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An Efficient Data Dissemination Method with Intelligent Routing for Road-side Information Station (RIS) in VANETs

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Dedicated to

My Family

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Abstract

Wireless communications are becoming the leading appearance of transferring information, and the most active research field. In this dissertation, we will present one of the most applicable forms of Ad hoc networks, the Vehicular Ad hoc Networks (VANETs). VANET is an application area of Mobile Ad hoc Networks (MANETs) that is formed by a collection of vehicles that interacts with other vehicles and Road-side Information Station (RIS) to share local resources. Nowadays, the Intelligent Transport Systems (ITS) are expected to offer fundamental breakthroughs in road safety, congestion reduction, driving comfort and environmental improvement. In general, there are two types of communication: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure or Infrastructure-to-Vehicle (V2I/I2V) communications. Vehicles must be able to communicate with each other and with RIS (fixed infrastructure) such as IEEE 802.11 access point, in real time. By forming an ad hoc network, a vehicle can receive information from its neighbors using multi-hop transmission relayed by the intermediate vehicles. With the support of the RIS, vehicles can access the data stored in the RIS and with the infrastructure network access through the Internet.

VANET can provide wide variety of services; safety related warning systems to improved navigation systems, dynamic routing, as well as scalable and cost-effective solutions for applications. To function properly, these applications require efficient routing protocols. Design issues for developing a routing protocol for VANET are complex due to the frequent path disruptions caused by vehicles mobility. This mobility is constrained in vehicle moving-direction due to existence of the roadways and can therefore be cleverly exploited for message propagation. There are some existing routing protocols that have been explored for application in this domain but need to be used the characteristics (mobility, vehicle moving-direction,

location of information etc.) for enhancing the performance of routing protocols. Existing MANET routing protocols, do not make use of these mentioned characteristics of VANET. However, it is possible to achieve a significant improvement by adjusting MANET routing protocols to compensate for the dynamic topology change of VANET, taking advantage of additional information on position, speed, direction, digital mapping of roads, and so on.

Given the fact described above, in this dissertation, we cope with the problem of data dissemination in VANETs, trying to give an overview of the main techniques used in this field, and presenting a cache-augmented data distribution scheme based on the RIS model, after designing a routing protocol referred to as Intelligent Routing for Road-side Information Station (IR-RIS). The routing protocol, working on standard vehicle networks, takes the advantage of vehicle's moving direction to narrow down the routing message propagation between a vehicle and RIS in intersection areas. Caching is a common technique for saving network traffic and enhancing response time, especially in wireless environments where bandwidth is often a scare resource. Combined with a mobile cache, which caching makes the intermediary nodes on the route from the data source and the requestor also cache the data item during the specific lifetime, not discarding right after the message passes by, the performance can be boosted. Due to the diverse and road-restricted moving pattern, this strategy can distribute the cached data to the place where other vehicles can highly demand it. The simulation results obtained from the simulation using ns-2 reveal that the proposed cache scheme improves the response time by up to 20%, compared with the conventional protocols, for the given parameter set. Moreover, it can significantly enhance control traffic overhead, packet delivery ratio, end-to-end packet delay, and network performance.

요약

무선통신은 다양한 분야의 정보전달에 있어서 핵심적인 기능을 담당하고 있을 뿐 아니라 향후에도 이의 적용범위는 계속 확장될 것으로 예측되고 있다. 본 논문에서는 무선통신을 차량네트워크에 적용함에 있어서 가장 효율적인 구조인 차량 애드혹 네트워크(VANET)에 대한 연구를 수행한다. VANET은 이동 애드혹 네트워크의 범주에 속하며, 무선 네트워크를 장착하고 고속으로 주행하는 차량들과 고정된 위치에 설치된 노변 정보 스테이션(RIS)들로 구성되는데 이들은 공유된 통신 채널 자원들을 공유하면서 상호 통신한다. 최근 지능형 운송 시스템은 도로 안전, 혼잡 감소, 운전의 편리 및 환경 개선에 있어서 획기적인 돌파구를 제공할 것으로 기대되며 VANET은 차량이 이에 접근할 수 있는 게이트웨이 역할을 수행한다. VANET에서는 차량간 통신, 차량과 인프라간 통신 등 두 가지 통신 형태가 발생한다. 먼저, 차량들은 다른 차량들이나 IEEE 802.11 액세스 포인트에 해당하는 RIS들과 실시간으로 통신할 수 있어야 하며 또 주행 혹은 정지중인 VANET을 통해 중간 차량들이 정보를 중계해 주는 다중 홉 전송을 통하여 정보를 교환할 수 있다. 이를 통해 차량은 RIS에 저장되어 있는 데이터에 접근하거나 RIS를 통해 인터넷과 접속하여 원하는 데이터를 조회할 수 있다.

VANET은 향상된 네비게이션 시스템에 관련된 안전 경고 시스템, 동적 라우팅 뿐만 아니라, 확장가능하고 비용-효율이 우수한 응용 솔루션 등 다양한 서비스들을 제공해 줄 수 있다. 이러한 응용들이 효율적으로 동작하기 위해서 지능적인 라우팅 프로토콜이 필요하다. VANET을 위한 라우팅 프로토콜을 설계하는데 있어서는 차량의 이동성에 기인한 잦은 경로 두절 문제를 우선적으로 고려하여야 한다. 그런데 차량은 도로 네트워크를 따라서만 이동하기 때문에 차량들의 이동방향은 유한하게 되며, 메시지

전파를 위한 라우팅에 있어서 이를 지능적으로 이용할 수 있다. 도로망에서의 차량통신 분야에서 이동속도, 차량 이동방향, 정보의 위치 등을 고려한 기존의 라우팅 프로토콜들이 있으며 MANET 라우팅 프로토콜들도 기본적으로 앞에서 언급한 VANET의 특성을 그대로 갖고 있다. 하지만, VANET의 동적 위상 변화에 대처하기 위해서는 위치, 속도, 방향, 도로의 디지털 매핑 등 추가적인 정보를 활용하여 MANET 라우팅 프로토콜을 개선한다면 현격한 통신 성능의 향상을 기할 수 있다.

이상에서 설명한 바를 기초로 본 논문은 VANET에서의 데이터 전파의 문제에 초점을 맞추어 이 분야에서 사용해 왔던 중요한 기술들의 특성들을 분석하고, RIS를 위한 지능적인 라우팅(IR-RIS)라고 명명된 라우팅 프로토콜을 설계한 후 RIS 모델을 기반으로 한 캐쉬 결합 데이터 전파 기법을 제시한다. 표준 차량 네트워크에서 동작하는 본 라우팅 프로토콜은 교차로 부근에서 차량과 RIS간 라우팅 메시지가 전파되는 영역을 줄이기 위하여 차량의 현재 이동방향을 이용한다. 기본적으로 캐쉬는 대역폭이 제한된 무선 환경에서 응답 시간을 향상시키고 네트워크 트래픽을 감소시키는 전형적인 기법이다. 또, 모바일 캐쉬에서는 송신자와 수신자간 경로상의 모든 노드들로 하여금 송수신 혹은 중계된 데이터 항목을 주어진 기간동안 저장하도록 한다. 이러한 모바일 캐쉬를 라우팅에 결합함으로써 성능을 향상을 기할 수 있으며 다양하지만 도로에 제한된 이동 패턴을 고려하여 저장된 데이터를 다른 차량들이 해당 데이터를 요구할 가능성이 가장 높은 장소로 배포할 수 있다. ns-2를 활용한 시뮬레이션 결과는 기존의 프로토콜들과 비교해볼 때 제안된 캐쉬 기법이 주어진 실험인자들에 있어서 응답 시간을 20%까지 향상시켰음을 보인다. 더욱이, 본 기법은 제어 트래픽 오버헤드, 패킷 전송률, 단대단 패킷 지연, 네트워크 성능을 현격히 향상시킬 수 있다.

Chapter 1

Introduction

Wireless Networking is gaining wide spread and becoming very popular these past few years, due to its potential and possibilities. Infrastructure networks and mobile ad hoc networks are two main architectures of wireless networking. Infrastructure networks include cellular networks and wireless local area network. Users are connected via base stations/access points, and backbone networks. A class of wireless ad hoc networks wherein nodes are cable of moving autonomously, such networks are generally referred to as Mobile Ad hoc Networks (MANETs). MANETs are self-organizing and self-configuring multi-hop networks wherein nodes act co-operatively to establish the network "on-the-fly". Communication between any two nodes might require the packets to traverse multiple hops and the constituent nodes act both as host and router. MANETs bear great application potential where wired infrastructure is not viable and temporary wireless network for instant communication is desirable such as disaster and emergency situations, battlefield communications, mobile conferencing, lectures, meetings, law enforcement operations, crowd control and so on [5].

In this dissertation, we focus on one of the most applicable forms of ad hoc network, namely Vehicular Ad hoc Networks (VANETs). The rest of this chapter presents several useful applications of vehicular networks and discusses other vehicles-based network solutions in Section 1.1. Section 1.2 presents the characteristics of VANETs. Section 1.3 discusses the challenges in routing, and data dissemination in VANETs. The accomplishments and contributions are presented in Section 1.4. Finally, Section 1.5 presents the organization of this dissertation.

1.1 Vehicular Networks

In 1999, the Federal Communication Commission (FCC) allocated a frequency spectrum for vehicle to vehicle and vehicle to road side wireless communication. The commission then established Dedicated Short Range Communications (DSRC) services in 2003. Vehicular networks are a subject of much attention lately. In December 2003, the U.S. FCC approved 75 MHz of spectrum for DSRC, and the resulting DSRC system is expected to be the first wide-scale VANET in North America. DSRC is a communication service that uses the 5.850 to 5.925 GHz band for the public safety and private applications [1]. In Japan, two DSRC standards have been adopted (the ARIB STD-T75 in 2001, the ARIB STD-T88 in 2004), and Japanese auto manufactures are working with Ministry of Land, Infrastructure, and Transportation in the third phase of an ambitious Advanced Safety Vehicle project. The German Ministry of Education and Research has sponsored the Fleetnet and Network on Wheel projects. Throughout the world, there are many national/international projects in government, industry, and academia devoted to vehicular networks. In recent years, most new vehicles come already equipped with GPS receivers and navigation systems. Car manufactures such as Ford, GM, and BMW have already announced efforts to include significant computing power inside their cars [2, 3] and Chrysler became the first car manufacture to include Internet access in a few of its 2009 line of vehicles [4]. This expansion is expected to continue and in the near future, the number of vehicles equipped with computing technologies and wireless network interfaces will increase dramatically. These vehicles will be able to run network protocols that will exchange message for safer, entertainment, and more fluid traffic on the roads.

The emerging and promising VANET technology, which has drawn tremendous attention from government, academics, and industry in the past few years, has been envisioned as one of the forefront research hotspots and increasingly available for a large number of cutting-edge applications as diverse as imminent collision warning and avoidance, forward obstacle detection and avoidance, emergency message dissemination, intersection decision support, cooperative driving assistance, traffic congestion advisory, dynamic route update, traveler and tourist information, automated toll collection and parking services, interactive multimedia and internet access, and so on. However, to deploy these services or applications, three types of communications involving moving vehicles are considered: cellular network, vehicle-to-vehicle, and vehicle to roadside infrastructure communications (See Figure 1.1). A brief description of each of these types of communication is presented here:

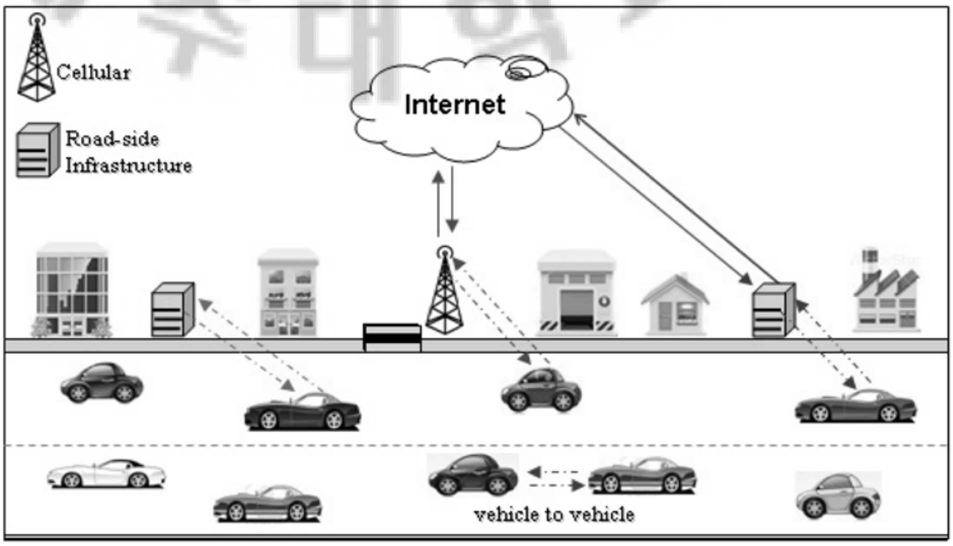

Figure 1.1 Three ways communication in vehicular networks

1.1.1 Cellular Network Communications

This method connects vehicles to the Internet through cellular data networks using the GPRS, 3G, EV-DO, DO Advanced, etc. [6, 7] technologies. This service is commercially available from car manufactures [4] and from other third-parties [8]. In most commercially available solutions, the vehicle is transformed into an IEEE 802.11 (Wi-Fi) hotspot and the Internet connection can be shared by many computers in the car. Usually, a limit is set on the amount of data transfer (e.g., 1GB or 5GB maximum per month). The main advantage of this method of connection is that the vehicle will have Internet access wherein cellular coverage is available. The main drawbacks are the dependence on the cellular operator coverage network and the limited available data rates (rates vary around 500Kbps-800Kbps) [9].

1.1.2 Vehicle-to-Vehicle Communications

Vehicle-to-vehicle communication allows vehicles to interact with each other. Currently, the development of an open wireless protocol, such as DSRC, is allowing manufactures to develop vehicle-to-vehicle systems for more moderately priced vehicles. Similar to Wi-Fi, prototype systems transmit vehicle speed, GPS locations and braking information. The idea is that other vehicles in the vicinity equipped with vehicle-to-vehicle capabilities will also be able to receive and process the signals. Once fully integrated, vehicles may provide drivers with blind-spot warnings, alert drivers to vehicles approaching at high speeds and automatically perform emergency braking. The advantage here is the addition of a distinct, high bandwidth network to the existing infrastructure network. The main drawback is that these networks could require new set of protocols as the viability of vehicular networks applications described above is conditioned by whether or not VANET routing protocols are able to satisfy the throughput and delay requirements of these applications.

1.1.3 Vehicle to Roadside Infrastructure Communications

In this communication method, vehicles connect to other vehicles or to the Internet through roadside access points positioned along the roads. Two main variants can be found in the literature: the access points could be installed specifically for the purpose of providing Internet access to vehicles or the latter could make use of open 802.11 (Wi-Fi) access points encountered opportunistically along city streets [10]. The advantage of this method of connection is that vehicles will be able to connect to the Internet using much higher data rates (e.g., 11Mbps) than through the cellular network. The drawbacks include the cost related to installing access points along the roads to obtain reasonable coverage. Moreover, in the case where open access points are used, the access point's owners consent would legally be required before such a service is deployed [10].

