is an explanation of the routing and some of the tools we use in our studies and how we executed them towards the findings we made in the course of this thesis study.

### 3.2.1 AODV routing protocol

Ad hoc On-Demand Distance Vector (AODV) routing protocol is a reactive routing protocol which discovers routes only when they are needed. It offers quick adaptation to dynamic link conditions with low processing and memory overhead, also with low network utilization, and determines unicast routes to a destination within ad hoc networks. It is claimed that AODV can handle low, moderate, and relatively high mobile rates, together with a variety of data –traffic loading **[32]**.

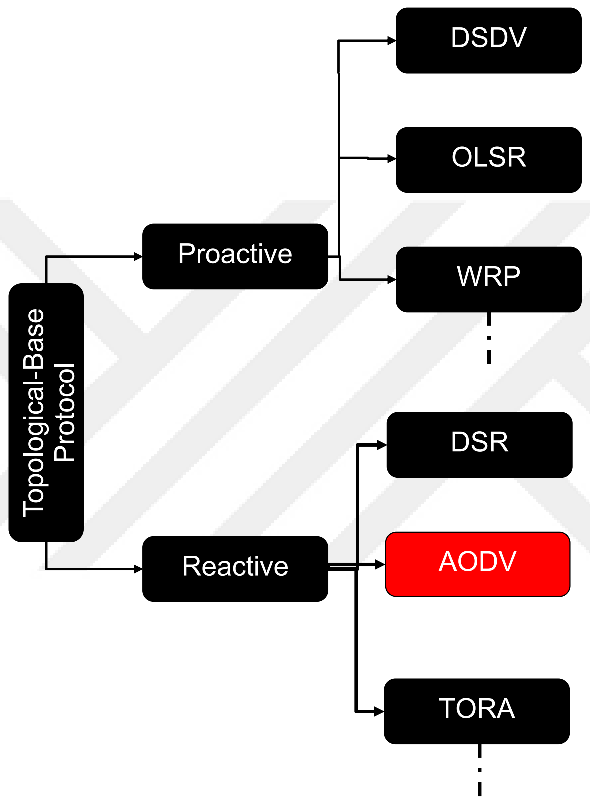


**Figure 3.1:** AODV as a Topology-based Routing Protocol.

In **[33]**, it is shown that routing protocols are sub-divided into Topology-based and geographic routing protocols. AODV falls under the sub-category of topology-based routing protocol, as depicted in Figure 3.1. A topology-based routing protocol is categorized into two main groups as Proactive and Reactive routing protocol.

Proactive uses routing table for propagation but the Reactive type, under which AODV routing protocol falls, build routes only when it needs to propagate a message to a destination node. AODV operates on the hop-by-hop pattern and in **[34]**, the author made mention that, AODV routing protocol enables dynamic, self-starting, multihop routing between participating nodes willing to establish and maintain an ad hoc network.

In **[35]** the author stated that there are three main types of messages of AODV: route request (RREQ), route reply (RREP), and route error (RERR) messages. It was further mentioned that, when a node wants to communicate with another node in the network and does not have a fresh route to that destination, it starts a route discovery process by broadcasting an RREQ message for the destination node in the network. Any of the intermediate node that receives this request either send an RREP to the source node if they have a fresh route to the destination node and the "destination only" flag is not set, or forward the RREQ message to other nodes in the network.

A fresh route is a valid route entry whose sequence number is either equal to or greater than that contained in the RREQ message. If the request packet has been forwarded by this intermediate node before, it is silently dropped. When a destination node receives an RREQ for itself, it sends back an RREP message on the reverse route. The requesting node and the node receiving RREP messages on the route update their routing table with the new route.

### 3.2.2 Simulation tools

It is a known fact that results can not be gotten without a prior process of experimentations, and a conclusion can not be reached without proper research study of the problem in question, thence, in this thesis, we present to you the tool we made use in reaching our conclusive results.

#### 3.2.2.1 Citymob mobility traffic pattern generator

CityMob **[36]** is a mobility traffic pattern generator for vehicular ad hoc network (VANET) developed at the polytechnic University of Valencia which allows for creation of three (3) different vehicular traffic mobility scenarios. It is implemented in C programming language and distributed under GNU/GPL license, which can be used once downloaded and unzipped without any installation step involved.

To generate a simulation of vehicular movement in CityMob, we must execute the application followed by the appropriate and required parameters depending on the desired trace of vehicular mobility model trace file to be generated, which could be trace file of Rural/Simple, City/Highway or Urban/Manhattan traffic mobility models respectively. In the console or terminal, depending on which Operating System (OS) is in use, navigate to the directory where the CityMob executable is placed and execute the following command:

./citymob – m M – n N – t T – s S – w W – h H – d D – a A – x x1 – y y1 – X X1 – Y Y1 – p P

Where;

M: Model

- M = 1: Rural/Simple Simulation Traffic Model
- M = 2: City/Highway Simulation Traffic Model
- M= 3: Downtown/Urban/Manhattan Simulation Traffic Model

N: Number of nodes to be created for the simulation

T: Simulation Time

S: Max Speed

W: Map Width

H: Map Height

D: Street Distance

A: Accident Number

x1: min X downtown (only for M=3)

y1: min Y downtown (only for M=3)

X1: max X downtown (only for M=3)

Y1: max Y downtown (only for M=3)

P: Probability of a node being initially located inside the downtown (only fo M=3)

CityMob generates three (3) different traffic mobility scenario thus; (i) simple model, (ii) highway model, and (iii) the improved manhattan model.

- Simple traffic model **[36]** creates a scenario of vertical and horizontal mobility patterns of vehicular nodes without directional changes or traffic light.

  As its name implies, it does not complicate road or the traffic mobility scenario, nor does it simulate traffic light or road accident unlike othe traffic mobility scenarios, it is easy to configure and very straight forward in its implementation.

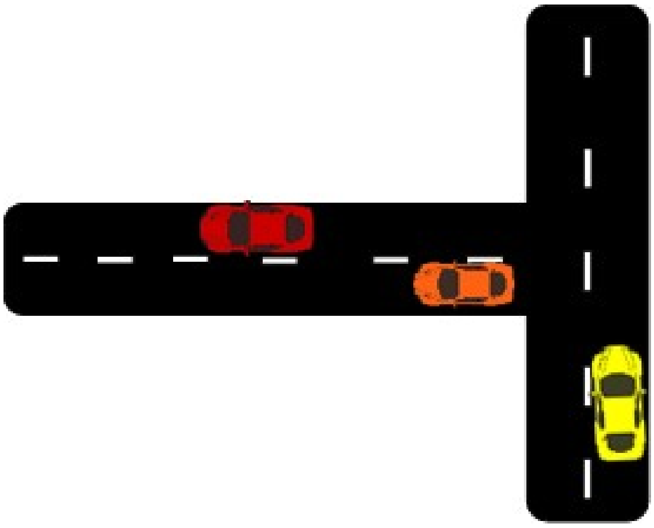

**Figure 3.2:** Simple Traffic Mobility Model.

- Highway traffic model is modeled to move vehicular nodes in horizontal or vertical fashion with two-way street having one lane in each direction of node movement constrained by defined lanes. The direction of node movement is randomly selected and cannot be repeated in two consecutive movements. Traffic lights are simulated at random positions, not only at a road crossing with different delay values at each point.

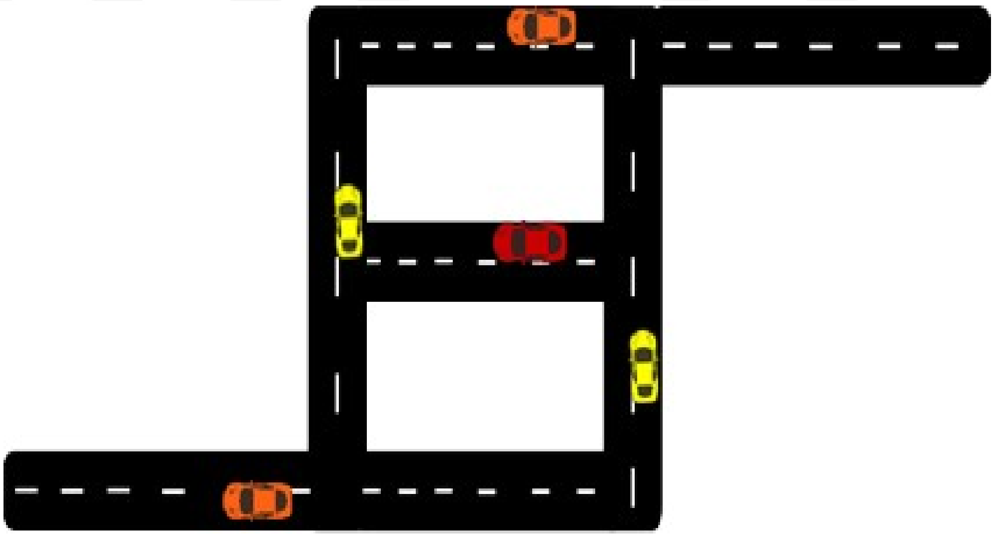

**Figure 3.3:** Highway Traffic Mobility Model.

- Improved Manhattan model adds traffic density to highway traffic model depicting a real downtown scenario with non-uniformly distributed vehicular node traffic within the model. Zones with higher traffic density are known as the Downtown, and the vehicle moves more slowly at this point compare to other points on the model.

