IMPROVED CONNECTIVITY IN GEOGRAPHIC ROUTING PROTOCOLS USING DELAY-TOLERANT NETWORKS SCHEME IN VEHICULAR AD HOC NETWORKS

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IMPROVED CONNECTIVITY IN GEOGRAPHIC ROUTING PROTOCOLS USING DELAY-TOLERANT NETWORKS SCHEME IN VEHICULAR AD HOC NETWORKS

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To my beloved parents and wife

Any number of words cannot sufficiently express the love and encouragement I received from them.

ABSTRACT

Vehicular Ad hoc Networks (VANET) used to build wireless networks between vehicles (V2V), and between vehicles to infrastructure (V2I) are a subclass of Mobile Ad hoc Networks (MANET). VANETs introduce a variety of applications to enhance the safety and create a comfortable driving environment for drivers. Connectivity in VANET is a fundamental operation that allows a vehicle to construct a source-to-destination but is problematic due to the rapidly changing topologies and high speed mobility of the vehicles involved. This study presents a Predictive Geographic Routing Protocol (PGRP) to improve connectivity with predict greedy forwarding which could handle a recovery strategy for local maximum environment. In PGRP, every vehicle gives a weight to its neighbors according to the direction and location of the vehicle. Besides that, PGRP is capable of predicting the location of every vehicle in the interval time of hello packet based on the acceleration of the vehicle before forwarding the packets based on location after a short interval. An improved PGRP known as Predictive Geographic Routing Protocol with Delay-Tolerant Network (PGRP+DTN) would be used whenever a network disconnection occurs. A buffer can be used for every vehicle and each packet could be stored when a network is disconnected. To simulate the PGRP and PGRP+DTN, an integrated simulation NS2.35 based model and Simulator of Urban Mobility (SUMO) were used to generate a realistic traffic situation. The simulation results show that PGRP outperformed GPSR and GPCR in terms of packet delivery ratio, end-to-end delay, and average hops for improve connectivity between every two nodes. PGRP+DTN also outperformed Geopps, GeoDTN+NAV, and VADD in terms of packet delivery ratio, end to end delay, average hops for improve connectivity between every two nodes whenever they want to exit from DTN. The research has proven that the problems of connectivity in VANET can be resolved by using the proposed protocols.

ABSTRAK

Rangkaian Ad-hoc Kenderaan (VANET) digunakan untuk membina rangkaian tanpa wayar antara kenderaan (V2V) dan antara kenderaan dengan infrastruktur (V2I) adalah subkelas Rangkaian Ad-hoc Bergerak (MANET). VANET memperkenalkan pelbagai aplikasi untuk meningkatkan keselamatan dan mewujudkan persekitaran pemanduan yang selesa kepada pemandu. Perhubungan dalam VANET adalah operasi asas yang membolehkan kenderaan membina sumber-ke-destinasi tetapi bermasalah disebabkan oleh perubahan topologi yang cepat dan pergerakan berkelajuan tinggi kenderaan yang terlibat. Kajian ini membentangkan Protokol Ramalan Laluan Geografik (PGRP) untuk memperbaiki hubungan dengan meramalkan kelewahan penghantaran yang boleh mengendalikan strategi pemulihan persekitaran tempatan yang maksimum. Dalam PGRP setiap kenderaan memberikan berat kepada kenderaan-kenderaan lain yang mengikut arahan dan lokasi kenderaan terbabit. Selain itu PGRP mampu meramal lokasi setiap kenderaan dalam jangkamasa paket hello berdasarkan kecepatan kenderaan sebelum penghantaran paket berdasarkan lokasi selepas jangkamasa yang singkat. Sebuah PGRP yang ditambah baik yang dikenali sebagai Protokol Ramalan Laluan dengan Rangkaian Toleran Tertangguh (PGRP+DTN) akan digunakan setiap kali terjadi pemutusan rangkaian. Penimbal boleh digunakan pada setiap kenderaan dan setiap paket boleh disimpan apabila rangkaian diputuskan. Untuk mensimulasikan PGRP dan PGRP+DTN simulasi berasaskan model bersepadu NS2.35 dan Simulator Pergerakan Perbandaran (Sumo) telah digunakan untuk menjanakan keadaan lalu lintas yang realistik. Keputusan simulasi menunjukkan bahawa PGRP mengatasi GPSR dan GPCR dari segi nisbah paket penghantaran, penangguhan hujung-ke-hujung, dan loncatan purata bagi meningkatkan hubungan antara setiap dua nod. PGRP+DTN juga mengatasi Geopps, GeoDTN+NAB, dan VADD dari segi nisbah penghantaran paket, penangguhan hujung-ke-hujung, loncatan purata bagi meningkatkan hubungan antara setiap dua nod apabila kedua-duanya hendak keluar dari DTN. Kajian ini telah membuktikan bahawa masalah perhubungan dalam VANET boleh diselesaikan dengan menggunakan protokol yang dicadangkan.