1.2 Characteristics of VANETs

VANET are special case of MANET in which fast moving vehicles form a temporary network. Similar to MANET, nodes in VANET self-organize and self-manage information in a distributed fashion without a centralized authority or a server dictating the communication. In this type of network, nodes engage themselves as servers and/or clients, thereby exchanging and sharing information like peers. Moreover, nodes are mobile, thus making data transmission less reliable and suboptimal. Apart from these characteristics, VANET possess a few distinguishing characteristics, presenting itself a particular challenging class of MANET:

- **Highly dynamic topology:** The speed of vehicles and choice of path defines the dynamic topology of VANET. If we assume two vehicles moving away from each other with a speed of 60mph (25 m/sec) and transmission range is about 250 m, then the link between these two vehicles will available only for 10 seconds. This defines its highly dynamic topology.

- **Frequently disconnected network (Intermittent connectivity):** The highly dynamic topology results in frequently disconnected network since the link between two vehicles can quickly disappear while the two nodes are transmitting information. Due to this feature, the nodes needed another link with nearby vehicle to maintain seamless connectivity for longer communication. But in case of such failure, particularly in case of low vehicle density zone, frequent disruption of network connectivity will occur. Such problems can be deal with road-side deployment of relay nodes.

- **Mobility modeling and prediction:** in volatile network topology connectivity between nodes requires knowledge of its position and their movements which as such is very difficult to predict keeping in view the pattern of movement of each vehicle. a mobility model, node position prediction, predefined roadways model and vehicle speed are very important for effective network design.

- **Communication Environment:** the mobility model highly varies from highways to that of city environment. The node prediction design and routing algorithm also be adapted for these changes. Highway mobility model is simple and predictable due to one-dimension model. But for city mobility model, street structure, variable node density, presence of buildings and trees that behave as obstacles to even small distance communication make the model application that very complex and difficult.

- **Unlimited Battery Power and Storage:** The on-board unit (OBU) and roadside unit (RSU) can provide mobile ad hoc inter-connectivity in vehicular environment; generally do not have distinct energy constraints due to their access to external power supply systems. Therefore, Nodes in VANETs are not subject to power and storage limitation as in sensor networks, another class of ad hoc networks where nodes are mostly static. Nodes are assumed to have ample energy and computing power. Therefore, optimizing duty cycle is not as relevant as it is in sensor networks.

- **On-board Sensors:** Nodes are assumed to be equipped with sensors to provide information useful for routing purposes. Many VANET routing protocols have assumed the availability of GPS unit from on-board Navigation system. Location information from GPS unit and speed from speedometer provides good examples for plethora of information that can possibly be obtained by sensors to be utilized to enhance routing decisions.

Since these aforementioned characteristics are not well considered in MANET, the conventional research dedicated for MANET cannot be directly applied to VANET. In VANETs, the restricted road topology imposes a directional nature to the message flow. Also due to the higher node speeds and unstable connectivity among the nodes, it becomes essential that data be transmitted in the most efficient ways and with minimal delay.

1.3 Problem Statement

Recently, a lot of research articles have been published for road-side data access in vehicular environment. Most of them reflect on the city scenarios for routing or data accessing in VANETs. Note that, for accessing data items from database/Internet, a number of access points are needed to meet the network requirements in city scenarios, which are currently unavailable in the road-based networks. Our goal is to select some specific road intersection points in the city areas, where data dissemination is extremely needed, and giving the RIS only to those of specific points. This dissertation addresses the problem of efficient routing and data dissemination in the Road-side Information Station (RIS) area in VANETs. Even though VANETs show great promise, their success is dependent on whether VANET routing protocols are able to satisfy the throughput and delay requirements of applications deployed on these networks. Thus, this dissertation aims to answer questions such as: Do existing MANET routing protocols work well in road intersections in VANET? If not, what are the main characteristics of VANETs that influence routing and how can they be incorporated in better protocols? Also, caching or replication method is a common technique for saving network traffic and enhances response time in ad hoc networks. Are these existing schemes applicable in the road intersections in VANETs or can they optimize for VANETs characteristics?

1.4 Routing and Data Dissemination Challenges in VANETs

1.4.1 Routing Challenges

Due to the various limitations in VANETs, designing an efficient and reliable routing protocol is a challenging task. Major challenges faced by a VANET routing protocol are frequent path disruptions caused by vehicles mobility, limitations of connectivity, scalability, dealing with partitions and so on. An ongoing session may suffer frequent path breaks due to the self-organization of mobile nodes. Disruptions may take place due to the movement of intermediate vehicles in the path or due to the change of vehicles direction in the intersections or due to the vehicles movement of end roads. Routing protocols are, therefore, responsible for not only constructing durable paths but also for maintaining and reconstructing the failed paths in an efficient and timely manner. An intelligent routing strategy is required which is adaptive to the changing network conditions such as topology, network density, partitioning etc. and can accomplish the above tasks without incurring excessive control traffic overhead.

1.4.2 Challenges in Data Dissemination

The most important challenges in VANETs are high mobility and frequently disconnected topology at different parts of metropolitan area. Some vehicles move on the road at the speed of less than 10 km per hour in a traffic jam condition, while others move at over 80 to 100 km per hour on highways. The traffic density is low in suburban areas and during night, on the other hand, the network node density is usually extremely high in downtown areas during rush hours in day time, which may result in frequent network disconnections. Thus the correct approach for data dissemination in VANETs needs to consider the network diversity and adapt the dissemination mechanism according to the different network environments.

Because of the diversity, there is no simple 'one-for-all' solution for disseminating data to all recipients spreading across the metropolitan. In order to disseminate data to a far away vehicle, the data need to be forwarded over multi hops, spanning a large geographic area. The data delivery in the presence of disconnections or sparse network becomes the most eminent problem. When the target vehicle moves closer to the road-side unit and is located in a vehicle densely populated area, disconnection is of less concern. Instead, it becomes the major problem when many vehicles close to one another are requesting data at the same time, and sharing same wireless media. Therefore usage of limited bandwidth becomes the key issue. When a vehicle moves within the one-hop range of the roadside units, data can be delivered to the vehicle at the highest throughput. However, the vehicle only stays in the one-hop coverage of the roadside unit for very short time while it is moving. Thus, as a vehicle passes by the roadside unit, it is most desirable to extend the connection time between the vehicle and the roadside unit so as to disseminate more data. For more efficient data dissemination, multiple roadside units can be wirelessly connected together to form an infrastructure mesh network and cooperatively disseminate data to vehicles. Then how to distribute the data over the mesh nodes is an important issue.

In addition to diversity, several other unique properties further complicate the data dissemination in VANETs, which have never been considered in other types of ad hoc networks. Vehicles generally move at high speed than nodes in other kinds of MANETs, and the link topology changes rapidly [11, 12]. Many existing structures in the literature for efficient data dissemination, such as clustering, grid and tree are extremely hard to set up and maintain. Because of network diversity in both topology and mobility, the network can be sparse at some regions, which may result in frequent network disconnections and network partitions. In other areas where network node density is high, the conventional broadcast based mechanism for data dissemination may lead to broadcast storm [13]. In urban areas, roads are often separated by buildings and other obstacles which can block radio communication, so communication is often restricted along roads.

The above challenges are unique to VANETs, particularly in large scale metropolitan. They have never been considered in designing data dissemination protocols for other forms of MANETs before, making the existing protocols insufficient to serve VANETs. It has been shown in [14, 15, 16, 17] that many traditional MANETs data dissemination schemes result in poor overall network performance in VANETs, such as long delay, low data delivery rate, low bandwidth utilization and high network overhead.

1.5 Accomplishments and Contributions

The focus of this dissertation is how to improve the data dissemination and routing in road intersection areas in VANETs by incorporating VANETs characteristics into protocol designs. The main accomplishments and contributions of this dissertation are summarized as follows:

- We have given a new dimension to the concept of data dissemination process for Road-side Information Station (RIS) model in VANETs. Different scenarios are presented to understand the data dissemination process in RIS model along with the subsequent difficulty in accessing the required data.

- A novel routing protocol referred to as Intelligent Routing for Road-side Information Station (IR-RIS) is proposed to maintain the reliable connections between RIS and vehicles for road-side data access in road intersections in VANETs.

- The grouping roads layout from RIS allows requesting vehicle to send the vehicle moving-direction with the request message, and RIS takes the advantage of the vehicle's moving-direction to find the stable paths for packet forwarding.

- In the proposed protocol, RIS takes the routing decision based on the requested data availability in RIS database or other database/Internet.

- After designing the routing protocol, a cache-augmented data distribution scheme based on the RIS model is proposed for enhancing the data accessibility in road intersections.

- Extensive simulation is performed and comparative analysis is performed with well known MANET routing protocols.

- The dissertation sets the tone and stage for interesting future research work and extensions.

1.6 Organization of the Dissertation

The remaining of this dissertation proposal is structured as follows:

- **Chapter 2: Data Dissemination in VANETs**

  This chapter surveys the different types of information exchanges adopted in vehicular networks with common practices and methodologies that have been considered in research literature with data dissemination approaches and techniques.

- **Chapter 3: Routing, Caching and Replication Schemes in MANETs**

  In this chapter an overview of the related and previous literature on routing protocols, caching and replication schemes in MANETs are surveyed.

- **Chapter 4: Proposed Work**

  This chapter presents how the proposed protocol and cache scheme works in the RIS area. The details of the RIS model, basic concepts of RIS, routing algorithm, and cache scheme are explained respectively.

- **Chapter 5: Performance Evaluation**

This chapter shows the analysis and comparison of the proposed protocol and cache scheme with the other routing mechanism.

- **Chapter 6: Conclusions**

  This chapter presents the summary of the dissertation, draws conclusion to the research and sheds light on possible enhancements and the future work.

Chapter 2

Data Dissemination in VANETs

This chapter presents the types of information involved in the dissemination and working of data dissemination approaches, their strengths, and weaknesses. Moreover, some of the data dissemination techniques are also described.

2.1 Types of Information Involved in the Dissemination

The different types of information that need to be communicated and then shared in a vehicular network can be roughly classified in four categories:

2.1.1 Safety Information

Safety information Safety information is probably the most important information type that are communicated in a vehicular network [18], as motor vehicle crashes cause more than 120.000 victims in Europe and 1.2 million worldwide1. DSRC technology designed to support V2V and V2I and conceived by the Federal Communications Commission (FCC) to "increase traveller safety, reduce fuel consumption and pollution and continue to advance the nation's economy". DSRC will support safety-critical communications such as collision warnings as well as other valuable Intelligent Transportation System applications (i.e.: electronic-toll-collection (ETC), real-time traffic advisories, digital map updates, etc.). As it concerns safety messages, FCC recognizes safety messages and safety-of-life messages, which have the highest priority, whether originated by vehicles or roadside transmitters. Thus, DSRC can be used to prevent collisions between vehicles by providing important informations to the drivers about whether the vehicle ahead is braking, if the speed is too high or the distance to other vehicles (or objects, more in general) is getting too close. US Department of Transportation and the Vehicle Safety Communications Consortium (VSCC) have identified eight applications that rely on security informations [19]. These are:

(1) Curve speed warning,

(2) Traffic signal violation warning,

(3) Emergency electronic brake lights,

(4) Pre-crash warning,

(5) Left turn assistant,

(6) Lane change warning,

(7) Stop sign movements assistance, and

(8) Cooperative forward collision warning

The communication requirements of these eight applications are shown in table 5.1. Note that communication frequency ranges from 1-50 Hz, the size of the packet ranges 200-500 bytes, and the maximum communication range spans from 50-300 meters. Further, high-level Data Element requirements are specified and several of these Data Elements (e.g. position and heading) are needed by multiple applications. Responding to these identified applications, the "Dedicated short range message set" defines over seventy vehicle Data Elements (e.g. heading, acceleration (with varying precision: 4bit, 8bit, 16 bit), headlight status and brake status). Of these Data Elements, thirty of the most commonly used elements are selected for a common message set, as listed in table 2.1. However, very few of these applications have actually been implemented or fully developed. Hence, the exact usage characteristics of the safety messages were in flux at the time the safety messages were being defined and standardized.

Table 2.1 Eight high priority vehicular safety applications as chosen by NETSA [20] and VSCC (Vehicle Safety Communications Consortium), which is a consortium born in May, 2002 with the mission to facilitate the advancement of vehicle safety through communication technologies (the members are: BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VWGM, VW). Note that, P2M represents "point-to-multipoint", I2V "infrastructure-to-vehicle" and V2I "vehicle-to-infrastructure".

Application	Comm. type	Freq.	Latency	Data transmitted	Range
traffic signal violation	I2V one-way, P2M	10 Hz	100 ms	signal status, timing, surface heading, light pos., weather	250 m
curve speed warning	I2V one-way, P2M	1 Hz	1000 ms	curve location, curvature, bank speed limit, surface	200 m
emergency brake lights	V2V two-way, P2M	10 Hz	100 ms	position, deceleration heading, velocity	200 m
pre-crash sensing	V2V two-way, P2P	50 Hz	20 ms	vehicle type, yaw rate, position heading, acceleration	50 m
collision warning	V2V one-way, P2M	10 Hz	100 ms	vehicle type, position, yaw rate heading, velocity, acceleration	150 m
left turn assist	I2V and V2I one-way, P2M	10 Hz	100 ms	signal status, timing, position direction, road geom., heading	300 m
lane change warning	V2V one-way, P2M	10 Hz	100 ms	position, heading, velocity acceleration, turn sign. status	150 m
stop sign assist	I2V and V2I one-way	10 Hz	100 ms	position, velocity heading, warning	300 m

2.1.2 Traffic Information

Congestion of roads is very important information to share on vehicular networks in order to let personal electronic navigators to select the best route and avoid traffic. This can be extremely useful in case of car crash or even under emergency circumstances because mobile nodes can be informed in advance on the congestioned area so that service vehicles can quickly reach the destination. Of course, these kinds of messages are without any doubt useful for safety and efficiency but less time-critical than the "life safety" ones discussed earlier. With respect to infotainment and content information, this class of data still has higher priority.

2.1.3 Infotainment Information

With infotainment information we intend all that kind of messages about entertainment and, more in general, useful messages to the driver. An example can be:

⇒ Locating the closest coffee shop

⇒ Locating the closest cinema or mall

⇒ Locating the fuel station which offers the best price in that area

⇒ Locating the closest available parking spot

⇒ Many and many others.

2.1.4 Content

This kind of information differs from the others especially in the quantity of data exchanged between nodes and recent research works in vehicular networks have focused on content distribution as multimedia data are becoming essential in everyone's life [21], [22], [23]; this means the main assumption is that vehicles are interested in obtaining extremely large files (e.g. videos and movie clips) that cannot be shared through a limited transactions with either the infrastructure or the nearby mobile nodes. The discovery and distribution of large quantities of information is still a challenging problem especially in a dynamic environment such as a vehicular network.