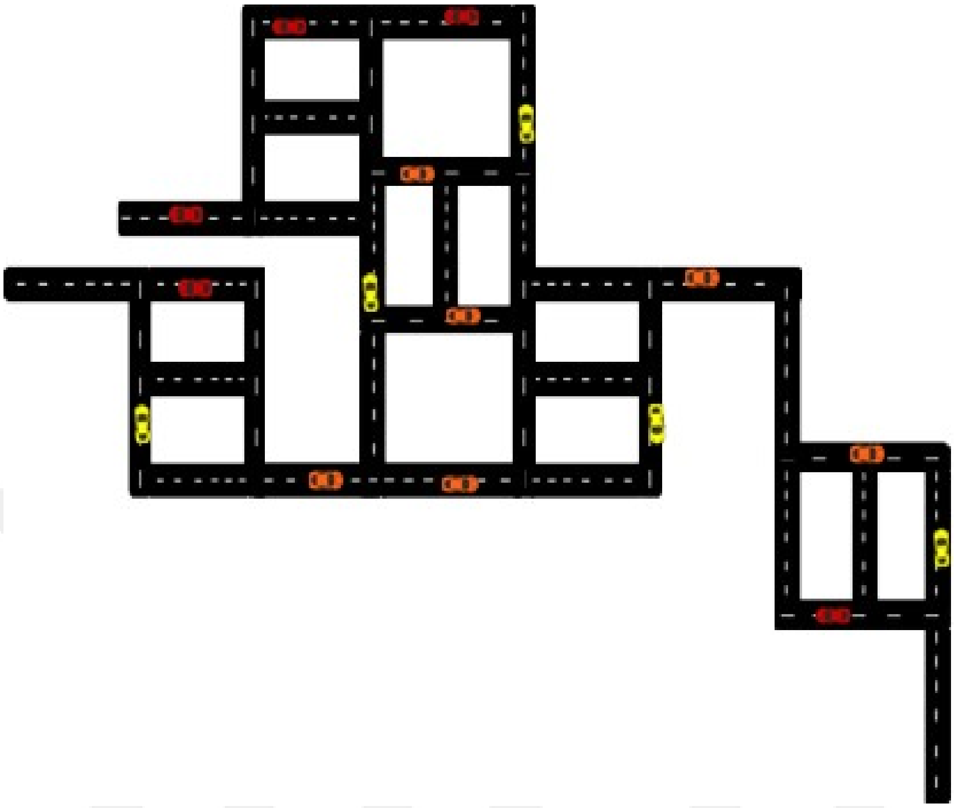

**Figure 3.4:** Improved Manhattan Traffic Mobility Model.

**3.2.2.2 Network simulator 2 (NS-2)**

Network Simulator 2 (NS-2) is a well-known simulating tool in the field of networks which is an object-oriented simulator, written in C++, with an OTcl interpreter as a frontend. It is also known as a discrete event simulator which supports a class hierarchy in C++ and a similar hierarchy in OTcl interpreter. Ns is a discrete event simulator targeted at networking research. Ns provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. These two hierarchies are closely related to each other, from the users' perspective, there is a one-on-one correspondence between a class in the interpreted hierarchy and that in the compiled hierarchy. Ns began as a variant of the REAL network simulator in 1989 and has evolved substantially over the past few years. In 1995 ns development was supported by DARPA through the VINT project at LBL, Xerox PARC, UCB, and USC/ISI. Currently ns development is support through DARPA with SAMAN and through NSF with CONSER, both in collaboration with other researchers including ACIRI.

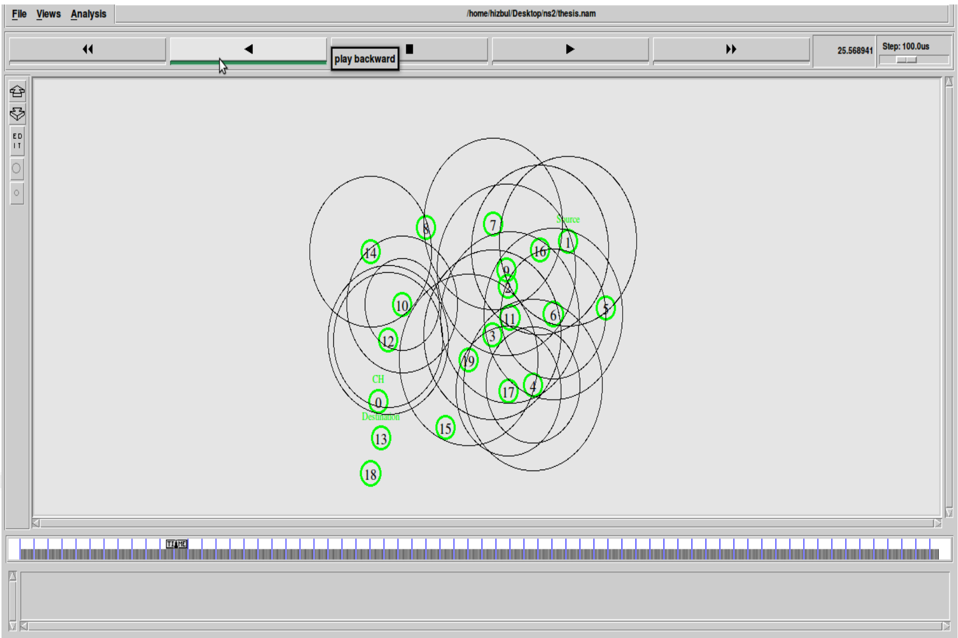


**Figure 3.5:** Network Simulator 2 Graphical User Interface.

### 3.2.3 Simulation/Experimental configurations

In this thesis, we investigated the impact on inter-vehicular communication in different traffic mobility models scenarios using the Ad hoc On-Demand Distance Vector (AODV) routing protocol as our case study. CityMob traffic mobility generator was the tool used in generating the traffic mobility trace files, in this case, the three generated vehicular traffic movement scenario as Simple, highway and Improved Manhattan mobility model, that we used in implementing the simulation which was introduced into the Network Simulator 2 (NS-2) program.

The configuration for our simulation in NS-2 is as given in Table 3.1. The dimension of the simulation topography is 1500 x 1500 square meters, the number of the node created for proper simulation scenario capture of performance metrics is 25 nodes for each scenario. The two-ray ground radio propagation model implemented in our simulation considers the path of the reflection from the ground and is suitable for long distance communication, we adopted it at the physical layer.

IEEE 802.11p is set setup for NS-2 at the MAC layer. UDP connection is used in order to get better result and for easy analysis compare to TCP protocol that does otherwise, therefore, considering the unstable factor of the vehicular ad hoc network, we choose to use UDP protocol at the transportation layer, while at the application layer, we implemented the constant bit rate (CBR) generator with packet size of 512 bytes.

AODV is the protocol in question that we experimented in different traffic mobility model scenarios, which is the protocol for the network layer because, from previous study and research, it is noted that, it takes a shorter time to set up and a routing path than DSR protocol, that is in the same category as AODV routing protocol.

**Table 3.1:** Simulation/Experimental Configurations.

| **Simulation Configurations** | |
|---|---|
| ***Parameters*** | ***Values*** |
| **Dimension of Topography** | 1500 by 1500 sq m |
| **Number of Vehicular Nodes** | 25 for each scenario |
| **Channel Type** | Channel/Wireless Channel |
| **Network Interface Type** | Phy/WirelessPhy |
| **Antenna Model** | Antenna/OmniAntenna |
| **Routing Protocol** | AODV for each scenario |
| **Radio Propagation Model** | Propagation/TwoRayGround |
| **Traffic Type** | CBR |
| **Interface Queue Type** | Queue/DropTail/PriQueue |
| **Transmitting Radio Range** | 150m |
| **Packet Size** | 512bytes |
| **MAC Protocol Type** | IEEE802.11p |
| **Vehicular Node Speed** | 15-30m/s |
| **Number of Road Lanes** | 2 in each scenario |
| **Distance between streets** | 100m |
| **Simulation Time** | 2000secs |

Twenty-five (25) vehicular nodes with speed between 15 to 30 $ms^{-1}$ were created for each mobility scenario, out of which 8 nodes was made to communicate to each other, with four vehicular source nodes (1, 4, 7, 11) and four vehicular destination nodes (2, 5, 8, 12). The nodes communicate by transmitting packets using UDP traffic type and ofcourse, AODV routing protocol serving as the path builder for the packet to be disseminated to the various destination vehicular nodes.