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LIST OF ABBREVIATIONS

A-STAR – Anchor- Based Street and Traffic Aware Routing
CAR – Connectivity Aware Routing
CBF – Contention Based Forwarding
CFO – Checking For Out of Bounding
DSRC – Dedicated Short Range Communications
DTN – Delay-Tolerant Network
GG – Gabriel Graph
GeoDTN+Nav – Geographical Delay-Tolerant Network +Navigation
GeOpps – Geographical Opportunistic Routing
GPSR – Greedy Perimeter Stateless Routing
GPS – Global Positioning System
GPCR – Greedy Perimeter Coordinator Routing
GSR – Geographical Source Routing
SUMO – Simulation of Urban Mobility
ITS – Intelligent Transportation System
MANETs – Mobile Ad hoc NETworks
MOVE – Mobility Model Generator for Vehicular Networks
MOT – Maximum Of Transmission Range
NS2 – Network Simulator
PDGR – Predictive Directional Greedy Routing
PDF – Packet Delivery Ratio
RNG – Relative Neighborhood Graph
TTL – Time-to-Live
V2V – Vehicle-to-Vehicle
V2I – Vehicle-to-Infrastructure
V2x – Vehicle-to-Vehicle and Vehicle-to-Infrastructure

VADD	–	Vehicle-Assisted Data Delivery
VANETs	–	Vehicular Ad hoc NETworks
VCLCR	–	VANET Cross Link Corrected Routing Protocol
WLAN	–	Wireless Local Area Network
PGRP	–	Predictive Geographic Routing Protocol

LIST OF SYMBOLS

Loc_{cur} – the location for current node

Loc_{dest} – the location for destination

$Loc_{cur,dest}$ – location vector between current node and destination

D_k – Distance between neighbor k and destination

D_{cur} – Distance between current node and destination

$Weight_k$ – Total Weight for neighbor k

V_{cur} – Velocity vector for current node

PD_k – Prediction of distance between neighbor k and destination

PD_{cur} – Prediction of distance between current node and destination

PD_k/PD_{cur} – prediction of closeness next candidate hop for next time

$V_{vehicle\ c}$ – Velocity for vehicle C

$V_{vehicle\ B}$ – Velocity for vehicle B

CFO – Checking For Out of bound

DIS – Distance between every two node in next time

Dest – destination for the packet

hc_{max} – the maximum hops

hc_{min} – the minimum hop count

chc – current hop count

CHAPTER 1

INTRODUCTION

1.1 Overview

A novel class of wireless networks introduced as Vehicular Ad hoc Networks (VANETs) is presented in this research. VANETs are topologies of moving vehicles used in similar and different radio interface technologies and equipped with wireless interfaces that use short-range to medium-range communication systems. One of the classes of the mobile ad hoc networks is a VANET that facilitates communication between vehicles by using close stable equipment on a roadside when vehicles are surrounded by other vehicles. In the field of Vehicular Ad hoc Networks, new developments are strongly encouraged for industries that involve automotive and wireless technology.