2.2 Data Dissemination Approaches

The data dissemination approaches in VANETs may be categorized as vehicle to infrastructure (V2I) or infrastructure to vehicle (I2V) and vehicle to vehicle (V2V). The concept of data dissemination is wide and useful in VANETs. Data dissemination among vehicles depends on the type of assumed architecture. In the existence of infrastructures or road side units, two data dissemination approaches are assumed: push-based and pull-based. With lacking of infrastructure two dissemination approaches can be considered: flooding and relaying. This section firstly defines the V2I/I2V and V2V approaches and afterward explains the several available techniques to disseminate data.

2.2.1 Vehicle to Infrastructure/Infrastructure to Vehicle (V2I/I2V)

Push-based and Pull-based approaches are considered for V2I (or I2V) data dissemination.

2.2.1.1 Push-based

In push based data dissemination scheme data is managed by data center which collects the data from the out side world and make it ready to deliver to the vehicles. The data center can be a computer having a wireless interface; it may be a wireless access point, or an infostation [24]. Data center makes a list of the data items that has to be disseminated over network. It transmits this information on the road with header which stores all the necessary information like source id, source location, forwarding direction, packet generation time, etc.

Data item also has two attributes: (1) Dissemination zone in which packet can transmit, and (2) Expiration time after which time the packet will expire.

Push-based scheme can be justified with traffic condition, e-advertisement etc.

2.2.1.2 Pull-based

The pull based dissemination scheme is mainly used by vehicles to query the data for the specific response from data center or from other vehicles. Pull based scheme is used by some specific users. In this scheme the data is managed by the data center and the vehicles which are moving on the road. When the vehicle needs any data query then firstly these vehicles sends beacon message to find the list of neighbor vehicles. These vehicles are already equipped with digital maps, having street-level maps and traffic details like traffic density and vehicle speed on roads at different times [25]. The carry and forward mechanism is used to deliver the data in this approach. In this mechanism data packets are carried by the vehicles and when they found and other vehicle moving in the direction of destination in his range, it forward that packet to this vehicle. This mechanism takes tolerable delay to transfer data to the destination. In this approach data packets are mostly transferred using wireless channels but if the packet has to be transferred through the roads then those roads will be chosen for data transfer through which highly mobile vehicles are moving. Since the vehicular ad hoc network are unpredictable in nature, so optimal path for successful routing can not be computed before sending the packet. So the dynamic path selection is done through out the packet forwarding process. Since, pull based mechanism is generally used for making queries and receiving responses. So this whole process is typically divided into two sub processes:

(1) Requesting data from moving vehicle to fixed location: this mechanism is explained in Vehicular Assisted Data Dissemination (VADD) protocol [14] and forwards packet either in Intersection mode or in straightway mode until it reaches to the destination.

(2) Receiving response from fixed location to moving vehicle: if the GPS system is used then using this exact location of the vehicle may be calculated and the trajectory of vehicle could be calculated and this trajectory could be included with query response packet and forward to the intermediate vehicles and these intermediate vehicles will calculate the destination position.

In pull-based type, enquiry about parking lot, nearby coffee shop etc. are the cases.

2.2.2 Vehicle to Vehicle (V2V)

Flooding and relaying are two approaches that can be considered for vehicle to vehicle data dissemination.

2.2.2.1 Flooding

In the flooding mechanism all types of data is broadcasted to neighbors. Whenever another vehicle receives a broadcast message, it stores and immediately forwards it by rebroadcast. It is suitable for delay sensitive applications and also very much suitable for sparse network during low traffic conditions.

2.2.2.2 Relaying

In the relaying mechanism relay node is selected for disseminating the messages. The relay node (next hop) is responsible for forwarding the packet further. In this approach contention is less and it is scalable for dense networks. This is due to the less of number of the nodes participating in forwarding message and as a result generated overhead is less. This generally preferred for congested networks.

The comparison of the data dissemination approaches (V2I/I2V and V2V) are presented in table 2.2. In this table, we have added 'dissemination in partitioned network' approach (opportunistic scheme), which brief description can be found in the next section.

Table 2.2 Comparison of data dissemination approaches

Data Dissemination Approaches		
V2I/I2V	**Pros**	**Cons**
Push-based	Suitable for popular data	Not suitable for unpopular data
Pull-based	Suitable for non-popular data, user specific data	Cross traffic incurs heavy interferences, collisions
V2V	**Pros**	**Cons**
Flooding	Reliably and quickly distributed data	Not scalable for dense networks
Relaying	Works well in dense networks	Selecting best next hop and reliability is difficult
Dissemination in Partitioned Network	**Pros**	**Cons**
Opportunistic	Suitable for network partitions	Difficult to estimate rebroadcast interval, high overhead in dense network

2.2.3 Some of the Data Dissemination Techniques

Data dissemination is a challenging task because by utilizing limited bandwidth, maximum data has to disseminate over the vehicular network. Many researchers have provided several techniques to disseminate data so that the data can be accessed more efficiently. Some of the techniques related with our works are described here.

Xu *et al*. have proposed data dissemination issues in the VANET in the scheme called opportunistic dissemination (OD) scheme [26] and similar type of approach has been discussed in [28, 29, 30]. In this approach, the data center is periodically broadcasting the data, and the vehicles which are passing through the range of data center, they are receiving and storing the data. Whenever two vehicles will reach into the transmission range of each other, they exchange data. There is no need of any infrastructure and hence, is suitable for highly dynamic VANETs. But drawback of this scheme is that the data can not be efficiently updated in the urban areas where the vehicle density is too high because using this scheme media access control (MAC) layer collision [27] occurs.

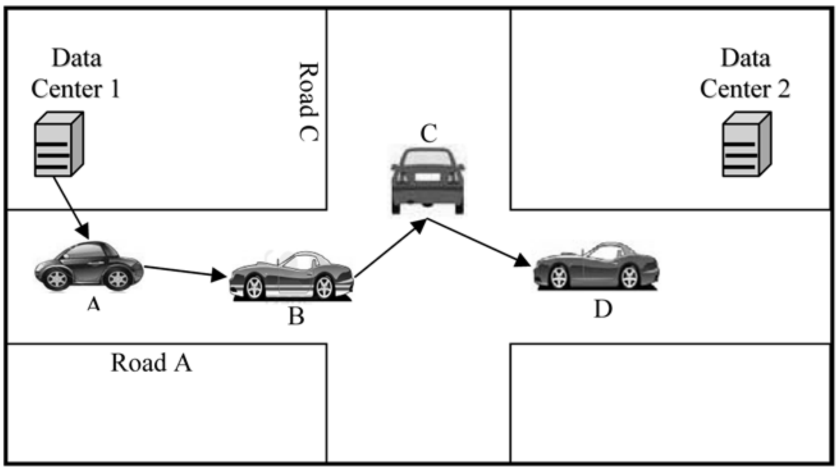

Figure 2.2.3.1 Directional broadcast

Zhao, Cao [31] have proposed Data Pouring and buffering scheme for push based data dissemination. The Data Pouring (DP) scheme selects one or some road having high density and mobility of vehicles i.e. axis road (A-road) and data center delivers data not only on that road but on the crossing roads (Croads) if the vehicles are near to the intersection on C-roads as explained in figure 2.2.3.1. The Data Pouring Intersection Buffering (DP-IB) mechanism uses relay and broadcast stations which are actually the buffers (IBer) [22, 32]. These IBers are placed at the intersection points and used to store data at the intersections. In the DP-IB scheme the data has been transferred from data center to the buffers present at the intersections by this way the availability of the data is increased at the intersection and the load on the server is reduced and data delivery ratio is increased. IBers periodically rebroadcast data so that vehicles passing through Croad can receive data packets. IBers update themselves with the updated data send by data center. There may be possibility of collision between the new data item send by data center and broadcast data by IBer. To avoid this collision, broadcast period is divided into two parts: (1) Busy period in which IBer can only broadcast data, and (2) Idle period in which IBer only listen the forwarded data. The broadcast cycle time at the intersection Ti is used to determine DC, delivery ratio of DP and DP-IB scheme. This Ti should be less than the time taken by vehicles to go through intersection region i.e. Ti to guarantee that all the vehicles moving from the intersection can receive the broadcast data. The delay in the DP scheme is more because many time receiver can not receive data packets in a single cycle and in Reliable DP (R-DP) scheme, vehicles uses request to send/clear to send (RTS/CTS) handshakes to reduce collision and hidden node problem but due to this handshake, delay is more as it blocks the flow until it receives the acknowledge of the previous packets and in DP-IB scheme the delay is more as IBer uses only idle cycle to receive the forwarded packets. The delivery ratio of DP is good for very small set of data but as size of data set increases it decreases. The R-DP and DP-IB have very high data delivery ratio for limited data set size but as the data set size increases more the delivery ratio of R-DP falls whereas DP-IB scheme keeps the same delivery ratio.

Gupta *et al.* proposed Vehicle Density Dependent Data Delivery (VD4) [33] protocol that deals with efficient data delivery in VANETs. As the packet can be forwarded through multiple paths but that path should be chosen which is going to take minimum tolerable delay. Therefore, at every intersection data packets are transferred to RSU and RSU forwards this packet to the vehicle which is moving to the optimal road to the destination with minimum delay. In this protocol, the packet is transmitted from source to destination using the intermediate node. The vehicle needs two types of transmission:

(i) In which packet is forwarded to the vehicle which is farthest to this vehicle in its range, and

(ii) In which packet is carried by the vehicle until it is getting any vehicle in its range as shown in figure 2.2.3.2. This transmission is slower than previous one but very important during the forwarding process.

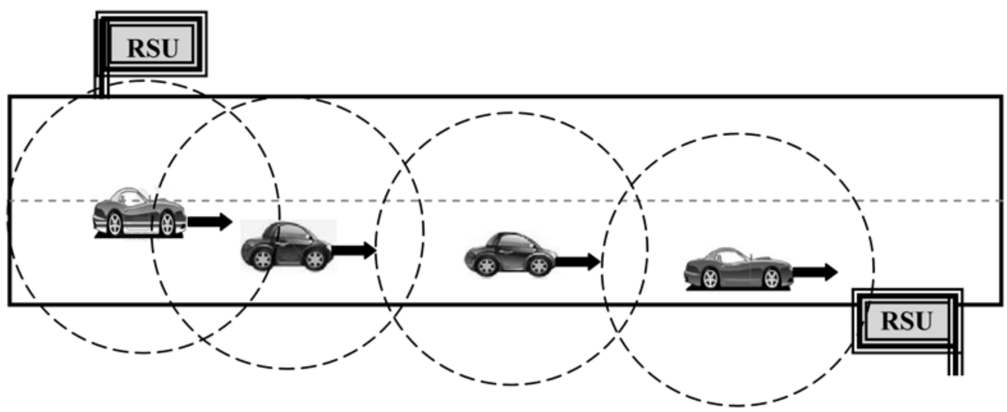

Figure 2.2.3.2 Packet carried partially by a vehicle and partially wirelessly transmitted

As the vehicle reaches to the RSU, the time of arrival of vehicle, the speed of vehicle, direction of movement and data packets are obtained by RSU. If this packet is already present at that RSU then it is dropped else the packet is forwarded to the farthest vehicle present in its range traveling towards the destination.

As the vehicle reaches to the RSU, the time of arrival of vehicle, the speed of vehicle, direction of movement and data packets are obtained by RSU. If this packet is already present at that RSU then it is dropped else the packet is forwarded to the farthest vehicle present in its range traveling towards the destination.

Similarly, if the packet is found as acknowledge packet then it is deleted from the memory of RSU but if it is not present then its entry is made in the memory of RSU and the also the packet is forwarded to the farthest vehicle present in its range traveling towards the destination. These packets are delivered to all the vehicles moving towards the destination until one of the packets is delivered to the RSU at the next hop. When this packet is delivered at next hop, the acknowledgement is sent by that RSU to the source RSU via traveling in the same direction. When the acknowledge packet is received by source RSU, the packet transmission stops and packet deleted from the memory of the RSU. In the case of high density vehicular conditions, the VD4 performance is nearly similar to the performance of Hybrid-VADD. But in case of high density road conditions VD4 performance is better than the performance of Hybrid-VADD.

X. Yang *et al*. have proposed Vehicle Collision Warning Communication (VCWC) [57] protocol for forwarding warning messages to other vehicles moving on the road. When any vehicle is suffering some kind of mechanical failure or any accident has occurred on the road to any vehicle. Then this vehicle is danger to the other vehicles that are passing through the same road. The vehicles that are behaving abnormally are Abnormal Vehicle (AV) vehicles (figure 2.2.3.3) and they generate Emergency Warning Messages (EWMs) which includes speed, direction of motion and location of event. In VCWC protocol, EWM message is send by the AV's and this message is repeatedly transmitted as the every vehicle approaching to AV needs that message. But this retransmission of the same data packet actually creates the redundancy of same data.

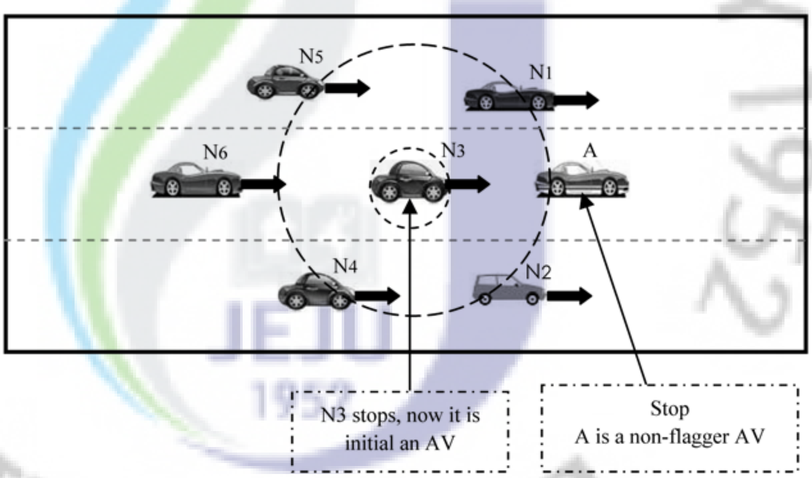

Figure 2.2.3.3 (a) N3 Sends EWM and A becomes a non-flagger

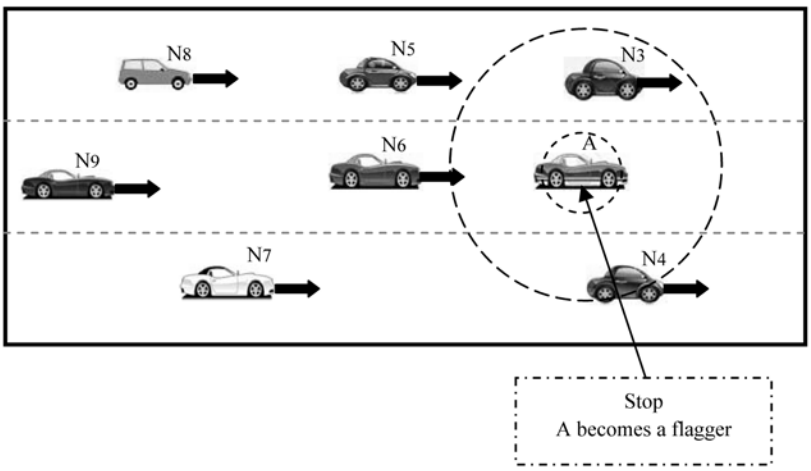

Figure 2.2.3.3 (b) N3 changes lane and drives away; A identifies itself a flagger

Figure 2.2.3.3 VCWC protocol for forwarding warning message

Every AV may be in one of the three states, initial AV, nonflagger AV and flagger AV. As the vehicle becomes abnormal it is an initial AV. Initial AV becomes non-flagger AV by eliminating redundant EWMs and this transmission of message will be further carried by only that vehicle which has over headed the AV vehicle and depending upon the road situations nonflagger AV can be converted into flagger AV If non-flagger AV is not receiving any EWM message from its followers after the Flagger Timeout (FT) timer expires that was set by non flagger AV. and resumes the EWM messages transmissions at the minimum required rate. As shown in figure 2.2.3.3 (a), trailing vehicle N3 stops by receiving EWM messages from vehicle A. and then N3 starts transmitting EWM messages. Since both A and N3 are messaging the same warning so A stops messaging and enters in the non flagger state. After some time when the vehicle N3 is getting way on some other lane then vehicle A has again to start EWM messaging and will enter into flagger state (As shown in figure 2.2.3.3 (b).