In order to evaluate the performance of the subjected routing protocol (the AODV routing protocol) in our experimentation, we measured some performance metrics against the different traffic mobility models such as:

- Average throughput, which is the amount of packet data per unit time that was delivered successfully from the source vehicular node to the respective destination vehicular node. The throughput was calculated thus:

$$T = \Sigma i \frac{Pi}{(ti - to)}; \quad i = 1, 2, 3 \ldots \qquad (1)$$

Where $i$ is the sequence number of packets, $t_i$ is the time when the packet $i$ is received by the destination vehicular node, $t_0$ is the time when packet $0$ is received by the destination vehicular node and $p_i$ is the packet size of the packet $i$.

- Average end-to-end delay defines the average transmission delay between the emission of a packet by a source vehicular node till its reception by the destination vehicular node. It is calculated as:

$$D = \frac{\sum i(tr(i) - ts(i))}{n}; \quad i = 0, 1, 2, 3 \ldots \qquad (2)$$

Where $i$ is the sequence number of packets, $tr(i)$ is the time when the packet is received by the destination vehicular node, $ts(i)$ is the time when the packet is sent by the source vehicular node, and $n$ is the total number of packet received by the destination vehicular node.

- Average Packet data loss due to multihop is the total number data lost per vehicular nodes which the message sent from the source vehicular node traversed to reach the destination node and it is calculated thus:

$$L = \frac{\Sigma i \; li}{n}; \quad i = 0, 1, 2, 3 \ldots \qquad (3)$$

Where *i* is the sequence number of the packets, *li* is the number of hops when the packet *i* is delivered from the source vehicular node to the destination vehicular node, and *n* is the total number of packet received by the destination node.

For the inter-vehicular communication amongst the vehicular nodes, we made nodes (1, 4, 7, 11) to be the source vehicular nodes, transmitting the data packet to nodes (2, 5, 8, 11) which we made to be the respective, destination vehicular nodes. In each of the traffic mobility models, these nodes were the communicating vehicular nodes.

The main reason for creating 4-pair of communicating vehicular nodes was prompted by the need to be able to accurately capture all the necessary performance metrics efficiently, in order to be able to reach a conclusive result, without leaving room for mistakes, using efficient and reliable methodology/approach. Thus, the simulations/experimentations were carried out successfully.

# 4. RESULTS AND ANALYSIS

Simulations and experimentations were carried out according to the specified vehicular traffic pattern mobility model scenarios and the performance metrics against the AODV routing protocol was recorded for each individual mobility model scenario, after which, the overall performance metrics for the total mobility model scenario, that enabled us to reach a conclusion, were also recorded **[37]**.

We used Xgraph tool to pictorially represent our results and each graph depicted for the individual and overall mobility model scenario is the representational output of the performance metric of the AODV routing protocol in each mobility model, respectively. As previously stated, we ensured gathering better inferences in order to reach a conclusive result on the experimental scenarios.

In each individual mobility scenario, the communicating vehicular nodes are represented by the colors in the graph thus; Communicating node 1 to 2 are represented with red color, the green color represents nodes 4 to 5, the blue color represents nodes 7 to 8 and finally, the yellow color represents, communicating nodes 11 to 12, respectively.

In the overall graphical result output representation, the color in the graphs represent the mobility model and shows how the performance metric against the AODV routing protocol thrives in the respective model. The red color represents the Rural/Simple traffic mobility model, the green color represents the City/Highway traffic mobility model and the blue color represents the Urban/Downtown/Improved Manhattan traffic mobility model, respectively.

## 4.1 Simple Traffic Mobility Model Scenario

The simulation was carried out for the simple mobility model scenario and we were able to infer from the performance of AODV routing protocol against the metric as shown in the figures. In figure 4.1, the highest end-to-end packet delay of about 240 milliseconds was recorded between communication vehicular nodes 1 and 2 at about 500 seconds of the simulation time which dropped down significantly over the course of the simulation to about 5milliseconds, while the lowest end-to-end delay was recorded in communicating node 4 to 5 at about 1600 seconds of the simulation time of about 5 milliseconds and other communicating vehicular nodes showed considerable delays.

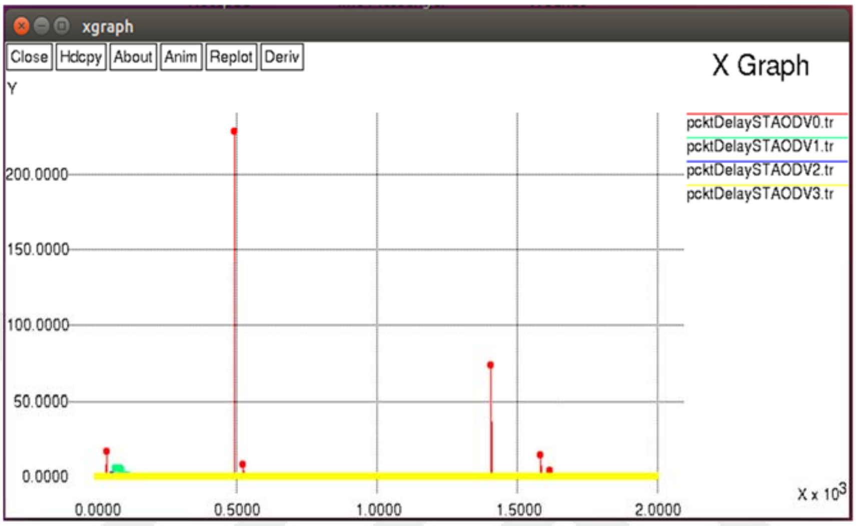


**Figure 4.1:** End-to-End Packet Delay for Simple Mobility Model.

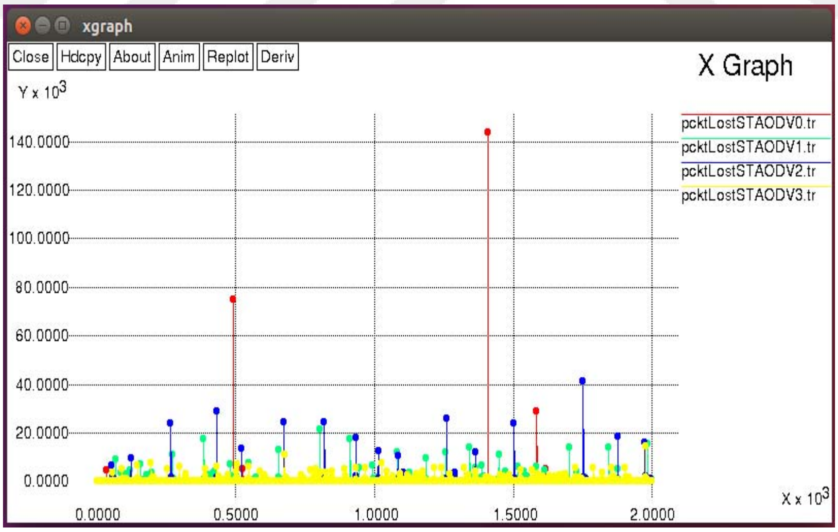


**Figure 4.2:** Packet Data Loss for Simple Mobility Model.

In figure 4.2, the Packet loss metric performance measured against the AODV routing protocol shows that, communication node 1 to 2 experienced the highest packet loss of up to about 145 per traffic interval length (TIL) at 1400 seconds of the simulation time but reduces over time to about 30 while other communicating nodes showed considerable packet loss during the course of the simulation.

Throughput, as shown in figure 4.3, was recorded for the scenario of the simple mobility model scenario and we observed that the communicating node 7 to 8 had the maximum throughput of about 2.15bits/TIL at about 1100 seconds of the simulation time, while other communicating nodes showed throughput of about 1.10bits/TIL throughout the course of the simulation.