In 2003, a dedicated short-range communications (DSRC) system was proposed in North America. In this DSRC system, 75 MHz of spectrum was appropriated by Federal Communication Commission (FCC) in the U.S. for use with Vehicular Ad hoc Networks (Intl, 2003a). In Europe, a Vehicle-to-Vehicle Communication Consortium (V2V-CC) emerged as the Original Automotive Equipment Manufacturers (OEMs) where vehicle manufacturers have been attempting to improve the efficiency and safety of road traffic using inter-vehicle communication (Kenney, 2011).

The use of a routing protocol in VANETs would guarantee the way for two nodes to exchange information with each other. The protocol contains the route establishment procedure, forwarding decision maker procedure, and procedure for recovery of failed route. For these procedures to take place, knowing the exact location of a node is important.

Presently, nearly 250 million newly registered vehicles in the US are equipped with navigation systems and GPS receivers. (Hummels, 2007). This situation has caused Geographic routing protocols to be popular routing protocols in VANET because of their simplicity, low overhead, and availability of GPS devices. The geographic routing protocols are very compatible with sparse and dense traffic environment and categorized as either Delay-Tolerant Networks (DTN) Geographic routing or non-DTN Geographic routing.

DTN Geographic routings have been used in situations where there is no connectivity between vehicles in VANETs. This normally happens in sparse traffic environments. Unlike traditional ad hoc networks, the end-to-end path between a source and destination will only be available for a short and unpredictable period of time. In a DTN, the mobile node keeps a packet until it finds an opportunity to send it to the destination and when there is no connectivity between nodes, the data will be stored in the buffer (Fall and Farrell, 2008). When a neighbor appears within the transmission range of the mobile node, the data in the buffer would be forwarded to that neighbor. However, in non DTN geographic routings, it is assumed that vehicles in a network have end-to-end connectivity.

Geographic routing protocols are divided in two different modes: the first is a greedy mode and the second mode is a perimeter mode. In the greedy mode, the source or current node forwards a packet to a close neighbor who has a good chance of reaching the destination. However, problems will occur if there are no neighbors close to the destination. In the perimeter mode, the geographic routing protocol extracts packets from the local maximum (Cheng *et al.*, 2010a; Karp and Kung, 2000; Lochert *et al.*, 2005).

In non DTN Geographic routing protocols, Greedy Perimeter Stateless Routing (GPSR) (Karp and Kung, 2000) and Greedy Perimeter Coordinator Routing (GPCR) (Lochert *et al.*, 2005) use greedy and perimeter modes to forward a data packet to a destination. In Geographic Source Routing (GSR) (Lochert *et al.*, 2003), Anchor-based Street- and Aware Routing Protocol (A-STAR) (Kenney, 2011), VCLCR-VANET Cross Link Corrected Routing Protocol (VCLCR) (Bako and Weber, 2011), Connectivity-Aware Routing (CAR) (Naumov and Gross, 2007), Predictive Directional Greedy and Routing Protocol (PDGR)(Gong *et al.*, 2007) use only the greedy mode to forward the data packet to a destination and these routing protocols do not support the local maximum scenario.

In DTN Geographic routing protocols, Vehicle-Assisted Data Delivery (VADD) (Zhao and Cao, 2008) and GeOpps-Geographical Opportunistic Routing (GeOpps) (Leontiadis and Mascolo, 2007) use greedy mode to forward a data packet to a destination. Besides that, GeoDTN+NAV(Geographic DTN Routing with Navigator) (Cheng *et al.*, 2010a) also uses the greedy and perimeter modes to forward the data packet to a destination.

In a VANET, the structure of the network and connectivity between every two nodes are valid only for a few minutes or seconds because of the high mobility and different velocities of nodes in these networks. On the other hand, most of non DTN and DTN proposed geographic routing protocols assume that the velocity of vehicles in VANETs is static in interval time and every vehicle identifies its neighbors by a hello packet. These protocols in the non DTN geographic routing include Greedy Perimeter Stateless Routing (GPSR) (Karp and Kung, 2000) and Greedy Perimeter Coordinator Routing (GPCR) (Lochert *et al.*, 2005).