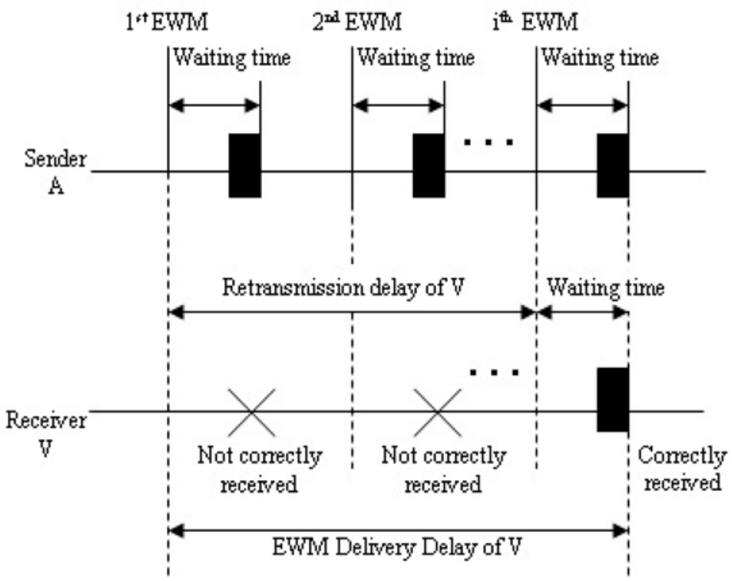

Figure 2.2.3.4 Waiting Time and Retransmission Delay

In VCWC different kind of messages have different priority levels and EWMs have highest priority. EWM delivery delay is the time taken between the occurrences of emergency at A and first successful receives of EWM message at V. EWM message may suffer some delay due to queuing delay, channel allocation delay and may face some retransmission delay due to collision, etc. Waiting time can be viewed as figure 2.2.3.4. In this mechanism the delay in retransmission of the packet depends on the kth retransmission and initial transmission rate λ. This VCWC protocol can satisfy emergency warning delivery requirements and support a large number of AVs at the low cost of channel bandwidth.

Zhao, Cao [14] have proposed Vehicular Assisted Data Dissemination (VADD) scheme for pull based data dissemination. VADD protocol deals with the pull based mechanism of data dissemination in VANETs. When the data has to be forwarded from one place to another place then this protocol suggests that path selection should be done on the basis of high density of vehicle even by following that path data has to traverse more distance but data forwarding delay will be less on this path.

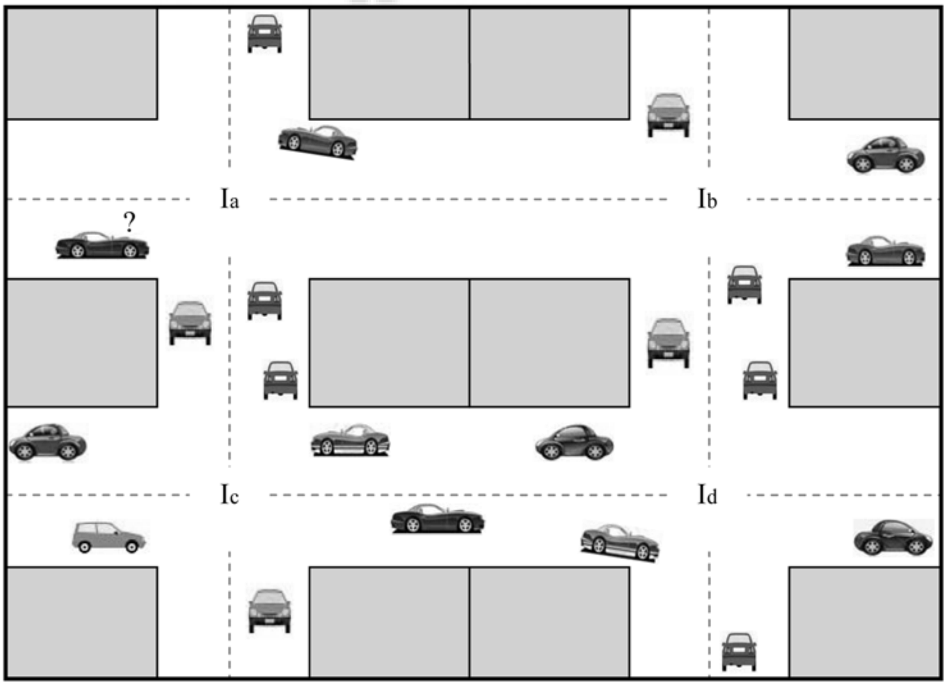

Figure 2.2.3.5 Find a path to the destination

Suppose any vehicle is coming closer to the intersection Ia and it is willing to send a request to his friend at the corner of intersection Ib (as shown in figure 2.2.3.5). To forward the request through Ia → Ic, Ic → Id, Id → Ib would be faster than through Ia→Ib even though the latter provides geographically shortest possible path. The reason is that in case of disconnection, the packet has to be carried by the vehicle, whose moving speed is significantly slower than the wireless communication. VADD follows the following basic principles:

(1) Vehicle in Intersection Mode: In figure 2.2.3.6, vehicle A has a packet to forward to certain destination D. There are two available vehicles for carrying the packet; B moving south and C moving north. A has two choices on selecting the next hop for the packet: B or C. If B is selected then it is geographically closer to D and can easily and immediately forward packet to D, whereas C could also be selected because by selecting C packet will move in the north direction as the vehicle C is moving towards the north direction.

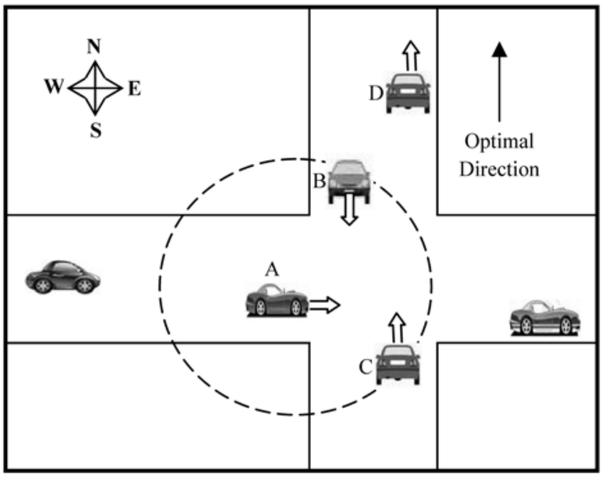

Figure 2.2.3.6 Select the next vehicle to forward the packet

These two choices lead to two different forwarding protocols: Location First Probe (L-VADD) and Direction First Probe (DVADD). In location first probe, the vehicle reaching to the intersection checks the priority order of the direction of flow of data packet and forwards the packet to the vehicle having high priority order. But in the L-VADD there are chances of the routing loop in which the vehicle is forwarding some packet to the vehicle in its range and that packet is forwarding the same packet back to the vehicle from which he got that packet as the next hop forwarding. This routing loop is avoided by simply using a mechanism in which every vehicle is using the previous hop information and never transfers the packet to that vehicle from which it has taken the packet as a previous hop. Now in the direction first probe the packet is forwarded to the vehicles which are moving in the direction of desired packet forwarding direction. The D-VADD protocol is free from routing loops. In Multi-Path Direction First Probe (MD-VADD) packets may be forwarded in more than direction. In this scheme the packet carrier forwards the packet using D-VADD protocol but it does not delete the packet from its buffer and waits for any vehicle which is moving in the higher priority direction and forwards the packet as it finds any such vehicle. The process of data buffering is continued until it finds any vehicle having highest priority. LVADD shows better performance than all other VADD protocols when there is no routing loop occurs but when the routing loop occurs then the performance affects severely and data delivery ratio decreases. So Hybrid probe H-VADD is developed in which both L-VADD and D-VADD protocols are used. Firstly packet is forwarded using L-VADD protocol but as the routing loop occurs the L-VADD protocol is dropped and D-VADD protocol is used.

(2) Vehicle in Intersection Mode: In this mode simple greedy approach is used to forward the packet to the destination in which packets waits for vehicles moving in the direction of destination and as it finds such vehicle it forwards the packet to that vehicle. The delivery ratio of the H-VADD protocol provides best delivery ratio of all other protocols. Delay in H-VADD is equivalent to the MD-VADD when the vehicle density is low as it depends more on D-VADD protocol to avoid the routing loops and when vehicle density is more, delay becomes equal to LVADD. H-VADD has advantage of both D-VADD and LVADD.

Chapter 3

Routing, Caching and Replication Schemes in MANETs

This chapter summarizes the related work already done in the field of mobile ad hoc networks (MANETs). In this chapter, we discuss the working of various MANET routing protocols (which are applicable in VANET), their silent features, strengths, weaknesses and prepare a stage whereon some of the deficiencies of the existing routing protocols can be overcome or reduced. Moreover, caching and replication schemes are common techniques for saving network traffic and enhancing response time, especially in wireless environments where bandwidth is often a scare resource. We have studied the working of cache and replication schemes in ad hoc networks to give a possibility to improve vehicle to roadside data access in VANETs.

3.1 Ad hoc Routing Protocols

Routing in wireless ad hoc networks is clearly different from routing found in traditional infrastructure networks. The responsibilities of a routing protocol include exchanging the route information; finding a feasible path to a destination based on criteria such as hop length, minimum power required, and lifetime of the wireless link; gathering information about the path breaks; mending the broken paths expending minimum processing power and bandwidth; and utilizing minimum bandwidth. The major challenges for routing protocols are: mobility, bandwidth constraint, error-prone and shared channel, location-dependent contention, and other resource constraint. Designing issues for developing a routing protocol for wireless ad hoc networks are much more complicated than those for wired network. Minimum route acquisition delay, quick route reconfiguration, loop-free routing, distributed routing approach, minimum control overhead, scalability, provisioning of QoS, support for time-sensitive traffic, security and privacy are the major requirements of a routing protocol in ad hoc wireless networks.

3.1.1 Classification of Routing Protocols

In general, ad hoc network routing protocols divided into two broad categories: proactive routing protocols and reactive (also known as on-demand routing) protocols according to their routing strategy. Next to the two described protocols there exist also hybrid protocols, which are a combination of the other two. Table 3.1 categories some of the well known routing protocols in MANET.

Table 3.1 Classification of MANET routing protocols

MANET Routing Protocols	
Reactive/ On Demand	Dynamic MANET On-Demand (DYMO) [39] Ad hoc On-demand Distance Vector (AODV) [38] Dynamic Source Routing (DSR) [37]
Proactive	Destination-Sequenced Distance Vector (DSDV) [34] Optimized Link State Routing (OLSR) [36] Wireless Routing Protocol (WRP) [35]
Hybrid Solutions	Zone Routing Protocol (ZRP) [40]
Geographic Position Assisted Routing	Location-Aided Routing (LAR) [41] Greedy Perimeter stateless routing (GPSR) [42]

Proactive routing protocols attempt to maintain consistent, up-to-date routing information between every pair of nodes in the network by propagating, proactively, route updates at fixed time intervals. The idea of such a protocol is to keep track of routes from a source to all destinations in the network. That way as soon as a route to a destination is needed it can be selected in the routing table. Advantages of a proactive protocol are that communication experiences a minimal delay and routes are kept up to date. Destination-Sequenced Distance-Vector (DSDV), Optimized Link State Routing (OLSR), and Wireless Routing Protocol (WRP) are the well known proactive routing protocols in ad hoc network.

On-demand routing protocols established a route to a destination only when there is a demand for it, usually initiated by the source node through route discovery process with in the network. When a route is needed by the source, it floods a route request packet to construct a route. Upon receiving route request, the destination selects the best route based on route selection algorithm. Route reply packet is then sent back to the source via the newly chosen route. In on-demand routing protocols, control traffic overhead is greatly reduced since no periodic exchanges of route tables are required. Numerous protocols of this type have been proposed. Dynamic Source Routing (DSR), Ad-Hoc On-Demand Distance Vector (AODV), and Dynamic MANET On-Demand (DYMO) are well known on-demand routing protocols.

Proactive protocols have the advantage that new communications with arbitrary destinations experience minimal delay, but suffer the disadvantage of the additional control traffic overhead to update routing information at all nodes because that routes may break, as a result of mobility, before they are actually used or even that they will never be used at all, since no communication may be needed from a specific source to a destination. To cope with this shortcoming, reactive protocols adopt the inverse approach by finding a route to a destination only when needed. Reactive protocols often consume much less bandwidth than proactive protocols, but they will typically experience a long delay for discovering a route to a destination prior to the actual communication. However, because reactive routing protocols need to broadcast route requests, they may also generate excessive traffic if route discovery is required frequently.

3.2 Routing Protocols Review

In this section, MANET routing protocols are surveyed. For the sake of simplicity and relevance to our work in this dissertation, we only present proactive routing protocol (DSDV), and reactive or on-demand routing protocols (DSR, AODV, and DYMO) respectively.

3.2.1 Dynamic Destination-Sequenced Distance-Vector Routing

The Destination Sequenced Distance Vector (DSDV) protocol [34] is a proactive hop-by-hop distance vector routing protocol, requiring each node to broadcast routing updates periodically. Here, every MH in the network maintains a routing table for all possible destinations within the network and the number of hops to each destination. Each entry is the marked with a sequence number assigned by the destination MH. The sequence numbers enable the MHs to distinguish stale routes from new ones, thereby avoiding the formation of routing loops. Routing table updates are periodically transmitted throughout the network in order to maintain consistency in the tables.

To alleviate potentially large network update traffic, two possible types of packets can be employed: full dumps or small increment packets. A full dump type of packet carries all available routing information and can require multiple network protocol data units (NPDUs). These packets are transmitted less frequently during periods of occasional movements.