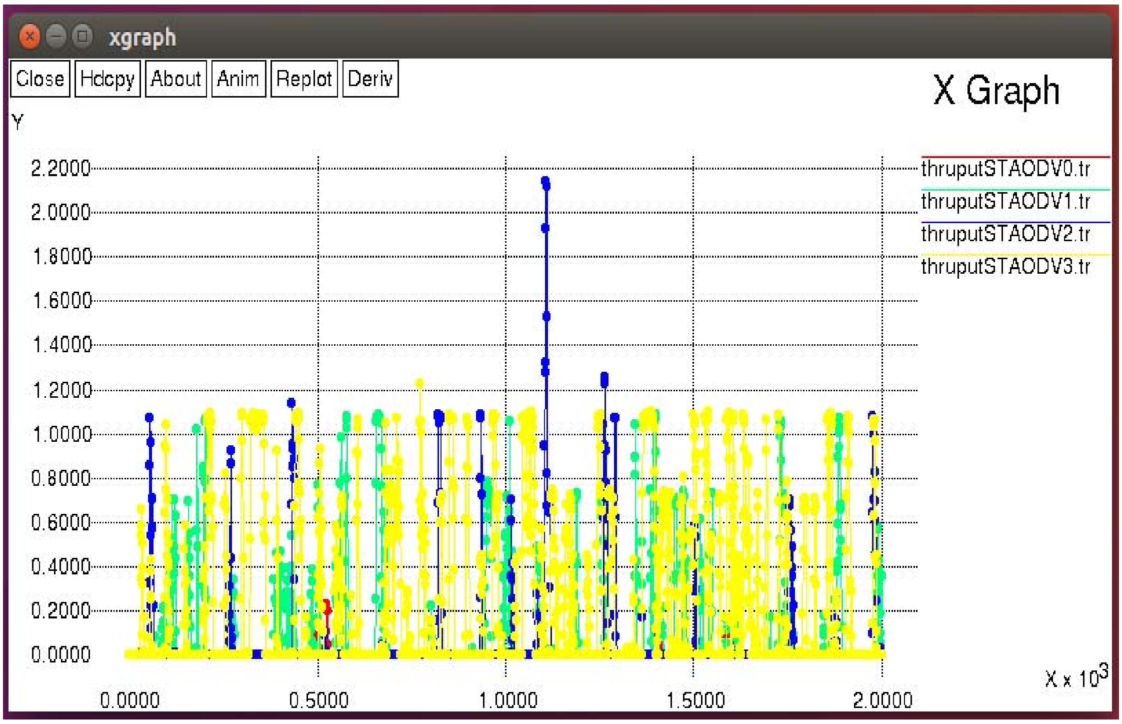


**Figure 4.3:** Average Throughput for Simple Mobility Model.

### 4.2 Highway Traffic Mobility Model Scenario

After the simulation was carried out on the Highway traffic mobility model, we found out that, the communicating node 1 to 2 experienced the highest end-to-end delay of about 37.5 milliseconds at exactly 600 seconds of the simulation time, while the communicating nodes showed less than 5milliseconds end-to-end delay over the course of the simulation time.

Disparities in the value can not be due to anything but improper communication or dissemination of the needed data packet, hence, resulting in a very low end-to-end delay.

The highest packet loss was recorded in communicating node 4 to 5 of up to 88.5 per traffic interval length (TIL) at 1650 seconds of the simulation time, while the nodes showed less than 60 per TIL of data loss over the course of the simulation.

Communicating node 7 to 8 experienced the highest throughput of about 2.25bits/TIL at about 400 seconds of the simulation time, communicating node 1 to 2 showed the minimum

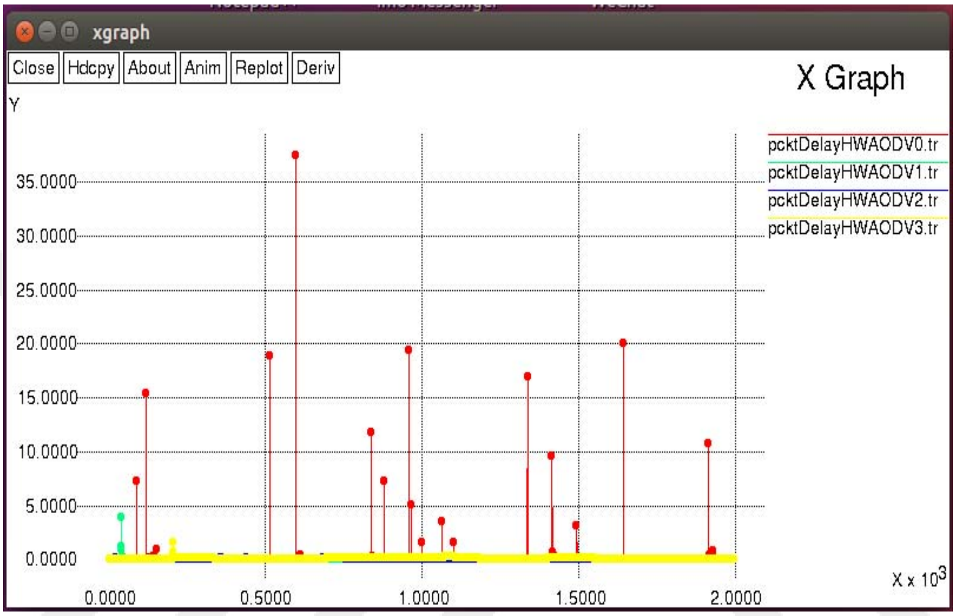


**Figure 4.4:** End-to-End Packet Delay for Highway Mobility Model.

throughput of about 0.65bits/TIL, while other communicating nodes showed considerable throughput of more than 2.0bits/TIL over the course of the simulation period.

Ofcourse, there may be some fluctuations in the value fluctuation in the simulation result, take for instance, having data packet delay of close to 2 milliseconds whereas as the standard stated, the lowest packet delay time even in LTE is between 20 to 35 milliseconds. In such case, we regards such value as close to zero or approximately zero and as such does not have much effect on the further outcome of the simulation because, as the simulation progressed, the we observed delay time of about 45 milliseconds in some scenarion and a little above that in some others, though, we still get some fluctuating value as close to zero and we believe it may have resulted from unsuccessful packet dissemnation to the destination node in question, from the transmitting source node.