Other non DTN geographic routing protocols such as Connectivity-Aware Routing (CAR) (Naumov and Gross, 2007), Geographic Source Routing (GSR) (Lochert *et al.*, 2003; Tian *et al.*, 2002), Anchor-based Street-and Traffic-Aware Routing (A-STAR) (Seet *et al.*, 2004) and Contention-Based Forwarding(CBR) (Füßler *et al.*, 2004) support static mobility in VANETs. In DTN geographic routing, protocols such as Vehicle-Assisted Data Delivery (VADD) (Zhao and Cao, 2008), GeOpps-Geographical Opportunistic Routing(GeOpps) (Leontiadis and Mascolo, 2007) and Geographic DTN Routing with Navigator (Cheng *et al.*, 2010b) support static mobility at interval time when every vehicle identifies its neighbors by hello packet. However, in the real world, the assumption that a vehicle is static may not be true given the mobility of vehicles.

Another problem faced by most geographic routings is that vehicles have different acceleration rates when they pass or overtake each other in interval time by hello packet. The passing or overtaking of vehicles increases the number of hops and end-to-end connectivity. Hence forwarding methods and prediction of location of neighbors for every vehicle to be affected and improve the connectivity in non DTN geographic routing and DTN geographic routing protocols (Cheng *et al.*, 2010b; Gong *et al.*, 2007).

A forwarding method in some non DTN geographic routings such as CAR and GSR is the greedy forwarding. A forwarding packet is sent to a close neighbor whose destination is within the transmission range. However, this forwarding method does not always operate when some nodes with connectivity to a destination is not close enough to the destination. In this situation, some non DTN routings such as GPSR , GPCR, and DTN geographic routing prefer GeoDTN+NAV (Cheng *et al.*, 2010b) to be applied as a recovery method for forwarding a packet to a destination. On the other hand, Delay-Tolerant Network (DTN) would be used in a geographic routing when greedy and recovery methods could not support the connectivity between a source and a destination.

The predict mobility is useful in non DTN and DTN geographic routings because moving vehicles have high mobility and the limitation of the transmission range is normally 250 meters. Furthermore, the life time of a connectivity between two vehicles is very short (Artimy *et al.*, 2005; Füßler *et al.*, 2004).

1.2 Background of Problem

Vehicular Ad Hoc Network (VANET) is a particular type of Mobile Ad Hoc Network (MANET), where vehicles equipped with transmission capabilities are interconnected to form a network. The topology created by vehicles is very dynamic and significantly non-uniformly distributed. Standard MANET routing algorithms are not suitable for transferring information in these networks. An advantage of VANET is the accessibility of its navigation systems that allow each vehicle to be aware of the geographic location of its neighbors.

It is a challenging task to develop an efficient VANET routing protocol that can handle connectivity in geographic routing and route recovery as well as have a forwarding method in highway and urban vehicular environment for high packet delivery ratio and low end to end delay and low average hops. The discussions on connectivity in geographic routing and route recovery, forwarding method are presented in the following sections.

1.2.1 Connectivity between Nodes in Interval Time of Hello Packet in Geographic Routing Protocol

Geographic Routing is a routing approach that forwards packets to close neighbors which will then be sent to a destination when a mediate node is available between a source and destination (Lochert *et al.*, 2003; Naumov and Gross, 2007) in VANET. The availability of GPS devices has made Geographic routing protocols popular, but, disconnected network partitions are created by the dynamic nature of Vehicular Ad hoc Networks.

Non DTN Geographic routing protocols in VANETs such as GPSR and GSR (Karp and Kung, 2000; Lochert *et al.*, 2003) face limitations such as routing loops, too many hops and wrong directions. On the other hand, every vehicle in geographic routing protocols sends a hello packet within the transmission range to identify its neighbors after the interval time. After receiving information from its neighbors, it sends the data packet according to the forwarding method to a destination. Some routing protocols such as GSR,GPCR, GPSR, A-STAR and VCLCR in non DTN geographic routing protocols do not support connectivity between every two nodes in interval time of hello packet because these routing protocols assume that the mobility in interval time in a hello packet is static.