Smaller incremental packets are used to relay only the information that has changed since the last full dump. Each of these broadcasts should fit into a standard-size NPDU, thereby decreasing the amount of traffic generated. The MHs maintain an additional table where they store the data sent in the incremental routing information packets. New route broadcasts contain the address of the destination, the number of hops to reach the destination, the sequence number of the information received regarding the destination, as well as a new sequence number unique to the broadcast. The route labeled with the most recent sequence number is always used. In the event that two updates have the same sequence number, the route with the smaller metric is used in order to optimize (shorten) the path. MHs also keep track of settling time of the routes, or the weighted average time that routes to a destination could fluctuate before the route with the best metric is received. By delaying the broadcast of a routing update by the length of the settling time, MHs can reduce network traffic.

Note that if each MH in the network advertises a monotonically increasing sequence number for itself, it may imply that the route just got broken. For example, MH 3 in figure 3.2.1 decides that its route to D with an infinite metric. This results in any node 2, which is currently routing packets through 3, to incorporate the infinite metric route into its routing table until node 2 hears a route to D with a higher sequence number.

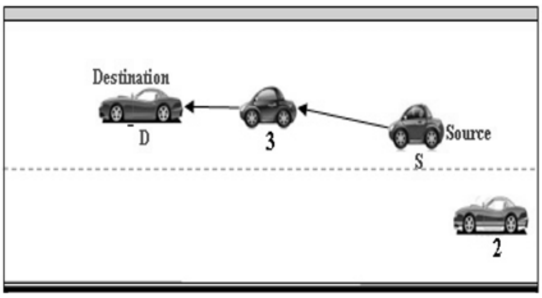

Figure 3.2.1(a) MH S uses 3 to communicate with MH D

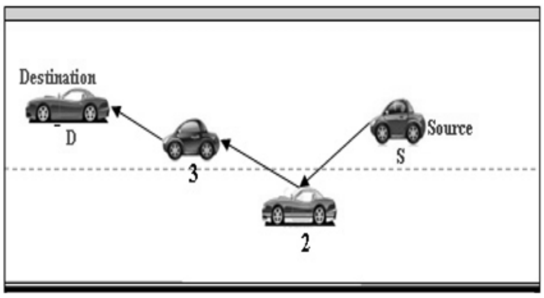

Figure 3.2.1(b) Due to movement of MHs, S now uses 2 and 3 to reach D

Figure 3.2.1 Dynamic Destination-Sequenced-Vectors Routing

3.2.1.1 Strength and Drawbacks

The advantages of DSDV protocol are as follows: it guarantees loop free paths, count to infinity problem is reduced, avoid extra traffic with incremental updates instead of full dump updates, and the amount of space in routing table is reduced as it maintains only the best path instead of maintaining multiple paths to every destination. However, even if there is no change in the network topology, there is wastage of bandwidth due to unnecessary advertising of routing information. It is difficult to determine a time delay for the advertisement of routes. Also, it is difficult to maintain the routing table's advertisement for larger network. Each and every host in the network should maintain a routing table for advertising. But for larger network this would lead to overhead, which consumes more bandwidth.

3.2.2 Dynamic Source Routing

Dynamic Source Routing (DSR) [37] is an on-demand source routing protocol. Each data packet carries along the path to the destination. The main benefit of source routing is that intermediate nodes need not keep topological information although intermediate nodes of a valid source path are required to temporarily store routing information in the form route caches. DSR does not depend on any kind of periodic messages to be sent and supports uni-directional and asymmetric links. The protocol consists of two major phases: route discovery and route maintenance, which are explained in the following sections.

3.2.2.1 Route Discovery

When a source has a data packet to send to some destination but does not have any route in its cache to that destination, it initiates route discovery. The source broadcasts a Route Request (RREQ) message. RREQ packet carries along address of the destination, source node's address, a unique request ID and the path it has traversed. When this RREQ message reaches the destination or a node that has route information to the destination, it sends a Route Reply (RREP) message with path information contained therein back to the source. Each node records routes the node has learned and overhead over time in its route cache to reduce overhead generated by the route discovery process.

When a node receives a RREQ packet, it forwards the packet only if following conditions are met: (i) the node is not the target (destination) of the RREQ packet, (ii) the node is not present in the source route, (iii) the packet is not a duplicate and (iv) no route information to the target node is available in its route cache. If all are satisfied, the node appends its ID to the source route and broadcasts the packet to its 1-hop neighbors. If either of the conditions (ii) and (iii) is not met, it simply discards the packet. If a node is the target of packet or has route information to the destination, it constructs and sends a Route Reply (RREP) to the source. By the time the packet reaches either the destination or such an intermediate node, it contains a route record yielding the sequence of hops taken.

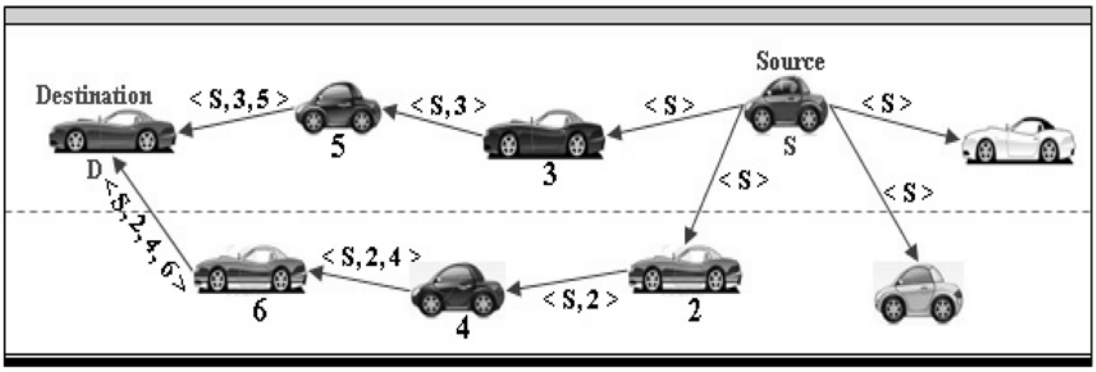

Figure 3.2.2.1 (a) Building Record Route

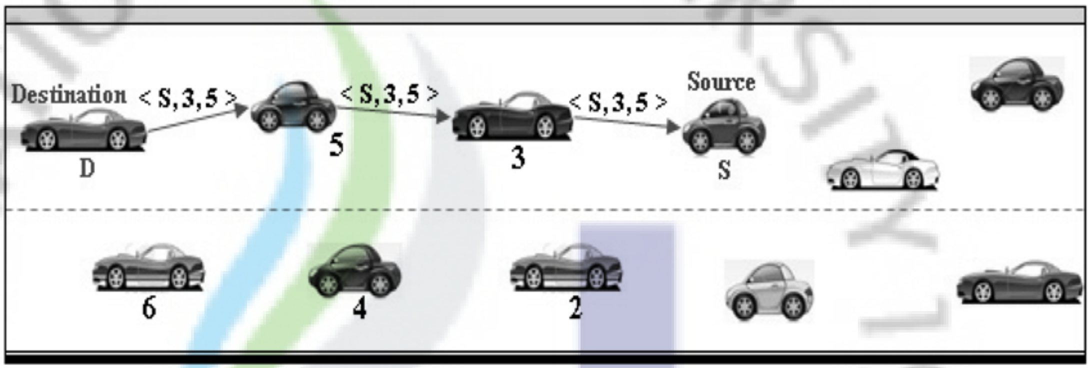

Figure 3.2.2.1 (b) Propagation of Route Reply

Figure 3.2.2.1 Route Discovery in DSR

Figure 3.2.2.1 (a) illustrates the formation of the route record as the route request propagates through the network. If the node generating the route reply is the destination, it places the route record contained in the route request into the route reply. If the responding node is an intermediate node, it will append its cached route to the route record and then generate the route reply. To return the route reply, the responding node must have a route to the initiator. If it has a route to the initiator in its route cache, it may use that route. Otherwise, if symmetric links are supported, the node may reverse the route in the route record. If symmetric links are not supported, the node may initiate its own route discovery and piggyback the route reply on the new route request. Figure 3.2.2.1 (b) shows the transmission of the route reply with its associated route record back to the source node.

3.2.2.2 Route Maintenance

DSR monitors the validity of existing routes and detects route failures based on the passive acknowledgements of data packets transmitted to neighboring nodes. When a node fails to receive an acknowledgement, a Route Error (RERR) packet is sent to the original sender to invoke a new route discovery phase. Nodes that receive RERR message delete any route entry (from their route cache) which uses the broken link. Note that RERR message is propagated only when a node has a problem to sending packets through that link. Although this selective propagation reduces control overhead, it yields a long delay when a packet needs to go through a new link.

3.2.2.3 Strength and Drawbacks

There are no table update messages due to the reactive approach employed by DSR. Routes are discovered only when there is demand of data transmission from the source. Hence there is no need to find routes to all other nodes in the network as is required by proactive routing approaches. The control overhead is further reduced by the use of route caches. However, DSR suffers from higher connection delays, possible inconsistent routes during reconstruction phase due to stale information in route caches and performance degradation in high mobility scenarios.

3.2.3 Ad Hoc On-Demand Distance Vector Routing

Ad Hoc On-Demand Distance Vector (AODV) routing [38] is a reactive protocol, even though it still uses characteristics of a proactive protocol. AODV takes the interesting parts of DSR and DSDV, in the sense that it uses the concept of route discovery and route maintenance of DSR and the concept of sequence numbers and sending of periodic hello messages from DSDV.

Routes in AODV are discovered and established and maintained only when and as long as needed. To ensure loop freedom sequence numbers, which are created and updated by each node itself, are used. These allow also the nodes to select the most recent route to a given destination node. AODV takes advantage of route tables. In these it stores routing information as destination and next hop addresses as well as the sequence number of a destination. Next to that a node also keeps a list of the precursor nodes, which route through it, to make route maintenance easier after link breakage. To prevent storing information and maintenance of routes that are not used anymore each route table entry has a lifetime. If during this the time the route has not been used, the entry is discarded.

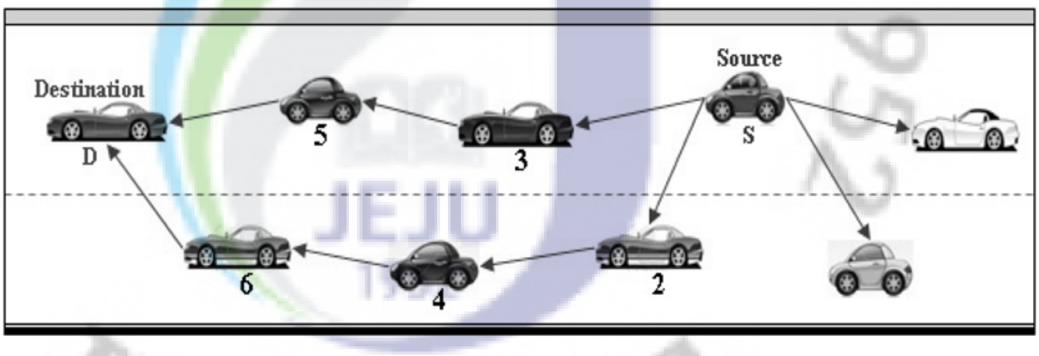

Figure 3.2.3.1 (a) Route Request Propagation

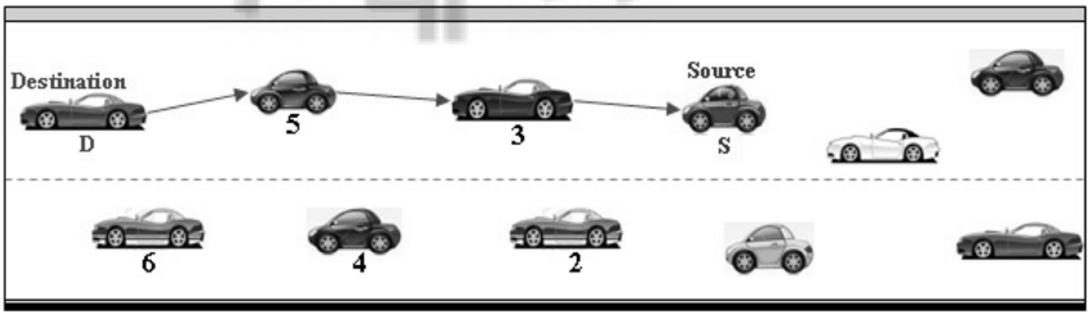

Figure 3.2.3.1 (b) Route Reply Sent Back to Source

Figure 3.2.3.1 Route Discovery in AODV

3.2.3.1 Route Discovery

When a source node wants to send a message to some destination node and does not already have a valid route to that destination, it initiates a route discovery process to locate the other node. It broadcast a route request (RREQ) packet to its neighbors, which then forward the request to their neighbors, and so on, until either the destination or an intermediate node with an active route to the destination is located. Figure 3.2.3.1(a) illustrates the propagation of the broadcast RREQ message across the network. AODV utilizes the destination sequence numbers to ensure all routes are loop-free and contain the most recent route information. Each node maintains its own sequence number, as well as a broadcast ID. The broadcast ID is incremented for every RREQ the node initiates, and together with the node's IP address, uniquely identifies an RREQ. Along with its own sequence number and the broadcast ID, the source node includes in the RREQ the most recent sequence number it has for the destination. Intermediate nodes can reply to the RREQ only if they have a route to the destination whose corresponding destination sequence number is greater than or equal to that contained in the RREQ.

During the process of forwarding the route request, intermediate nodes record in their route tables the address of the neighbor from which the first copy of the broadcast packet is received, thereby establishing a reverse path. If additional copies of the same RREQ are later received, these packets are discarded. Once the RREQ reaches the destination or an intermediate node with an active route, the destination/intermediate node responds by unicasting a route reply (RREP) packet back to the neighbor from which it first received the RREQ, shown in Figure 3.2.3.1(b). As the RREP is routed back along the reverse path, nodes along this path set up forward route entries in their route tables which point to the node from which the RREP came. These forward route entries indicate the active forward route. Associated with each route entry is a route timer which will cause the deletion of the entry if it is not used within the specified life time. Because the RREP is forwarded along the path establishing by the RREQ, AODV only supports the use of symmetric links.

3.2.3.2 Route Maintenance

When a route has been established, it is being maintained by the source node as long as the route is needed. Movements of nodes effect only the routes passing through this specific node and thus do not have global effects. If the source node moves while having an active session and loses connectivity with the next hop of the route, it can rebroadcast an RREQ. If though an intermediate station loses connectivity with its next hop it initiates an Route Error (RERR) message and broadcasts it to its precursor nodes and marks the entry of the destination in the route table as invalid, by setting the distance to infinity. The entry will only be discarded after a certain amount of time, since routing information may still be used. When the RERR message is received by a neighbor it also marks its route table entry for the destination as invalid and sends again RERR messages to its precursors.