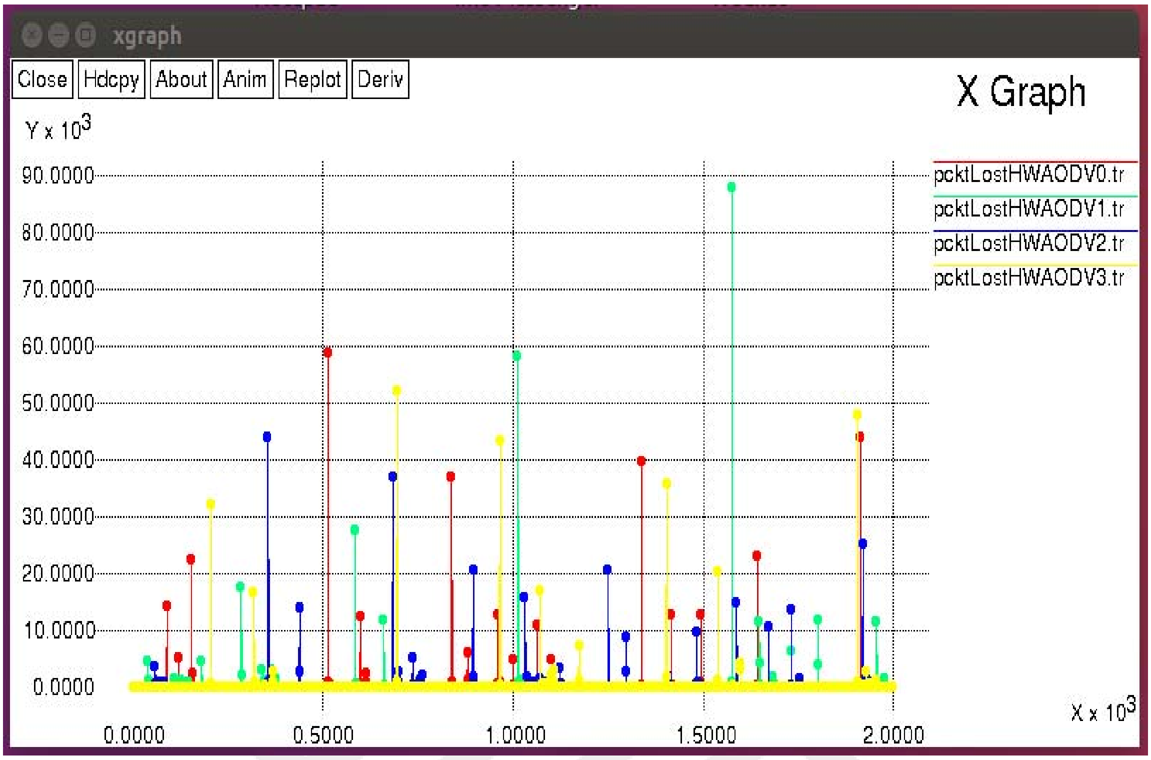


**Figure 4.5:** Packet Data Loss for Highway Mobility Model.

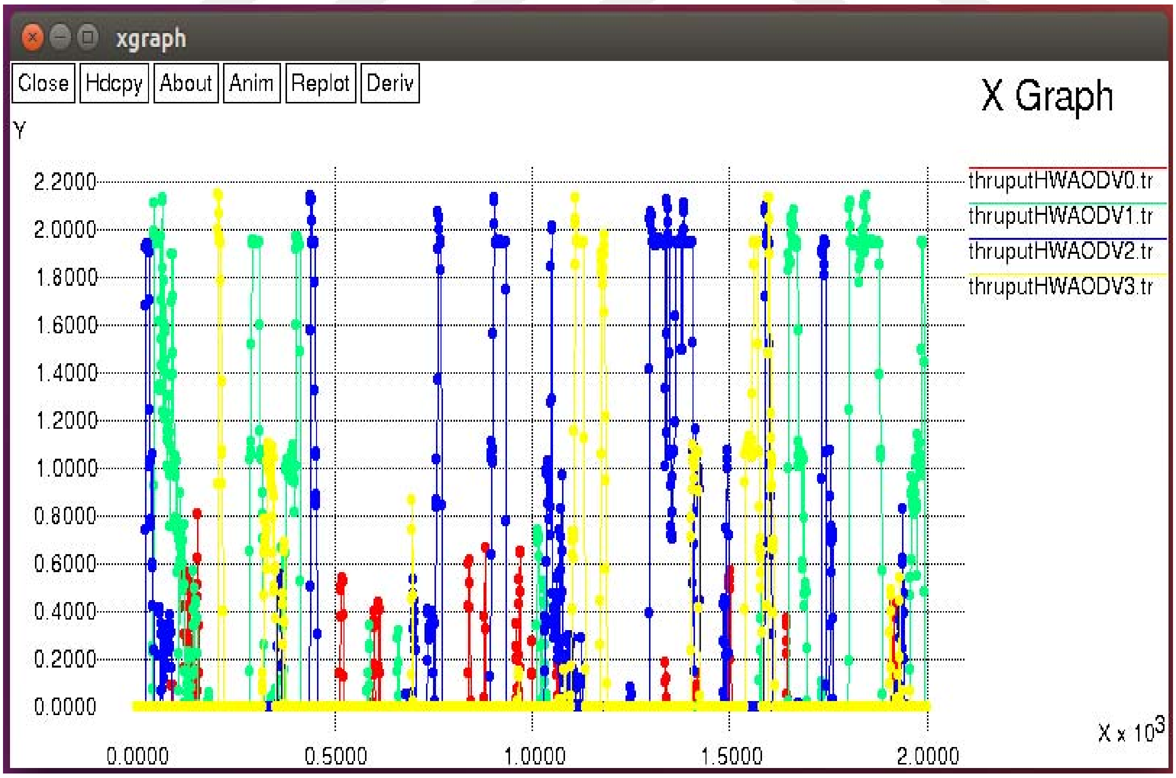


**Figure 4.6:** Average Throughput for Highway Mobility Model.

## 4.3 Improved-Manhattan Traffic Mobility Model Scenario

The performance metric of AODV routing protocol in Improved-Manhattan traffic mobility model scenario was as well recorded and it was observed that, communicating node 1 to 2 experienced the highest end-to-end packet delay of about 24 milliseconds at 250 seconds and 1150 seconds of the simulation time, respectively, while other communicating nodes experienced less than 5 milliseconds of end-to-end packet delay over the course of the simulation time.

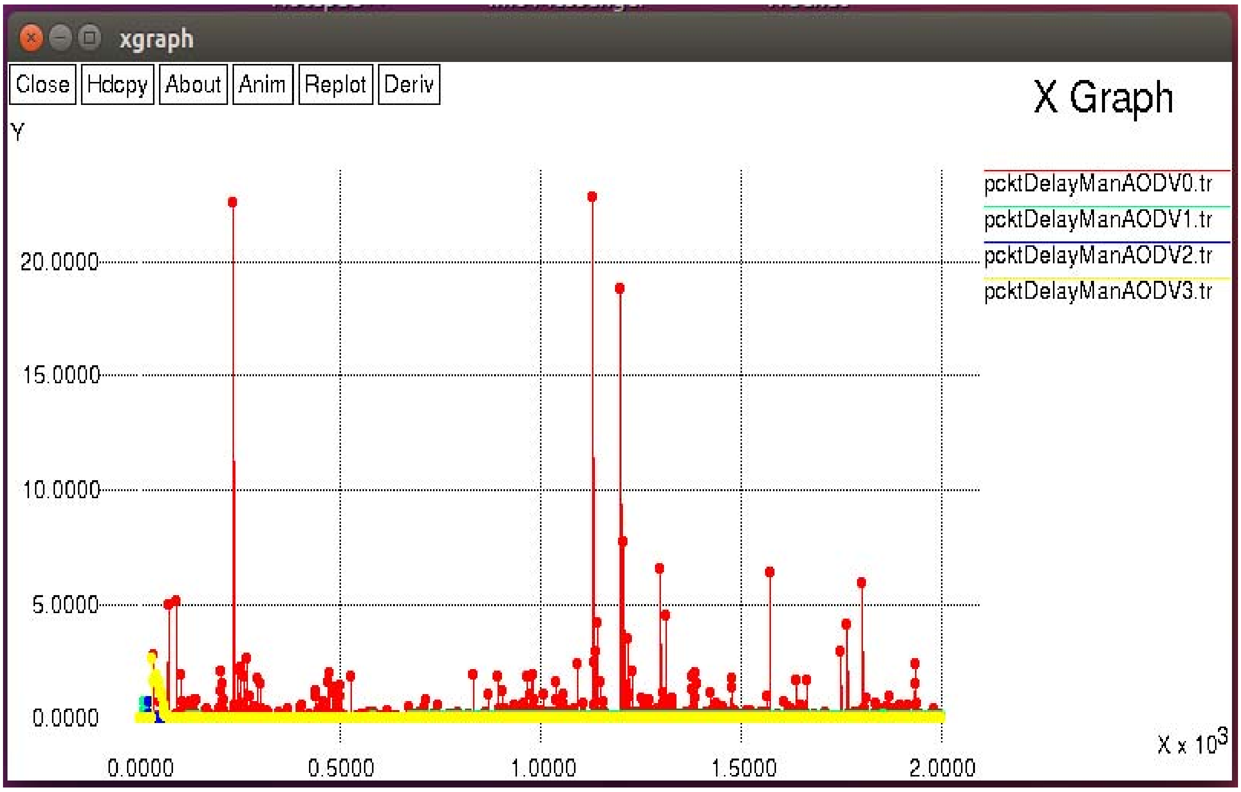


**Figure 4.7:** End-to-End Packet Delay for Improved-Manhattan Mobility Model.

The highest packet loss of about 27 per TIL was recorded in communicating node 4 to 5 at 800 and 1700 seconds of the simulation, respectively, while other nodes showed varied values less than 22.5 per TIL loss of data over the course of the simulation period.

We believe the highest packet loss observed in Improved Manhattan scenario may be due to the available infrastructure serving as obstacles on the communication path way of the data packet and this is one of the serious problem being faced in this particular scenario.

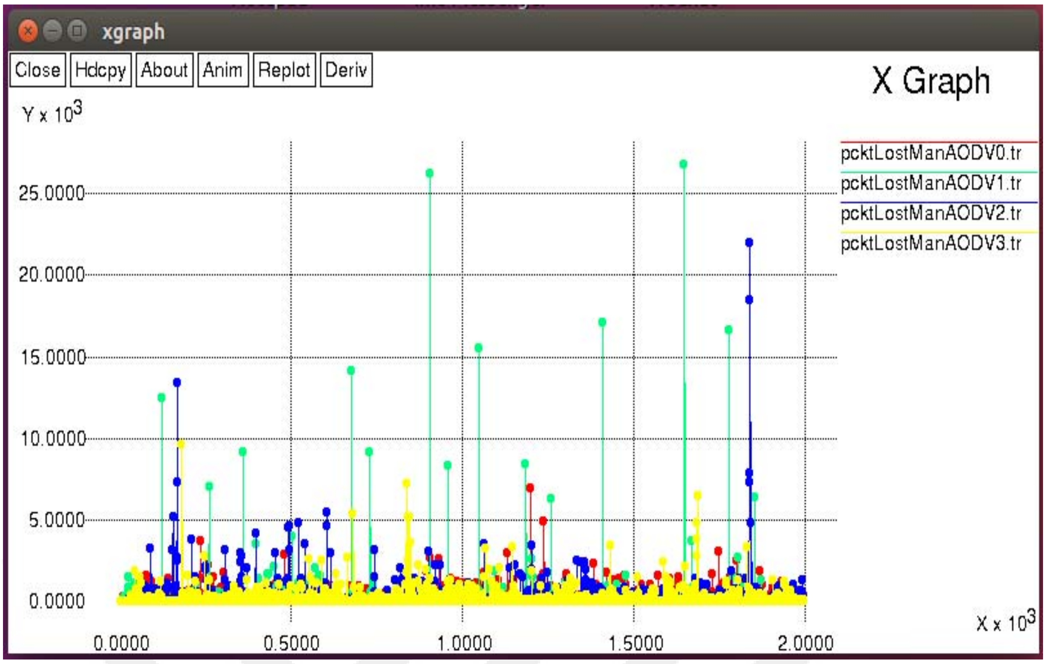


**Figure 4.8:** Packet Data Loss for Improved-Manhattan Mobility Model.

Maximum throughput for the improved-manhattan mobility model scenario was recorded in communicating node 4 to 5 of about 0.59bits/TIL, while other communicating nodes showed considerable less throughput which is less than 0.55bits/TIL over the course of the simulation