Predictive Directional Greedy Routing (PDGR) (Gong *et al.*, 2007) has been suggested to be used as a means to deal with this issue as it supports forwarding packet in a mobile node to every neighbor in future highway scenarios and this would help improve connectivity between every two nodes. However, this routing does not support urban scenarios and cannot support connectivity of every two nodes if they are out of bounds in the short interval time of a hello packet. Although PDGR supports overtaking in highway but it would not operate when two vehicles are close to each other because in this situation, the average hop and end-to-end delay will increase.

To improve connectivity in DTN geographic routing protocols, VADD (Zhao and Cao, 2008) uses a prediction mechanism for forwarding a packet to a destination. VADD uses predictable mobility to forward these packets and only predicts the direction of a vehicle in urban scenarios but does not predict forwarding them to neighbors in the short intervals. Unfortunately, it may cause more hops and longer routing delays. Furthermore, DTN geographic routing GeOpps (Leontiadis and Mascolo, 2007) and GeoDTN+NAV (Cheng *et al.*, 2010b) use a Delay-Tolerant Network mechanism in a sparse network but none of these routing protocols could predict the location of one hop in the short intervals when there is more than one neighbor. On the other hand, GeoDTN+NAV improve connectivity between every two nodes with forwarding method but this method is determined based on the static mobility of a hello packet in the interval time. Besides that, GeoDTN+NAV could not support the connectivity between nodes during the interval time of a hello packet. Hence, the delivery packet ratio decreases, and end-to-end delay and average hops between nodes increase in the connectivity.

In non DTN and DTN Geographic Routing protocols in VANETs, most routing protocols assume that velocities of vehicles are static in the interval time of a hello packet (Karp and Kung, 2000; Lochert *et al.*, 2005; Naumov and Gross, 2007) but this assumption may not be true in the real world. Additionally, these routing protocols do not support scenarios where one vehicle overtakes or passes another vehicle. In overtaking scenarios, the velocity between vehicles would be different resulting in an increased number of hops and end-to-end delay. The connectivity between two vehicles in VANETs is short lived at high speeds and each vehicle usually would have a maximum transmission range between 250-300 meters (Füßler *et al.*, 2004); which decreases the delivery ratio. In Figure 1.1, Vehicle A wants to send the data packet to Vehicle Destination while Vehicle A and Vehicle B are moving in the same direction. Vehicle A would send the hello packet to identify its neighbors within the transmission range. After receiving the hello packet reply, vehicle A would identify Vehicle B but during this time, vehicle A is close to its neighbor's destination. In this situation, Vehicle A in time (t_2) resends a hello packet to identify its neighbors closest to its destination.

In Figure 1.2, Vehicle B overtakes Vehicle A. In such a situation and according to traditional routing protocols such as GPSR (Karp and Kung, 2000), GPCR (Lochert *et al.*, 2005), CAR (Naumov and Gross, 2007), GSR (Lochert *et al.*, 2003), A-STAR (Seet *et al.*, 2004), when Vehicle A receives a packet to be forwarded to a destination at time (t_1), then Vehicle A would not choose Vehicle B as the next hop. After the interval time of a hello packet, Vehicle B would be closer to the destination at time (t_2). Then, Vehicle A at time (t_2) will forward the packet to Vehicle B that is closer to the destination. If Vehicle B receives a packet at time t, then Vehicle B can start the next round of forwarding the packet at time (t_2) which would decrease end-to-end delays and average hops as well as to increase the packet delivery ratio.