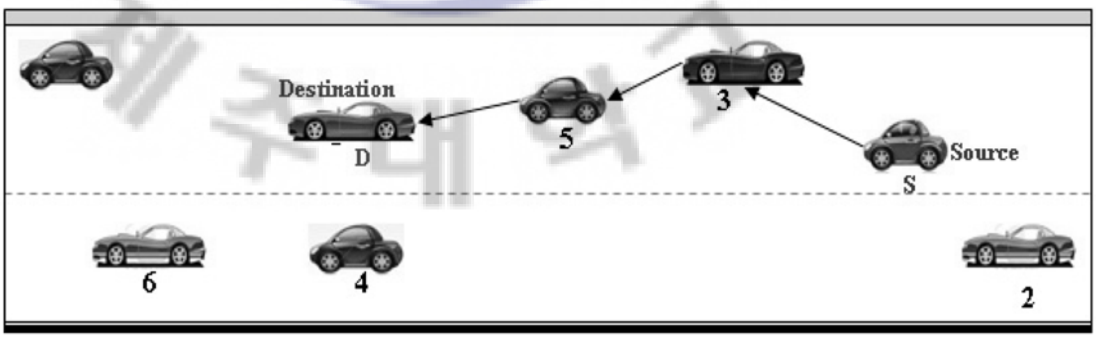

Figure 3.2.3.2 (a) Source Node Communicating with Destination

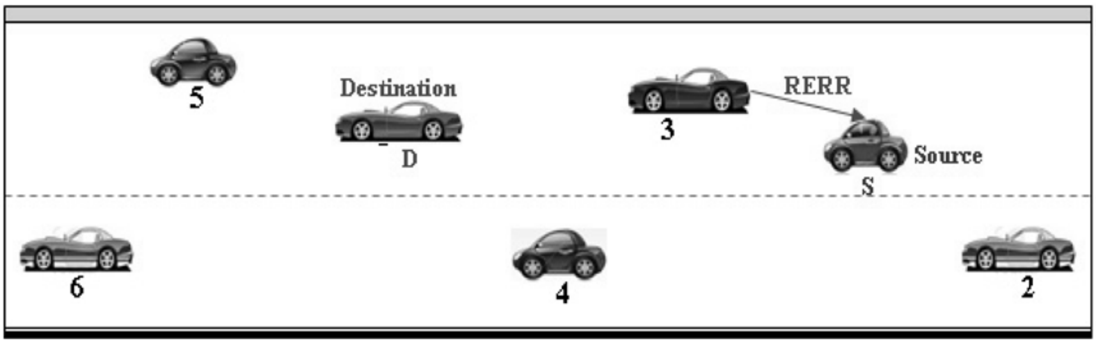

Figure 3.2.3.2 (b) Route Error Send to Source Node

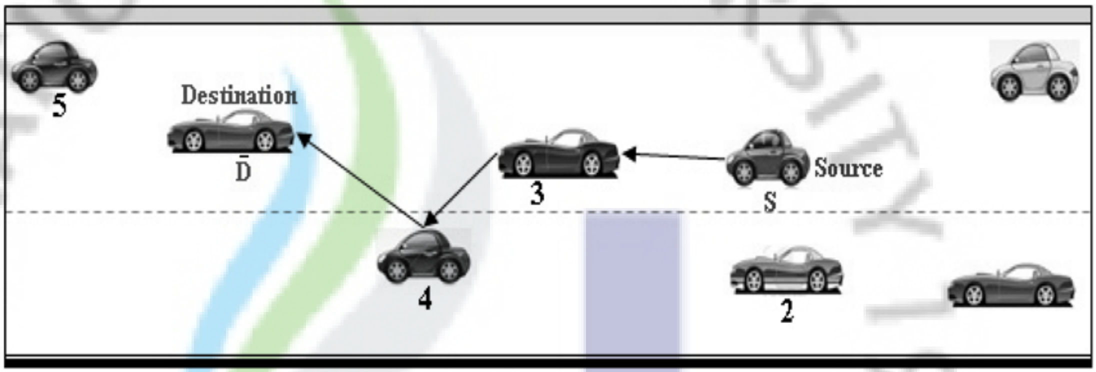

Figure 3.2.3.2 (c) New Route Discovered

Figure 3.2.3.2 Route Maintenance in AODV

In the Figure 3.2.3.2(a), source vehicle S is communicating with destination vehicle D. It can be observed that vehicle 5 moves forward to D in Figure 3.2.3.2(b) and so vehicle 3 cannot communicate with it anymore, connectivity is lost. Vehicle 3 creates a RERR message and unicasts the message to S. When the RERR is received at S and it still needs the route to the destination it reinitiates a route discovery. Figure 3.2.3.2(c) shows the new route from the S to D through vehicle 4.

Also if a node receives a data packet for a node which it does not have an active route too, it creates a RERR message and broadcasts it as described above.

If no broadcast has been send within, by default; one second, each node broadcasts Hello messages to its neighbors in order to keep connectivity up to date. These messages contain the nodes IP address and its current sequence number. So that these messages are not forwarded from the node's neighbors to third parties the Hello message has a TTL value of one.

3.2.3.3 Strength and Drawbacks

The main advantage of AODV is that routes are established on-demand and destination sequence numbers are used to find the latest route to the destination. The connection setup delay is less. One drawback of this protocol is that intermediate nodes can lead to inconsistent paths if the source sequence numbers is very old and intermediate nodes don't have the latest destination sequence number. Also periodic beaconing leads to unnecessary bandwidth consumption.

3.2.4 Dynamic MANET On demand Routing

Dynamic MANET On demand (DYMO) [39] is another reactive routing protocol that works in multi hop wireless networks. It is currently being developed in the scope of IETF's MANET working group and is expected to reach RFC status in the near future. DYMO is considered as a successor to the AODV routing protocols. DYMO has a simple design and is easy to implement. The basic operations of DYMO protocol are route discovery and route maintenance. When a node wants to discover a path to a destination node, it initiates the route discovery operation. A RREQ message is broadcast to the network. Every intermediate node participates in hop-by-hop dissemination of this message and records a route to the originator. When a destination node receives this RREQ message, it responds with a RREP message unicast toward the originating node. Every node receiving this message creates a route to the destination node and eventually this RREP message arrives at the originator of the RREQ message.

It appears that DYMO work much like the AODV routing protocol, but there is a subtle and important difference between the two routing protocols. In addition to the route about the requested node, the originator of the RREQ message using DYMO protocol will also get information about all intermediate nodes in the newly discovered path. In AODV, only information about destination node and the next hop is maintained, while in DYMO, path to every other intermediate node is also known.

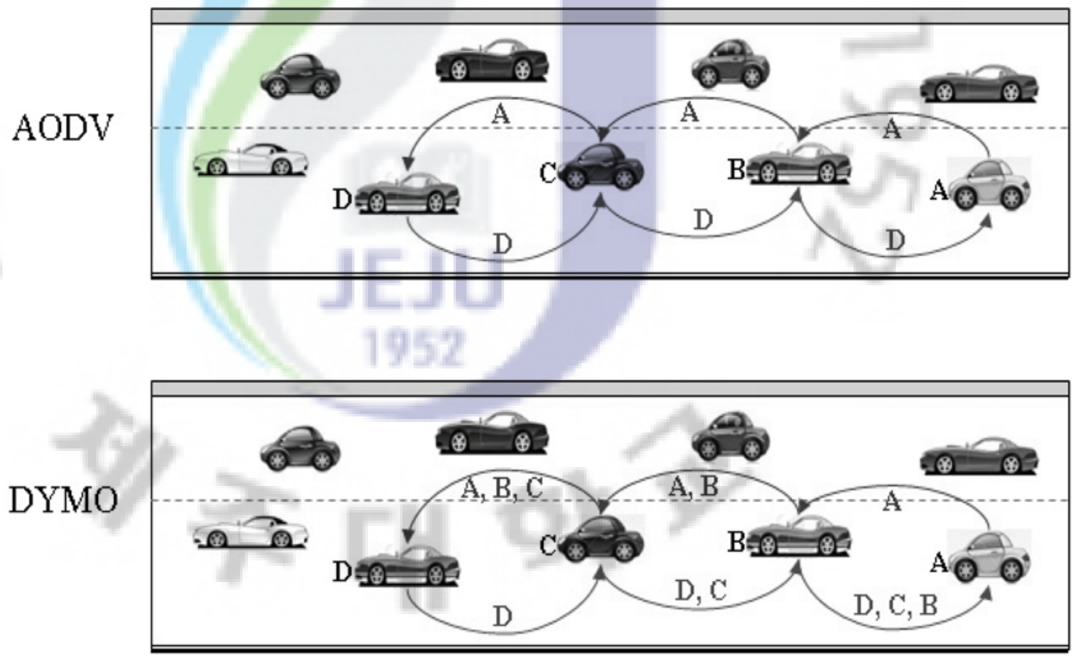

Figure 3.2.4 Comparisons between DYMO and AODV

Considering figure 3.2.4 above for the illustration of this phenomenon; In AODV, when node A initiated a route discovery process for node D, it only learned about routes to node B, its next hop neighbor, and the destination node D after route discovery process is finished. While when DYMO is used in the same scenario, node A additionally learned about the route to node C and B. This important feature in DYMO is referred to as path accumulation.

Route maintenance consists of two steps. First, in order to preserve the existing routes in use, the lifetime of the route is extended upon successful forwarding of a packet. Whenever a packet is successfully forwarded, the lifetime of the route is extended automatically to use it for further communication. Second, when a route to a destination is lost or a route to a destination is not known, then a RERR message is sent towards the packet source node, to notify it about a particular route being invalid or missing. Upon receiving RERR message the source node deletes the route. If the source node has another packet to forward for the same invalid or missing destination node, it will again initiate a route discovery process.

DYMO is envisioned to handle variety of mobility and traffic patterns. As DYMO is a reactive protocol in nature, it uses very little resources, and is ideal for memory constrained devices.

3.3 MANET Routing Protocols in VANETs

MANET Routing protocol discuss above are applicable in VANETs due to the similarities between them. Proactive protocols are easier to implement and stable compared with the reactive approaches. In the case of highly mobile environments such as VANETs, a stream of control messages is required to maintain an accurate view of network topology. This intuitively results in heavy traffic congestion, collisions of the packets due to massive broadcasting between neighboring nodes, and a significant waste of the wireless bandwidth. Therefore, reactive protocols are preferred for dynamically changing environments such as VANETs, where nodes have a fewer number of active routes. Traditionally, reactive protocols do not take into account mobility parameters during route discovery, so path break takes place often in highly mobile scenarios such as VANETs, causing too much broadcasting and flooding over the entire network to find a new route. Moreover, the additional latency introduced by the route discovery procedure poses serious challenges for the reactive protocols. For this reason, reactive protocols, in their current format, have been deemed inappropriate for time-critical applications in VANETs. A number of studies have been conducted to simulate and compare the performance of MANET routing protocols in various traffic scenarios in VANETs. Primarily because of the highly dynamic nature of node mobility, most of them are suffering from poor throughput in these scenarios.

An example of a routing protocol taking into account the mobility of vehicles, a distributed movement-based routing algorithm in VANETs is proposed in [43]. This algorithm exploits the position and direction of movement of vehicles. The metric used in this protocol is a linear combination of the number of hops and a target functional, which can be independently calculated by each node. This function depends on the distance of the forwarding car from the line connecting the source and destination as well as on the vehicle's movement direction. Each vehicle needs to implement this in a distributed manner.

A Geographic Source Routing (GSR) that assumes the availability of a street map in city environments is presented in [44]. In GSR, a Reactive Location Service (RLS) is used to get the destination position. This algorithm needs the global knowledge of the city topology as it's provided by a static street map. With the help of this information, the sender determines the junctions to which its packet will be sent by the packet using Dijkstra's shortest path algorithm. The simulation results show that GSR has better average delivery rate, smaller total bandwidth consumption, similar latency of first delivered packet with DSR and AODV. The performance of AODV and a geographic routing protocol, Greedy Perimeter Stateless Routing (GPSR) is evaluated based on the realistic vehicular scenario in [45]. Preferred Group Broadcasting (PGB) and Advanced Greedy Forwarding (ADF) techniques are also proposed to enhance the performance of reactive and geographic routing, respectively.

Basically, MANET routing algorithms assume that a sender mobile knows the location of the receiver based on the route information, which is accumulated and analyzed by a route discovery or route maintenance algorithm. However, it has to be executed whenever a source needs to transmit a data item. For avoiding the repetitive route discovery, the source can cache the previous information. Caching is one of the most common techniques to improve the performance of wired or wireless network. The performance comparison of two caching strategies on the DSR routing protocol, namely, a path cache and a link cache, is analyzed in [46]. In the path cache a complete path from a source to the destination is stored. In the link cache, a group of paths collected from previous route discovery constructs to generate a graph style data structure. Obviously, routing is an important issue and caching is one of the most efficient techniques to improve the network performance and data retrieval. An intelligent and efficient combination of routing and caching on the mobile nodes can enhance the data accessibility in the ad hoc networks.

3.4 Caching and Replication Schemes Overview

A number of studies have been conducted to improve the data access by deploying various caching and replication schemes in the wireless ad hoc network. In this section we only present cooperative cache-based data access and replica allocation methods in ad hoc network.

3.4.1 Cooperative Cache-based Data Access in Ad hoc Networks

A cache-based data access framework was proposed in [47], that describes how mobile nodes can work as request forwarding routers. Three different caching techniques were proposed: CachePath, CacheData, and HybridCache.

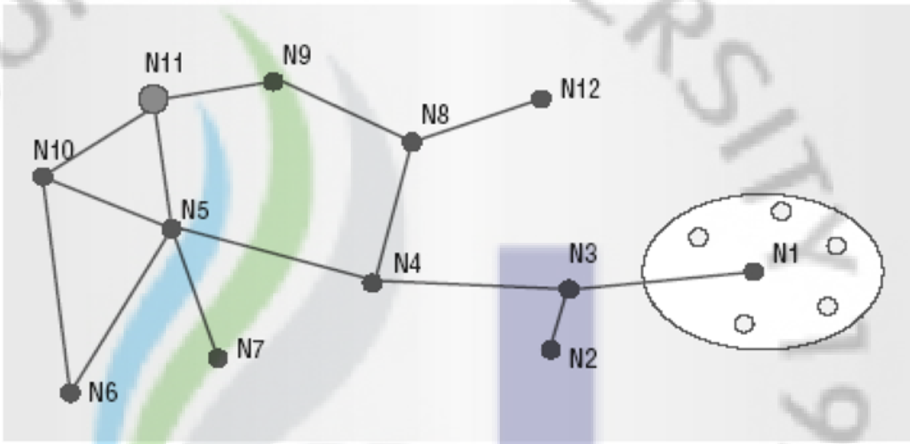

Figure 3.4.1 An ad hoc network used to demonstrate the caching techniques

In CachePath, a node need not record the path information of all passing data; rather, it only records the data path when it is closer to the caching node than the data source. An example is shown in figure 3.4.1. When node N11 forwards data *di* to the destination node N1 along the path N5-N4-N3, node N4 and node N5 will not cache *di*'s path information because they are closer to the data source than the caching node N1.

In CacheData, the router node caches the data instead of the path when it finds that the data is frequently accessed. In figure 3.4.1, if both node N6 and node N7 request data *di* through node N5, the latter might think that *di* is popular and cache it locally. N5 can then serve N4's future requests directly. However, if node N3 forwards several requests for *di* to node N11, the nodes along the path N3-N4-N5 might want to cache *di* as a frequently accessed item. Consequently, they will waste a large amount of cache space if they all cache *di*. To avoid this, a node does not cache the data if all requests for the data are from the same node.