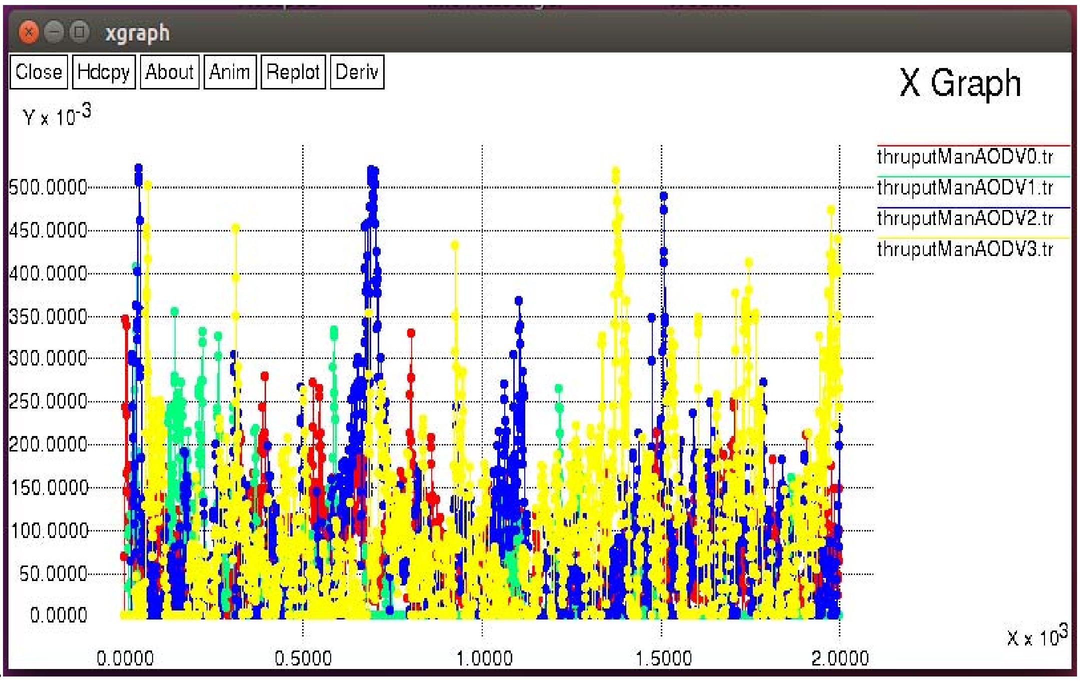


**Figure 4.9:** Average Throughput for Improved-Manhattan Mobility Model.

## 4.4 Overall Result of the Simulation

The overall result of the simulation was carried out after having carefully observed the communicating nodes that thrived better in the different traffic mobility models. These nodes were picked for their overwhelming performance against the metrics tested on AODV routing protocol, and from these nodes, final results were analyzed and graphed for better interpretation.

In the graph, the simple traffic mobility model was depicted in red, highway in green and improved-manhattan traffic mobility model in blue. It was observed that the highest end-to-end packet delay and packet loss were experienced in simple and highway traffic mobility model scenarios, while the least was experienced in improved-manhattan traffic mobility model scenario for both performance metrics.

In the overall result, graphed output, maximum throughput was recorded in the simple traffic mobility model the candid reason for this higher throughput of data packets could possibly be

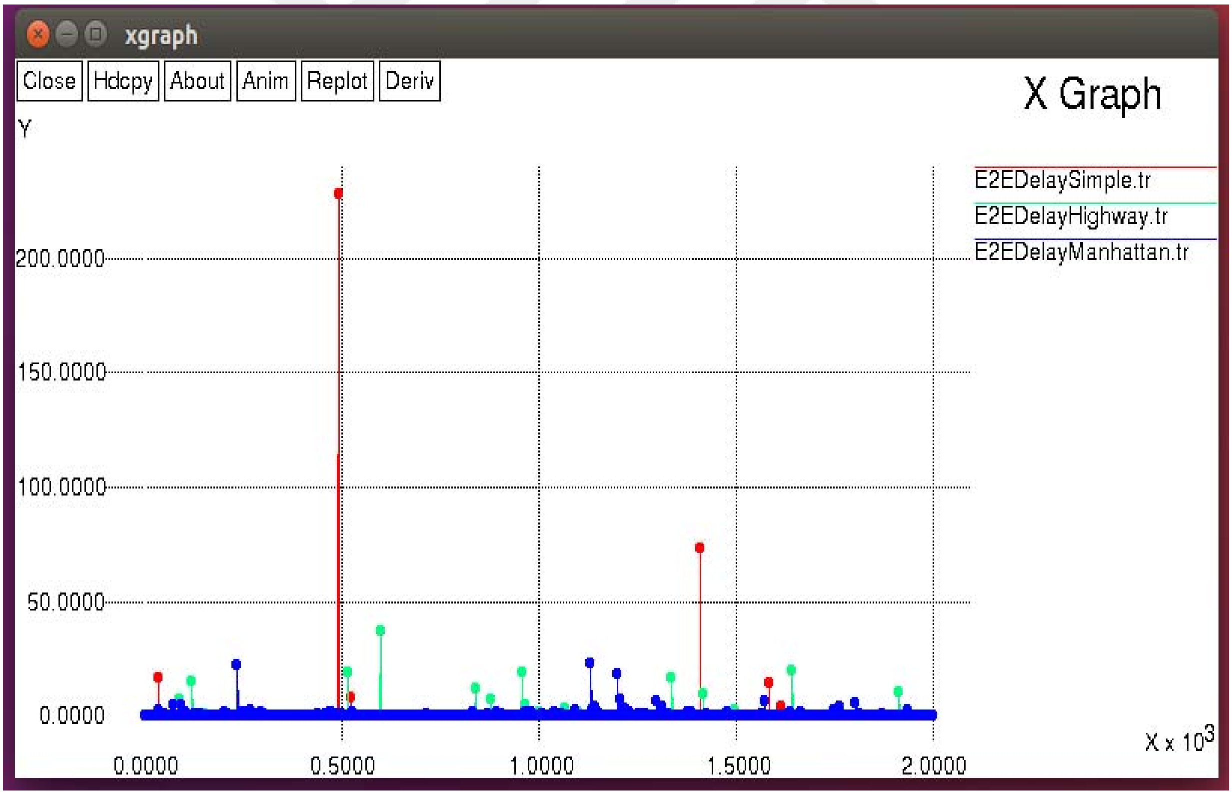


**Figure 4.10:** Overall End-to-End Delay for all Traffic Mobility Model Scenarios.

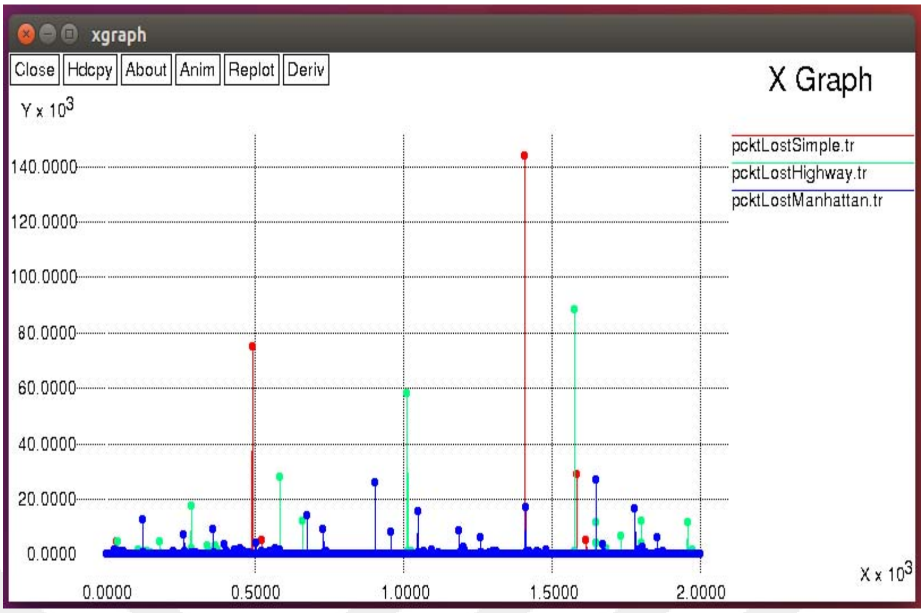


**Figure 4.11:** Overall Packet Loss for all Traffic Mobility Model Scenarios.

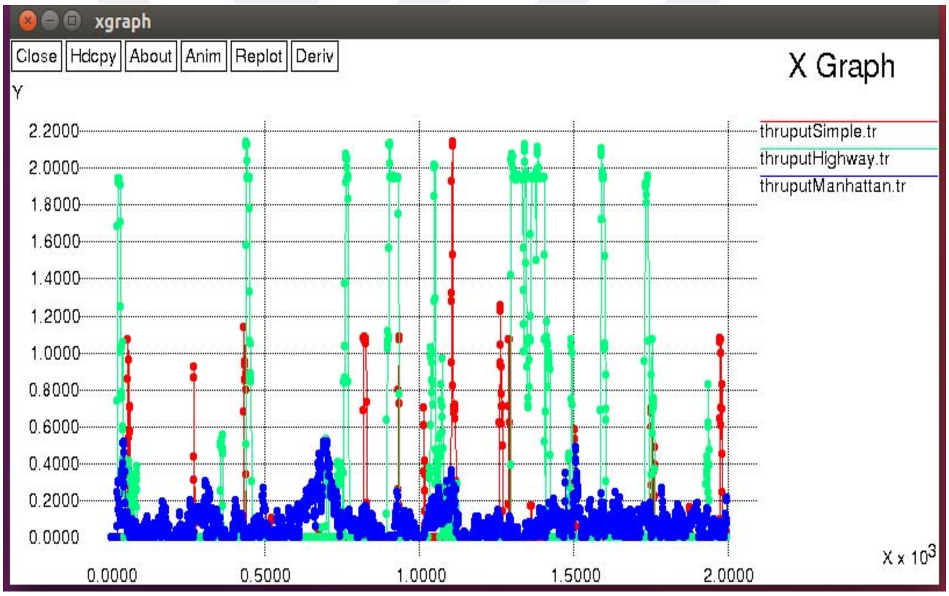


**Figure 4.12:** Overall Packet Throughput for all Traffic Mobility Model Scenarios.

in simple traffic mobility model scenario as compared to other traffic mobility model scenarios and to the obvious fact that, there may be less obstruction on the path of the wireless transmission; and ofcourse lesser data packet collision on the communicating path hence, it resulted to better throughput despite the higher rate of packet delay and packet loss in the scenario.