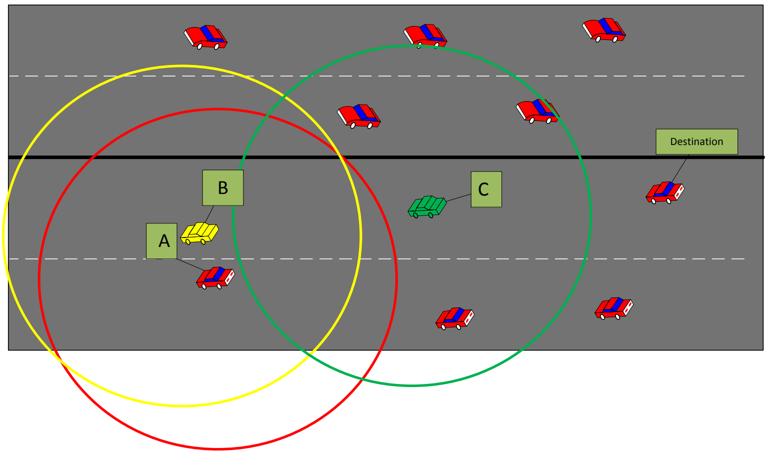

Figure 1.1 Different velocities more than zero at time (t_1)

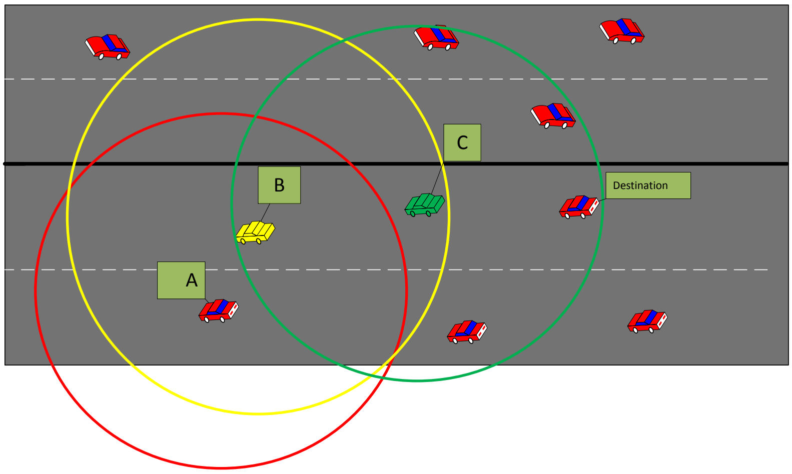

Figure 1.2 Different velocities more than zero at time (t_2)

Another scenario that these routing protocols cannot support is when vehicles are out of bounds. In Figure 1.3, Vehicle A sends a hello packet to identify vehicles within its transmission range at time (t_1). Vehicle A after receiving a reply hello packet from its neighbors and at time (t_2) sends the data packet to Vehicle C because it is a close neighbor to the destination but this neighbor may not be within the transmission range at the appropriate time causing the packet to be dropped. Figure 1.4 shows, Vehicle C as being out of bounds at time (t_2).

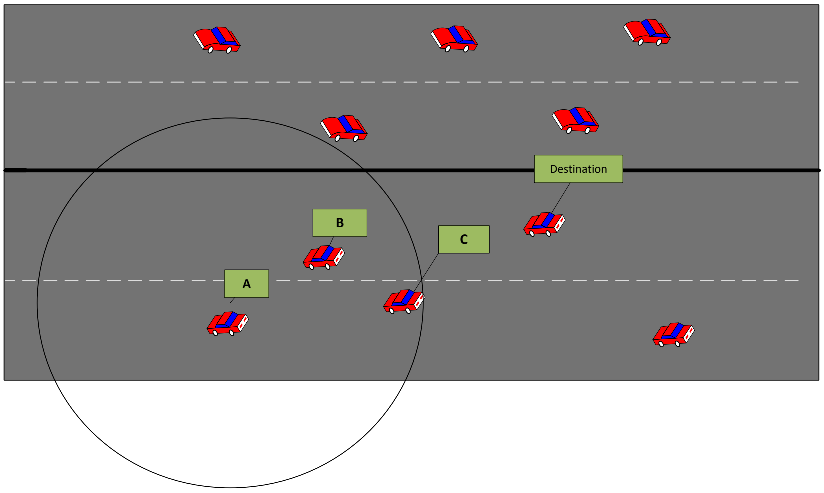

Figure 1.3 Out of boundary problem at time (t_1)