In HybridCache, a node caches the data or path based on parameters that include the data size and data time-to-live (TTL). If data size is small, CacheData is optimal because the data item *di* only needs a small part of the available cache. Otherwise, CachePath is preferred because it saves cache space. If TTL is small, then CacheData is preferable since *di* might soon become invalid. For a large TTL value, CachePath is acceptable. Caching a data path only requires a small overhead and hence, in HybridCache, when a node caches *di* using CacheData, it also caches *di*'s path. Later, if the cached *di* becomes invalid, the validation algorithm can remove *di* but keeps the path.

With HybridCache, router nodes help other mobile nodes to get the requested data quickly. A mobile node doesn't know whether the data source or some other nodes serve its request. If multiple data sources exist, or if the mobile node doesn't know where the data source is, HybridCache might not be a good option. One possible solution may be the proactive cooperative caching, in which the requesting node actively searches for data from other nodes and the data search can go through multiple hops. Indeed, in proactive cooperative caching, the requesting node broadcasts a request to its neighbor nodes. If a node receiving the request has the data in its local cache, it sends an acknowledgment (ACK) to the requesting node; otherwise, it forwards the request to its neighbors. In this way, a request is flooded to other nodes and eventually acknowledged by the data source or a node with the cached copy. Flooding can create problems such as redundancy, contention, and collision collectively referred to as the broadcast storm problem [48].

3.4.2 Replica Allocation Methods in Ad hoc Networks

Three replica allocation methods for improving data accessibility in ad hoc networks were proposed in [49] and [50]. They all assume that each mobile host creates replicas of the data items, and maintains the replicas in its memory space. When a mobile host issues an access request for a data item *di*, the request is successful in either case: (1) the requesting host itself holds the original/replica of *di* or, (2) at least one mobile host which is connected to the requesting host with a one-hop/multi-hop link holds the original/replica. Thus, first, the requesting host checks whether it holds the original/replica of the target *di*. If it does, the request succeeds on the spot, otherwise it broadcasts the request for the target *di*. Then, if it receives a reply from another host which holds the original/replica of the target *di*, the request is also successful. Otherwise, the request fails.

The three replica allocation methods differ in the emphasis put on access frequency and network topology. They are: Static Access Frequency method (SAF), Dynamic Access Frequency and Neighborhood method (DAFN), and Dynamic Connectivity based Grouping method (DCG). In the SAF method, only the access frequency to each data item is taken into account while in the DAFN method, the access frequency to each *di* and the neighborhood among mobile hosts are taken into account. In the DCG method, the access frequency to each data item and the whole network topology are taken into account i.e. stable groups of mobile hosts are created, and replicas are shared in each group. The technique in [49] assumes that data items are periodically updated, which is not the case of [50].

The replica allocation methods replicate the data item on the requesting node. Using SAF, the replication redundancy may become enormous if a considerable number of mobile nodes frequently access the same data. Using DAFN, the redundancy is eliminated among neighbors. However, this elimination is taking place after the occurrence of redundancy. Consequently, it will consume a considerable portion of the bandwidth.

3.5 Vehicle to Road-side Data Access

Recently, researchers have been particularly focusing on the vehicle to road-side data access in VANETs. Some of the important topics such as data dissemination [14], on scheduling scheme [32], opportunistic dissemination scheme [51], etc. are discussed to improve the road-side data accessibility in VANETs. However, none of them discuss the caching techniques for enhancing the data access in 4-way intersection roads of downtown area in VANETs. Therefore, this dissertation considers the road intersections as RIS model, which would be an important area for data access in near future. Henceforth, the intersection means 4-way intersection without any further specification. Data dissemination of the RIS model with a cache scheme can improve the data accessibility in road intersections of downtown area. Also, ad hoc routing protocols for road-side data access has not been well addressed before, especially for road intersections of downtown area in VANETs. We utilize our routing protocol for route discovery in the RIS model, while the cache scheme for the RIS model is aiming at enhancing the data accessibility in road intersections of downtown area in VANETs. The details of these mechanisms are explained in the next chapter.

Chapter 4

Proposed Work

4.1 Introduction

Diversity of newly developed wireless technologies, particularly DSRC (Dedicated Short-Range Communication) have made Inter-Vehicular Communications (IVC) and Road-Vehicle Communications (RVC) possible in Mobile Ad Hoc Networks (MANETs). Vehicular Ad hoc Networks (VANETs) are a special case of MANETs. Unlike MANETs, the mobility of vehicles in VANETs, in general, is constrained by predefined roads. Vehicle velocities are also restricted according to speed limits, the level of congestion in roads, and the traffic control mechanism (for example, traffic light and stop signs). In addition, given the fact that vehicles are being equipped with communication devices with potentially large transmission ranges, renewable source of energy and extensive onboard storage capacities, processing power and storage efficiency are no longer critical issues in VANETs in contrast to the MANETs, which are usually slow in processing and have limited storage capacity. From these features, VANETs are considered as an extremely flexible and relatively "easy to manage" network pattern of MANETs [52].

VANET is an application area of MANET, formed by a collection of vehicles that interact with other vehicles and Road-side Information Station (RIS) to share local resources [53, 54]. There are many local and general resources, so vehicle-drivers often need to search when they are in the RIS area. For example, vehicle-drivers might want to receive a roadmap of a point of interest, or need to check seat availability of the road-side restaurant or parking places around the road-side area, the traffic conditions in their intended area, the weather report, etc. Such information is important for vehicle-drivers to make their travel easier, to avoid traffic congestion, or to avoid disproportionate driving. By forming an ad hoc network, a vehicle can receive information from its neighbors using multi-hop transmission relayed by the intermediate vehicles. Moreover, with the support of the RIS such as 802.11 access point located at a fixed point, vehicles can access the data stored in the RIS and with the infrastructure network access through Internet.

In the traditional data access systems, users can wait for the services from the data server for considerably higher period of time. On the other hand, in vehicular environment, the vehicles are moving fast and they stay just for a short period of time in the RIS area. In the meanwhile, the vehicle can make the best use of the RIS and share the information with as many vehicles as possible. However, a vehicle moving out of the range of a particular information station can still access the requested data the station contains, if one of the vehicles along the path to the data source has a cached copy of the requested data. Therefore, if the vehicles can work as request-forwarding routers, they can save the bandwidth and power as well as reduce the processing delays.

In the vehicular environment, many vehicles are interested to retrieve a variety of data from the RIS at the same time. RIS has the single-handed responsibility to serve the information (such as requested data processing, forwarding, maintenance, and so on) to all the requesting vehicles, while vehicles are moving fast and stay only for a short amount of time. Therefore, when the network traffic load is high, some of the vehicles are unable to send their request on-time to the RIS and are incapable of receiving the requested data from the RIS. As a result, the response time will be increased and some of the data packets will be dropped from the RIS; in general the RIS performance will decrease in a real environment.

Design issues for the development of a routing protocol for VANETs are complex owing to the frequent path disruptions caused by vehicles mobility. This mobility is constrained in vehicle's moving-direction as well as the road network layout, so it can be appropriately exploited for message propagation. There are some existing routing protocols that have been explored for applications in this domain but they need to incorporate vehicle specific features such as mobility, vehicle's moving-direction, location of information, etc. for enhancing the performance of the routing protocols. Existing MANET routing protocols do not consider above characteristics of the VANETs and therefore, are not suitable for Vehicle-to-Vehicle (V2V) or Vehicle-to-Roadside (V2R) communication over VANETs. In these protocols, when a path breaks, packet loss is inevitable and in many cases, there is a significant delay in establishing a new path. In addition to the time overhead in discovering new paths, the flooding required for the path discovery would greatly degrade the throughput of the network as it introduces a large amount of traffic, especially if the flooding is not locally directed, as in the case of Location Aided Routing (LAR) [41] protocol. However, it is possible to achieve a significant improvement by adjusting MANET routing protocols to compensate for the dynamic topology change of VANET, taking advantage of additional information such as position, speed, direction, digital road mapping, and so on.

In this dissertation, we propose a cache-augmented data distribution scheme based on the Road-side Information Station (RIS) model for enhancing the data accessibility, after designing a routing protocol referred to as Intelligent Routing protocol for Road-side Information Station (IR-RIS). This protocol maintains reliable connections between the RIS and the vehicles for road-side data access in road intersections of downtown area in

VANETs. The RIS serves the most demandable data to the requested vehicles, while intermediate vehicles relaying the item also cache it for future use. We exploit vehicle's moving-direction to find the stable paths for packet forwarding. In this protocol, RIS takes the routing decision based on the availability of data requested from a vehicle in the RIS database or the other database/Internet. This decision making procedure reduces the disturbance of RIS services and increases not only the packet delivery ratio but also the network performance. We conduct a simulation-based performance evaluation to measure the impact of the proposed cache scheme and the protocol. Simulation results shows that the proposed cache scheme improves response time, and reduces average hop count, wherein the routing protocol can remarkably reduce control traffic overhead, and improve packet delivery ratio as well as network throughput.

The rest of the chapter is organized as follows: The RIS model is presented in Section 4.2, Section 4.3 describes the basic concepts, proposed routing protocol is explained in Section 4.4, and Section 4.5 presents the cache scheme.

4.2 RIS Model

The RIS model consists of two types of nodes, namely, the data center and vehicles. We consider RIS as a data center with wireless access point. It is located in the high-traffic intersections of the downtown area, providing the infrastructure network access through wired connection. Each vehicle is equipped with a radio transceiver and a GPS receiver, by which vehicles are fully aware of their locations, speed, direction, etc. Moreover, when vehicles are equipped with an on-board navigation system, it is also assumed that each vehicle is aware of its destination through the use of preloaded digital maps. When vehicle enters the RIS area, it listens to the wireless channel. If the vehicle wants to access the data from the RIS or Internet, it can send the request directly or via intermediate vehicles to the RIS.

4.3 Basic Concept

In ad hoc networks, a data request is forwarded hop-by-hop until it reaches the data center, which sends the requested data back along the same route. On the other hand, in the case of vehicular ad hoc networks, due to the highly dynamic nature of node mobility, network topology changes quite frequently and the route breaks between the communication paths unpredictably. Therefore, after receiving the request, the RIS, or data center, might need to rediscover the route back to the requesting vehicle for replying the requested data item. In addition, it should be noted that in order to discover a route, RIS needs sufficiently accurate knowledge of vehicle's moving-direction. Hence, we group the road intersections according to the direction from the RIS, say, east, west, south, and north. In each of the group, there are two subgroups of the road: vehicles entering the RIS area, i.e., 'inbound vehicles' and vehicles leaving the RIS area, i.e., 'outbound vehicles'. In addition, there can be several lanes in each subgroup.

Suppose that in the vehicular ad hoc network (Figure 4.3.1), a RIS, *Vs*, is a data source containing a database of *n* items (*d1, d2, d3,…,dn*) and connected to the other databases through a wired network. The other nodes (*v1, v2, v3,…,vn*) are router nodes (basically vehicles). Vehicles moving in each direction of the road to (inbound) or from (outbound) *Vs* are named as east-inbound (***Ein***), east-outbound (***Eout***), west-inbound (***Win***), west-outbound (***Wout***), south-inbound (***Sin***), south-outbound (***Sout***), north-inbound (***Nin***), and north-outbound (***Nout***) respectively. In the category of inbound vehicles from each direction, the vehicles may choose any one of the three probable directional options. For example, ***Ein***-

vehicles can be moved from the east to west (*e-w*), east to south (*e-s*), or east to north (*e-n*) direction. On the other hand, outbound vehicles don't have any directional option as their destination is inside RIS area.

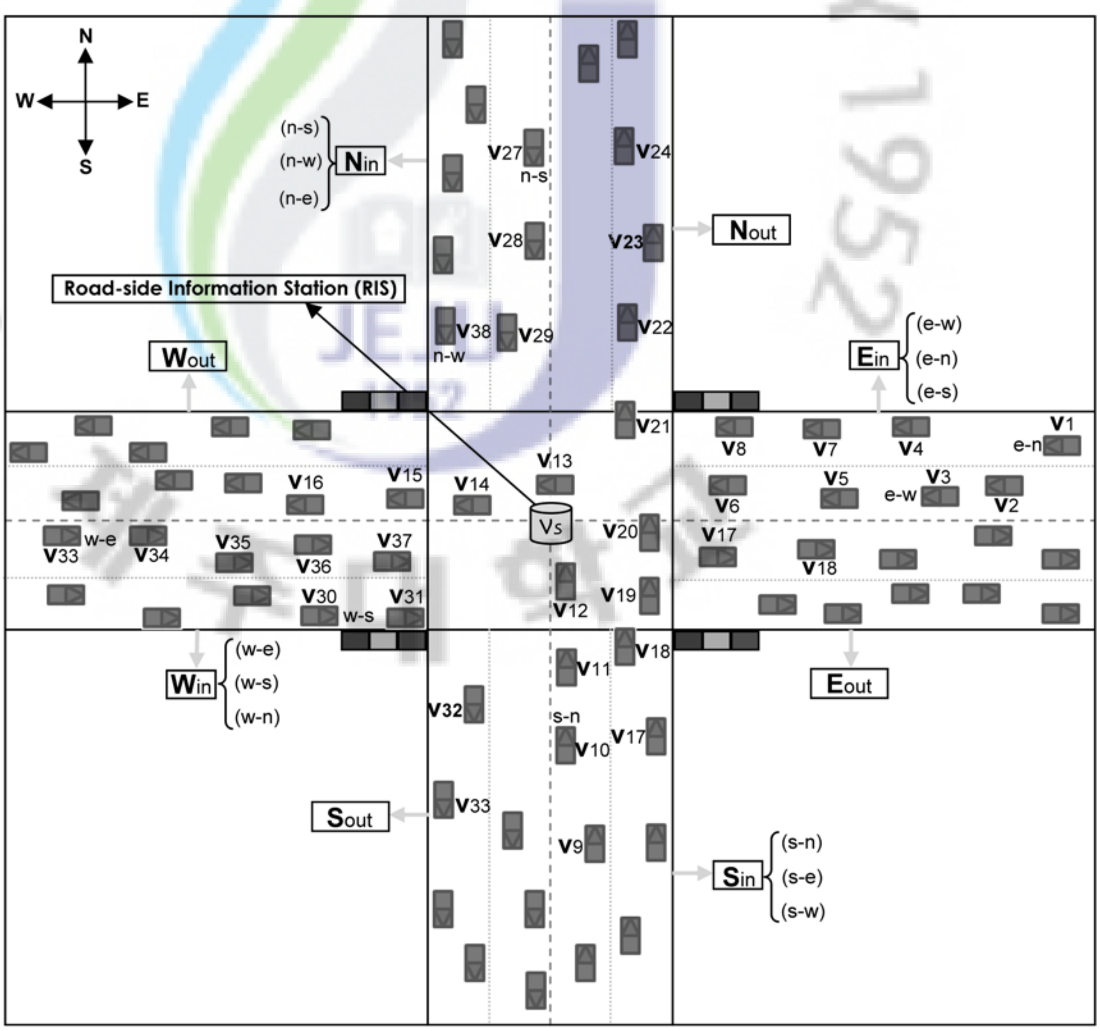

Figure 4.3.1 RIS model in road intersections of down town area in VANETs.