# 5. CONCLUSION AND FUTURE WORK

## 5.1 Conclusion

Ad hoc On-Demand Distance Vector (AODV) routing protocol stands out as one of the standard protocol that can be used to evaluate the performance metrics in different traffic mobility models. Its uniqueness and other characteristics made us choose it as a protocol of choice for this thesis, not only does it dynamically adjust to the continuous changing topology of the vehicular network but also adjusts to the network density of various vehicular node sizes and have efficient route discovery mechanism.

On our conclusive report on the simulations results discussed thus far, we can affirm and infer that:

- AODV routing protocol performed better in simple and highway traffic mobility model scenarios due to high data packet throughput in these mobility platforms, as compared to the conclusion of Venkateswarlu and Murali (2011) in **[9]**, where they claimed that DSDV routing protocol outperformed AODV routing protocol without considering different mobility scenario for the two protocols, their claim and conclusion has been refuted by our simulation experimentation result.
- AODV routing protocol performed poorly in improved-manhattan traffic mobility model scenario, which we can say, may be due to possible more packet collision enroute the vehicular destination nodes or as a result of possible packet drop due to data queue congestion or perhaps, route obstruction and other possible overheads, that may be present in the improved-manhattan traffic mobility model scenario, this observation only but depicts that, AODV is not suitable for Improved Manhattan traffic scenario and buttressed the point made by Kumar and Dave (2011) in **[12]**, where they stated that, utilization of vehicle routing protocol depends on the scenario prevailing and it is left

to the implementer of such protocol to decide on which protocol is suitable in such regard.

- Delay in AODV routing protocol is less compared to other categories of protocol, as it creates routes only when it needs to transmit or disseminate a message from a source node to a destination node as compared to Dynamic Source Routing (DSR) protocol of the same category as AODV protocol but with more end-to-end delay.
- Owing to the overall metric performance in the scenarios, we can confidently propose AODV routing protocol for simple and highway traffic mobility models, if the need for a reliable and efficient routing protocol for an unfailing end-to-end message transmission and dissemination in vehicles is to be implemented.

## 5.2 Future Work

We intend investigating the most suitable protocol that can homogeneously work in any mobility scenario without any overhead whatsoever.Our future work will, especially, to investigate the most suitable vehicle ad hoc network routing protocol for Improved-manhattan traffic mobility mode, and also to further research into how the high end-to-end delay and packet loss can be considerably reduced in the models.

Other experimental simulations for determining the most suitable routing protocol and how the present routing protocols could be further enhanced, in order to perform much better than its present operation, can as well be researched into, as part of our future work.

Implementation of other traffic mobility tools, asides CityMob, can as well be an area of further research, either by us or by any other interested researcher as an area of future research.