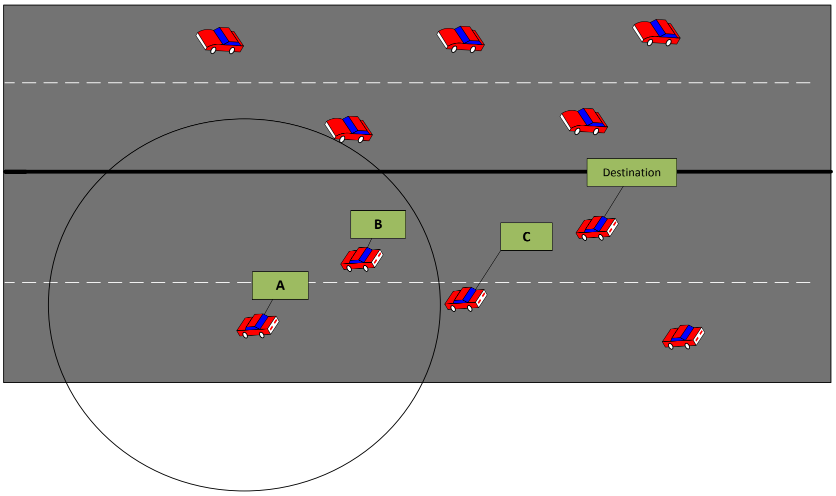

Figure 1.4 Out of boundary problem at time (t_2)

In order to design a Unicast protocol for VANET, two major problems must be considered. Firstly, the protocol must be able to predict the future position of a vehicle according to vehicle position information gathered from the GPS and hello packet. Secondly, the forwarding method protocol must be able to support the dynamic rate of velocity at the hello packet interval time.

1.2.2 Route Recovery and Forwarding Method in Geographic Routing Protocols

Geographic routing protocols have two modes. They are the greedy and the recovery modes (Karp and Kung, 2000). The greedy mode nodes use positions of one-hop neighbors from a hello packet. Greedy mode selects nearest vehicle to destination at each stage. Using greedy algorithm in a routing protocol is not always possible because of position of the sender and its one-hop neighbors. If there are no other vehicle in the transmission range of the sender, the packet may stop at this point and cannot make a progress toward destination. This problem called local maximum where there are not any node closer than the sender to the destination. In the case of local maximum problem, greedy algorithms fail to select any relay node for transmission. In the case of greedy algorithm failure, the uses of recovery algorithm are required. One of the recovery algorithms problems is that they do not predict the location and movement of vehicles during hello packet interval time (Lochert et al., 2005). In non DTN and DTN routing protocols, geographic routing protocols such as GPSR (Karp and Kung, 2000), GPCR (Lochert et al., 2005), VCLCR (Bako and Weber, 2011) and GeoDTN+NAV (Cheng et al., 2010a) use a recovery mode whenever it achieves the local maximum. In GPSR, GPCR and VCLCR, routing protocol forwarded packets are according to greedy forwarding, but the GeoDTN+NAV forwarded packet would be sent according to the greedy forwarding based on the calculated weight of every neighbor. Hence this routing protocol could not predict the location of its neighbors in the near future.

In geographic routing protocols in sparse environments, CAR (Naumov and Gross, 2007), VADD (Zhao and Cao, 2008), GeOPPs (Leontiadis and Mascolo, 2007) and GeoDTN+NAV (Cheng et al., 2010a) are used as the DTN mode for store carry-and-forward packet . However, none of these routing protocols could predict the location of its neighbors in the near future when it wants to exit from the DTN node.

1.3 Problem Statement

This research has addressed the problems of inefficient connectivity geographic routing protocol, its inability to predict neighbor locations and the forwarding method with consideration of local maximum scenario for real-time V2V communication in highway and urban scenarios. The considerations of two main problems are necessary in the VANET unicast protocol designs. First one is predication of greedy forwarding in the hello packet interval time and to handle recovery algorithms to handle local maximum problem. Recovery mode uses in network disconnection, nodes mobility because of routing in the wrong direction and causing error due to mobility increase the numbers of hop. Second problem is the connectivity in partitioned networks for highway and urban scenarios.

Even though VANET shows great promise, its success depends on whether VANET routing, predictions, forwarding mechanisms would be able to satisfy higher packet delivery ratios, incur minimum delays, and has the minimum average hops requirements of applications to be deployed on these networks. The following sections present the research questions and the main issues of this study.

This study was guided by the following questions:

i. How to design and develop an efficient geographical forwarding method that can predict greedy forwarding and handle a recovery strategy for local maximum environment?

ii. How to design and develop an efficient connectivity Geographic Routing protocol for VANET that can handle partitioned networks for highway and urban scenarios?

iii. How to implement an efficient connectivity geographic routing protocol with predict best next hop that can handle a disconnected network for highway and urban scenarios by comparing packet delivery ratio, end-to-end delay, and average hop with other similar works?

1.4 Purpose of Study

The purpose of this study is to design a predictive GeoDTN Routing and forwarding method for inter-vehicle communication in highway and urban environments.

1.5 Objectives

The purpose of this study was guided by the following objectives:

1. To design and develop an efficient connectivity geographic routing protocol that can predict greedy forwarding and handle a recovery strategy for local maximum environment.

2. To design and develop an efficient connectivity geographic routing protocol for VANET that can handle a disconnected network for highway and urban scenarios.

3. To implement an efficient connectivity geographic routing protocol with predict best next hop that could handle a disconnected network for highway and urban scenarios by comparing packet delivery ratio, end-to-end delay, and average hop with other similar works.

1.6 Scope of study

This study focused on the development of VANET routing protocols, predictive geographic routing and forwarding methods for inter-vehicle communications in highway and urban environments. The scope of this research covered the following:

1. Evaluation of the proposed protocols was based on both networking and vehicular mobility components. In this study, a traffic simulator, called Simulation of Urban Mobility (SUMO), and a mobility simulator called Mobility model generator for vehicular network (MOVE) were used to generate realistic traffic simulations. The performance of the proposed protocols was evaluated using a Network Simulator (ns2).

2. In the proposed VANET routing protocol, the data packets could be freely forwarded to the next available node within the communication range and there was no security check on data dissemination.

3. The geographic routings assumed that all vehicles have advanced and available GPS devices where each vehicle has a geographical routing and knows its own location and destination.

4. The vehicles are assumed to be the same size and equipped with an 802.11 DCF wireless interface.

5. For PGRP +DTN, it is assumed that a store carry forward mechanism for DTN is used.

1.7 Significance of the Study

In the wake of recent developments in information and mobile communications technologies, the Automobile Industry is paying special attention to Vehicular Ad hoc Networks research as new discoveries would benefit the industry and road users.

Vehicular Ad hoc Networks research specifically on routing in VANETs is a challenging task due to the high speed mobility and constant change in the topology of vehicles. Furthermore, geo- routing protocols are becoming popular due to the advancement and availability of GPS devices. Thus, seeking answers to the research questions listed above and developing an integrated routing architecture protocol would assist messages in a network to reach the destination in a more efficient way.

1.8 Summary and Organization of the Thesis

This chapter has presented the motivation underlying the research by reviewing the background of the problem, providing a problem statement, as well as outlining the purpose and objectives of the study. In addition, the potential contribution of this research has also been highlighted. This thesis consists of six chapters: Chapter 1 briefly explains the problem statement, aim of project, contribution and organization of the thesis, Chapter 2 has the background of VANET characteristics, applications, standards as well as the literature review on routing protocols in Vehicular Ad hoc Networks, Chapter 3 describes the research framework and experimental setups that correspond to the geographic routing in VANETs, Chapter 4 presents a Predictive Geographic Routing Protocol and Predictive Geographic Routing Protocol with Delay-Tolerant Network for VANETs, Chapter 5 illustrates the simulations and results, followed by chapter 6 which is the conclusion of the research.

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