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## APPENDICES

**APPENDIX A:** Simulation Code in Ns-2 (.tcl)

**APPEXDIX A**

```
# Simulation of 25 Vehicular nodes for Traffic mobility model
environment using AODV routing protocol.

#Definition of options for simulation
#***********************************************
set val(chan)     Channel/WirelessChannel ; #Channel type
set val(prop)     Propagation/TwoRayGround; #Radio-propagation
set val(ant)      Antenna/OmniAntenna     ; #Antenna type
set val(ll) LL;                    #Link layer type
set val(ifq)      Queue/DropTail/PriQueue ; #Interface queue type
set val(ifqlen) 50                     ; #max.packet ifq
set val(netif)    Phy/WirelessPhy        ; #network interface type
set val(mac)      Mac/802_11        ; #Mac type
set val(rp) AODV                ; #Routing protocol
set val(nn) 25                  ; #number of nodes in network
set val(cp)
"/home/taoy/GR_SimpleTrafficAODV/connectSimpleTraffic.txt";
#connection Pattern
set val(sp) "/home/taoy/GR_SimpleTrafficAODV/simpleModel.txt";
#scenario file
set val(stop)    2000                    ; #simulation time
set val(x)        1500         ; #x dimension
set val(y)        1500         ; #y dimension

# Initialization of Trace file Descriptors
# *** Throughput Trace ***
set f0 [open thruputSTAODV0.tr w]
set f1 [open thruputSTAODV1.tr w]
set f2 [open thruputSTAODV2.tr w]
set f3 [open thruputSTAODV3.tr w]

# *** Packet Loss Trace ***
set f4 [open pcktLostSTAODV0.tr w]
set f5 [open pcktLostSTAODV1.tr w]
set f6 [open pcktLostSTAODV2.tr w]
set f7 [open pcktLostSTAODV3.tr w]

# *** Packet Delay Trace ***
set f8 [open pcktDelaySTAODV0.tr w]
set f9 [open pcktDelaySTAODV1.tr w]
set f10 [open pcktDelaySTAODV2.tr w]
set f11 [open pcktDelaySTAODV3.tr w]

# Initializing Simulation
set ns_           [new Simulator]

# Initializing Trace file
set tracefd  [open simpleTrafficAODV.tr w]
$ns_ trace-all $tracefd

# Initializing Network Animator
set namtrace [open simpleTrafficAODV.nam w]
$ns_ namtrace-all-wireless $namtrace $val(x) $val(y)

# Setting up topography object
set topo    [new Topography]
$topo load_flatgrid $val(x) $val(y)
```

```
# Create  General Operations Director (GOD) object
create-god $val(nn)

#Configure Nodes
$ns_ node-config  -adhocRouting $val(rp) \
                  -llType  $val(ll) \
                  -macType $val(mac) \
                  -ifqType $val(ifq) \
                  -ifqLen  $val(ifqlen)\
                  -antType $val(ant)\
                  -propType $val(prop)\
                  -phyType  $val(netif)\
                  -channelType $val(chan)\
                  -topoInstance $topo\
                  -agentTrace ON\
                  -routerTrace ON\
                  -macTrace OFF\
                  -movementTrace OFF\

# Creating Nodes
      for {set i 0} {$i<$val(nn)} {incr i} {
            set node_($i) [$ns_ node]
            $node_($i) random-motion 0    ;# disable random motion
      }

# Defining node movement model
      puts "Loading connection pattern..."
      source $val(cp)

# Defining traffic model
      puts "Loading scenario file..."
      source $val(sp)

# Define node initial position in nam
      for {set i 0} {$i < $val(nn)} {incr i} {

          # 25 defines the node size in nam, must adjust it
according to your scenario
          # The function must be called after mobility model is
defined

          $ns_ initial_node_pos $node_($i) 25
      }

# Setup traffic flow between nodes # UDP connections between nodes #
Create Constant four Bit Rate Traffic sources

set agent1 [new Agent/UDP]             ;# Create UDP Agent
$agent1 set prio_ 0                    ;# Set Its priority to 0

set sink [new Agent/LossMonitor]       ;# Create Loss Monitor Sink
in order to be able to trace the number of bytes received
$ns_ attach-agent $node_(1) $agent1    ;# Attach Agent to source
node
$ns_ attach-agent $node_(2) $sink      ;# Attach Agent to sink node
$ns_ connect $agent1 $sink             ;# Connect the nodes

set app1 [new Application/Traffic/CBR] ;# Create Constant Bit Rate
application
```

```
$app1 set packetSize_ 512              ;# Set Packet Size to 512
bytes
$app1 set rate_ 600Kb                  ;# Set CBR rate to 200
Kbits/sec
$app1 attach-agent $agent1             ;# Attach Application to
agent

set agent2 [new Agent/UDP]             ;# Create UDP Agent
$agent2 set prio_ 1                    ;# Set Its priority to 1

set sink2 [new Agent/LossMonitor]      ;# Create Loss Monitor Sink
in order to be able to trace the number obytes received
$ns_ attach-agent $node_(4) $agent2    ;# Attach Agent to source
node
$ns_ attach-agent $node_(5) $sink2     ;# Attach Agent to sink node
$ns_ connect $agent2 $sink2            ;# Connect the nodes

set app2 [new Application/Traffic/CBR] ;# Create Constant Bit Rate
application
$app2 set packetSize_ 512              ;# Set Packet Size to 512
bytes
$app2 set rate_ 600Kb                  ;# Set CBR rate to 200
Kbits/sec
$app2 attach-agent $agent2             ;# Attach Application to
agent

set agent3 [new Agent/UDP]             ;# Create UDP Agent
$agent3 set prio_ 2                    ;# Set Its priority to 2

set sink3 [new Agent/LossMonitor]      ;# Create Loss Monitor Sink
in order to be able to trace the number obytes received
$ns_ attach-agent $node_(7) $agent3    ;# Attach Agent to source
node
$ns_ attach-agent $node_(8) $sink3     ;# Attach Agent to sink node
$ns_ connect $agent3 $sink3            ;# Connect the nodes

set app3 [new Application/Traffic/CBR] ;# Create Constant Bit Rate
application
$app3 set packetSize_ 512              ;# Set Packet Size to 512
bytes
$app3 set rate_ 600Kb                  ;# Set CBR rate to 200
Kbits/sec
$app3 attach-agent $agent3             ;# Attach Application to
agent

set agent4 [new Agent/UDP]             ;# Create UDP Agent
$agent4 set prio_ 3                    ;# Set Its priority to 3

set sink4 [new Agent/LossMonitor]      ;# Create Loss Monitor Sink
in order to be able to trace the number obytes received
$ns_ attach-agent $node_(11) $agent4   ;# Attach Agent to source
node
$ns_ attach-agent $node_(12) $sink4    ;# Attach Agent to sink node
$ns_ connect $agent4 $sink4            ;# Connect the nodes

set app4 [new Application/Traffic/CBR] ;# Create Constant Bit Rate
application
$app4 set packetSize_ 512              ;# Set Packet Size to 512
bytes
$app4 set rate_ 600Kb                  ;# Set CBR rate to 200
Kbits/sec
```

```
$app4 attach-agent $agent4             ;# Attach Application to
agent

# defines the node size in Network Animator
for {set i 0} {$i < $val(nn)} {incr i} {
    $ns_ initial_node_pos $node_($i) 25
}

# Initialize Flags
set holdtime 0
set holdseq 0

set holdtime1 0
set holdseq1 0

set holdtime2 0
set holdseq2 0

set holdtime3 0
set holdseq3 0

set holdrate1 0
set holdrate2 0

set holdrate3 0
set holdrate4 0

# Function To record Statistcis (Bit Rate, Delay, Drop)
proc record {} {
        global sink sink2 sink3 sink4 f0 f1 f2 f3 f4 f5 f6 f7
holdtime holdseq holdtime1 holdseq1 holdtime2 holdseq2 holdtime3
holdseq3 f8 f9 f10 f11 holdrate1 holdrate2 holdrate3 holdrate4

        set ns [Simulator instance]

    set time 0.9 ;#Set Sampling Time to 0.9 Sec
        set bw0 [$sink set bytes_]
        set bw1 [$sink2 set bytes_]
        set bw2 [$sink3 set bytes_]
        set bw3 [$sink4 set bytes_]
        set bw4 [$sink set nlost_]
        set bw5 [$sink2 set nlost_]
        set bw6 [$sink3 set nlost_]
        set bw7 [$sink4 set nlost_]
        set bw8 [$sink set lastPktTime_]
        set bw9 [$sink set npkts_]
        set bw10 [$sink2 set lastPktTime_]
        set bw11 [$sink2 set npkts_]
        set bw12 [$sink3 set lastPktTime_]
        set bw13 [$sink3 set npkts_]
        set bw14 [$sink4 set lastPktTime_]
        set bw15 [$sink4 set npkts_]

    set now [$ns now]

        # Record Bit Rate in Trace Files
        puts $f0 "$now [expr
(($bw0+$holdrate1)*25)/(2*$time*1000000)]"
        puts $f1 "$now [expr
(($bw1+$holdrate2)*25)/(2*$time*1000000)]"
```

```
        puts $f2 "$now [expr
(($bw2+$holdrate3)*25)/(2*$time*1000000)]"
        puts $f3 "$now [expr
(($bw3+$holdrate4)*25)/(2*$time*1000000)]"

        # Record Packet Loss Rate in File
        puts $f4 "$now [expr $bw4/$time]"
        puts $f5 "$now [expr $bw5/$time]"
        puts $f6 "$now [expr $bw6/$time]"
        puts $f7 "$now [expr $bw7/$time]"

        # Record Packet Delay in File
        if { $bw9 > $holdseq } {
                puts $f8 "$now [expr ($bw8 - $holdtime)/($bw9 -
$holdseq)]"
        } else {
                puts $f8 "$now [expr ($bw9 - $holdseq)]"
        }
        if { $bw11 > $holdseq1 } {
                puts $f9 "$now [expr ($bw10 - $holdtime1)/($bw11 -
$holdseq1)]"
        } else {
                puts $f9 "$now [expr ($bw11 - $holdseq1)]"
        }
        if { $bw13 > $holdseq2 } {
                puts $f10 "$now [expr ($bw12 - $holdtime2)/($bw13 -
$holdseq2)]"
        } else {
                puts $f10 "$now [expr ($bw13 - $holdseq2)]"
        }
        if { $bw15 > $holdseq3 } {
                puts $f11 "$now [expr ($bw14 - $holdtime3)/($bw15 -
$holdseq3)]"
        } else {
                puts $f11 "$now [expr ($bw15 - $holdseq3)]"
        }

        # Reset Variables
        $sink set bytes_ 0
        $sink2 set bytes_ 0
        $sink3 set bytes_ 0
        $sink4 set bytes_ 0

        $sink set nlost_ 0
        $sink2 set nlost_ 0
        $sink3 set nlost_ 0
        $sink4 set nlost_ 0

        set holdtime $bw8
        set holdseq $bw9

        set  holdrate1 $bw0
        set  holdrate2 $bw1
        set  holdrate3 $bw2
        set  holdrate4 $bw3

    $ns at [expr $now+$time] "record"    ;# Schedule Record after
$time interval sec
}

# Start Recording at Time 0
```

```
$ns_ at 0.0 "record"
$ns_ at 1.4 "$app1 start"                ;# Start transmission at
time t = 1.4 Sec
$ns_ at 10.0 "$app2 start"               ;# Start transmission at
time t = 10 Sec
$ns_ at 20.0 "$app3 start"               ;# Start transmission at
time t = 20 Sec
$ns_ at 30.0 "$app4 start"               ;# Start transmission at
time t = 30 Sec

# Stop Simulation at Time 80 sec
$ns_ at 2000.0 "stop"

# Tell nodes when the simulation ends
for {set i 0} {$i < $val(nn) } {incr i} {
    $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

proc stop {} {
        global ns_ tracefd f0 f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11

        # Close Trace Files
        close $f0
        close $f1
        close $f2
        close $f3
        close $f4
        close $f5
        close $f6
        close $f7
        close $f8
        close $f9
        close $f10
        close $f11

      # Execute NAM file
      exec nam simpleTrafficAODV.nam &

      # Reset Trace File
        $ns_ flush-trace
        close $tracefd

        # Plot Recorded Statistics
        exec xgraph thruputSTAODV0.tr thruputSTAODV1.tr
thruputSTAODV2.tr thruputSTAODV3.tr -geometry 800x400 -P -bg white &
        exec xgraph pcktLostSTAODV0.tr pcktLostSTAODV1.tr
pcktLostSTAODV2.tr pcktLostSTAODV3.tr -geometry 800x400 -P -bg white
&
        exec xgraph pcktDelaySTAODV0.tr pcktDelaySTAODV1.tr
pcktDelaySTAODV2.tr pcktDelaySTAODV3.tr -geometry 800x400 -P -bg
white &

        exit 0
}

puts "Starting Simulation..."
$ns_ run
```

**CURRICULUM VITAE**

**Name Surname:** **TAOFEEK ABIODUN OLASUNKANMI YUSUF**

**Place and Date of Birth:** **Ikire, Osun State, Nigeria – 1st August; 1984.**

**E-Mail:** **yusuftao@itu.edu.tr**

**EDUCATION**

- **B.Sc.:** July 2011; University of Middlesex, Faculty of Science and Engineering, Information Technology Department.

**PROFESSIONAL EXPERIENCE AND REWARDS:**

- 2008 Best Graduating Student in International Diploma In Computing (IDIC), at Informatics Academy, Singapore (Kazaure Branch).

**PUBLICATIONS, PRESENTATIONS, AND PATENTS ON THE THESIS:**

- **Taofeek A. O Yusuf, Deniz Turgay Altilar** (2017). Impact on Inter-Vehicular Communication Performance on different Traffic Mobility Model: A Case Study of Ad Hoc On-Demand Distance Vector Routing Protocol. International Journal of Computer and Information Engineering, Vol; 4, No: 7, 2017 (IJCIE '17).