By grouping the roads and the vehicles, we can ensure vehicle's moving-direction to/from the RIS. Vehicles send its heading with the data request to the RIS, and based on this directional information, the RIS decides a route for sending the required data back to the requesting vehicle. This process of data communication (Vehicle-RIS/Internet-Vehicle) reduces the path disruptions, packet collisions, and ensures the data delivery.

Three different scenarios (entire scenario is taken from figure 4.3.1) are presented here to understand the data distribution process in RIS model along with the subsequent difficulty in accessing the required data.

1) Assume that *v2* enters the RIS area, requesting the data item *di* from *Vs* (RIS) via intermediate vehicles *v3-v5-v6-v20*. After receiving the request, *Vs* processes *di* and forwards it to *v2*. How to forward data items to the requesting vehicle relies on the *Vs* status. If *Vs* is idle, it will serve the data item immediately to the requesting vehicle by using the same route as requested. On the other hand, when *Vs* is busy, *Vs* will dispatch the requested data in first-in, first-out (FIFO) discipline. In this dispatching discipline, *Vs* may have to discover the new route for forwarding *di* to *v2*, based on the unique ID of each vehicle.

2) Suppose that vehicle *v1* is requesting the data item *di* from *Vs*; during this period, it might be possible that some other vehicles (say *v2, v3,…, vn*) are also willing to access *di*. In this case, *Vs* can cache *di* and distribute it to the requesting vehicles, and in the meantime, intermediate vehicles relaying *di* can also cache it. When a new request for *di* reaches any of them distributed over certain area, the request can be promptly responded at the node. Otherwise, the routing and retrieving steps are repeated for each request.

3) While leaving RIS area, one of the vehicles may need access *di*. But the requesting vehicle may have gone far away from the RIS area/range and may no longer be able to receive *di* from *Vs*.

In all three scenarios, it can be easily observed that the vehicles may access a set of data items via intermediate vehicles from *Vs* or Internet, where *Vs* has the sole responsibility for all of the data distribution. As a result, *Vs* becomes the automatic choice for each vehicle to access the required data. The concentration of multiple requests on a single RIS usually decreases the *Vs*'s performance as well as increases the network traffic load. Thus, given the challenges faced by the RIS model to efficiently access the data, a caching scheme is essentially preferred to overcome the "idle situation" in the data distribution.

4.4 Routing Algorithm

The main goal of Intelligent Routing protocol for Road-side Information Station (IR-RIS) is to maintain the reliable connections between RIS and requesting vehicles for road-side data access in road intersections of downtown area with a very low routing overhead. When a vehicle enters the RIS area and wants to access the data from the RIS, it broadcasts a request message including its id, speed, position, and moving-direction. Every vehicle knows its one-hop neighbor through a well-established neighbor discovery procedure as each vehicle periodically exchanges HELLO packets to its one hop neighbors.

This knowledge of one-hop neighbors is utilized to decide the next hop request message during the route discovery process. If the receiving vehicle has seen this request message before, it will discard it. Otherwise, the receiving vehicle will add its own address to the request packet and rebroadcast the packet. When a request message is received by the RIS, it will check whether the requested data item is available in RIS database or not. However, it is important to estimate the requesting vehicle's total staying period in the RIS area so that RIS can ensure the requesting vehicle's position is inside of RIS area as well as set the service deadline for sending the requested data. Therefore, RIS calculates requesting vehicle's total staying period in RIS area according to the speed and location of the requesting vehicle. The probable total staying period and the service deadline for requesting vehicle can be calculated by RIS as represented in figure 4.4.1.

Vehicle's total staying period in RIS area $Vtsp = \dfrac{RISns}{Vs}$

Here *RISns* is total network size of RIS and *Vs* is vehicle speed

Requesting-vehicle staying period in inbound-area of RIS $RVinsp = \dfrac{RVp}{RVs}$

Here *RVp* is requesting-vehicle position, and *RVs* is the requesting-vehicle speed

Requesting-vehicle total staying period in RIS area $RVtsp = RVinsp + \dfrac{Vtsp}{2}$

Service deadline for immediate-reply set by RIS $RISirsd = \dfrac{RVinsp}{2}$

Maximum service deadline for data serving set by RIS $RISmsd = \dfrac{RVtsp}{2}$

Figure 4.4.1 Staying period and service deadline calculation in RIS.

For example, suppose RIS network size is *1 km x 1 km*, a vehicle with *15 ms* speed stays in the RIS area for *Vtsp = 1000 m/15 ms = 66.67 s*. If the position of a requesting vehicle is *350 meters* (with *15 ms* speed) away from the RIS then the probability of requesting vehicle staying period in inbound-area of RIS is *RVinsp = 350 m/15 ms = 23.33 s*, and total staying period in RIS area is *RVtsp=23.33 s + 66.67 s/2 = 56.67 s*. Note that this type of calculation is not always true due to the distinction of the moving vehicle's speed. Therefore, RIS can set the service deadline for immediate-reply, *RISirsd = 23.33 s/2 = 11.67 s* and set the maximum service deadline for data serving, *RISmsd = 56.67 s/2 = 28.38 s*.

If the data item is available in the RIS database, it retrieves the data item and sends it immediately to the requesting vehicle. In fact, RIS does not change the routing path when the response time is within some threshold. However, to achieve this goal, the RIS must know the entire path of a route to select the path to the requesting vehicle. Therefore, we employ the source routing approach where vehicle's route information is included in the request message.

On the other hand, if the requested data is not available in the RIS, it has to search the requested data from the other databases or Internet. In this case, the RIS needs some additional time compared with its local database processing. Therefore, the RIS stores the information of the requesting vehicle such as id, speed, and moving-direction until the service deadline expires. Generally, the RIS and other databases are directly connected to Internet through high capacity cables. We assume that the information can be exchanged between the RIS and the other databases via the wired network. When the requested item is ready in the RIS, RIS initiates a route discovery to the requesting vehicle. In this new discovery, traditional routing protocol usually floods the route message to all the direction of RIS. In IR-RIS, RIS does not need to send the route request to each direction of the intersections, since it already knows the requesting vehicle's id, speed, and moving-direction. Therefore, route request message will only be sent to the requesting vehicle's moving direction for finding the route. Once the route request message reaches the requesting vehicle, a reply message will traverse back to RIS, and finally, RIS sends the requested data item to the requesting vehicle using the new route. This controlled forwarding of request packets (intelligent routing) is important in the RIS model. It is important in the sense that RIS can easily presume the current location of the requesting vehicle and reconstructs another route within a delay short enough to guarantee the reliable connection between RIS and requesting vehicles. This controlled routing mechanism is called Intelligent Routing for Road-side Information Station (IR-RIS).

In most cases, routing error recovery is necessary when a RIS fails to send requested data from its database to the requesting vehicle immediately. Because of mobility, congestion, and packet collisions, route links can be broken from time to time in VANETs. In IR-RIS, a link can be disconnected when a vehicle fails to send the packet to the next hop vehicle along the route. In this case, the vehicle which witnesses the breakage will send a Route Error (RERR) packet to the upstream direction of the route. The RERR message contains the route to the RIS and the immediate upstream and downstream vehicles of the broken link. After receiving this RERR packet, the RIS removes every entry from its route table associated with the broken link, and it will initiate the route discovery process again, taking into account the moving-direction of the requesting vehicle. It is the main difference from traditional routing protocols, where route link breakage occurs often because of the higher mobility (and also, when vehicles turn at the intersection in the RIS area) and it is necessary to initiate a route recovery mechanism, which takes relatively long time to re-establish the route breaks.

For example, in Fig. 4.4.2, *v3* enters the RIS area and wants to access a data item *di* from the *Vs*. Suppose *v3* sends a request message including its id, speed, position, and moving-direction represented by ***Ein(e-w)*** to *Vs* via *v5-v6-v20*. If *di* is available in the *Vs*'database, *Vs* processes *di* and sends it to *v3* (requesting vehicle) via *v20-v6-v5*. On the other hand, if *di* is not available in the *Vs*'database, *Vs* stores *v3's* information until the service deadline expires. As soon as *di* is retrieved from the other database, *Vs* initiates a route discovery procedure, only in *v3's* moving-direction (***Ein*** and ***Wout)*** area. When the routing path is built, *Vs* sends *di* to *v3*. This process of controlled routing mechanism ensures the higher data accessibility in RIS area.

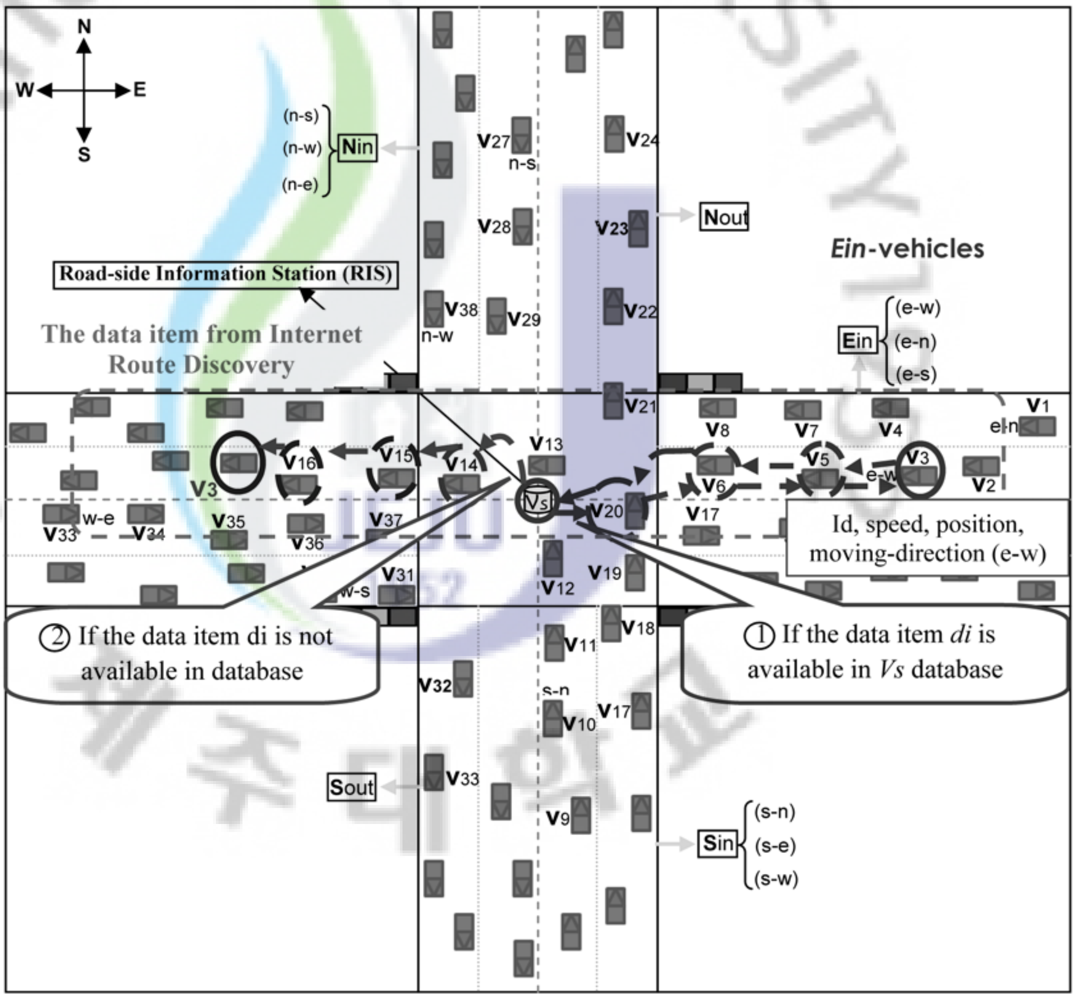

Figure 4.4.2 IR-RIS route discovery procedure in road intersections.

The pseudo code for the routing process maintenance by RIS is illustrated in figure 4.4.3. Symbol notations are taken from figure 4.4.1.

```
Procoedure RIS
   1.  SequenceNo=0;
   2.  Path=NULL;
   3.  lifetime=ServiceDeadline;
          //when RIS generates the requested data item to transmit
          //to the requesting vehicle
```

```
4.  if  there is a path from RIS to RequestingVehicle{
5.          if ((Current_time-
                 RequestingVehicle_Msg_generated_time)<
                  RISirsd)
6.              send_data(RIS_ID, RequestingVehicle_ID, path);
                 //sends requested data item to the requesting vehicle
7.          else   //new route_discovery needed
8.               store data in data_queue;
9.                   goto 11;
        }
10. else{   //no path available, begins route_discovey
11.          Sequence_No++;
12.          broadcast Route_Request_Msg(RIS_ID,
                 RequestingVehicle_moving_direction, sequenceNo,
                  RequestingVehicle_ID, path, lifetime);
        }
13. if  Route_Reply_Msg received{
        //Message contains.
        //RIS_ID, sequenceNo, RequestingVehicle_ID, path, lifetime
14.         if ((Current_time-
                 RequestingVehicle_Msg_generated_time)<
                  RISmsd)
15.            start transmitting requested data item along the path ;
16.         else
17.             discard the packet;
        }
18. if  Error_Msg received
19.         goto 11;  //invokes route_discovery
End-Procedure
```

Figure 4.4.3 Pseudo code for the routing process of an RIS

4.5 Cache Scheme

The general RIS cache scheme only deals with the data items. When a requested *di* is sent from *Vs* to the requesting vehicle, router vehicles (intermediate vehicles) cache *di* for future use. Figure 4.4.2 illustrates the cache data item concepts. Assume that vehicle *v3* enters the RIS area, and requesting *di* from *Vs*. If *di* is available in *Vs*, *di* is sent from *Vs* to the requesting vehicle *v3* via *v20-v6-v5*, while all of the intermediate vehicles (*v20-v6-v5*) cache *di* for future use. On the other hand, if *di* is not available in *Vs*, it searches *di* from the other databases or Internet and after getting *di*, *Vs* stores the data in its database for future use and initiates a route discovery to the requesting vehicle *v3*. When the route is established, *Vs* sends the data back to *v3 via v14-v15-v16* (see figure 4.4.2), whereas data passing (*di*) by intermediate vehicles *(v14-v15-v16)* makes the data cached.

If all of the intermediate vehicles between the communicating nodes (RIS and requesting vehicle) cache *di*, it is very useful for the RIS model, although it needs some space to save the data. It is constructive because vehicles individually select the directions at road intersections when they are in traffic signal area and stay temporarily in the RIS area.

Suppose that in figure 4.5.1, the intermediate vehicles *v5, v6, and v7* are waiting in front of the traffic signal of ***Ein*** area, and they commonly cache *di*. It might be possible that all of the vehicles will select the different direction of the road at intersection. If it happens, *di* will be distributed in the three (West, South, North) directions of road intersections. This gives the probability to the future requesting vehicles to get *di* in the nearby requesting vehicles in abovementioned directions of the road intersections. Therefore, by using this caching technique, data accessibility on the RIS model is improved significantly. It improves the response time as well as the network performance of the RIS. A life time value is used with the cache data items. The RIS sets this lifetime value when it generates the requesting data item to send to the requesting vehicle. If the lifetime value expires, cached data item will be automatically removed from the intermediate vehicles.

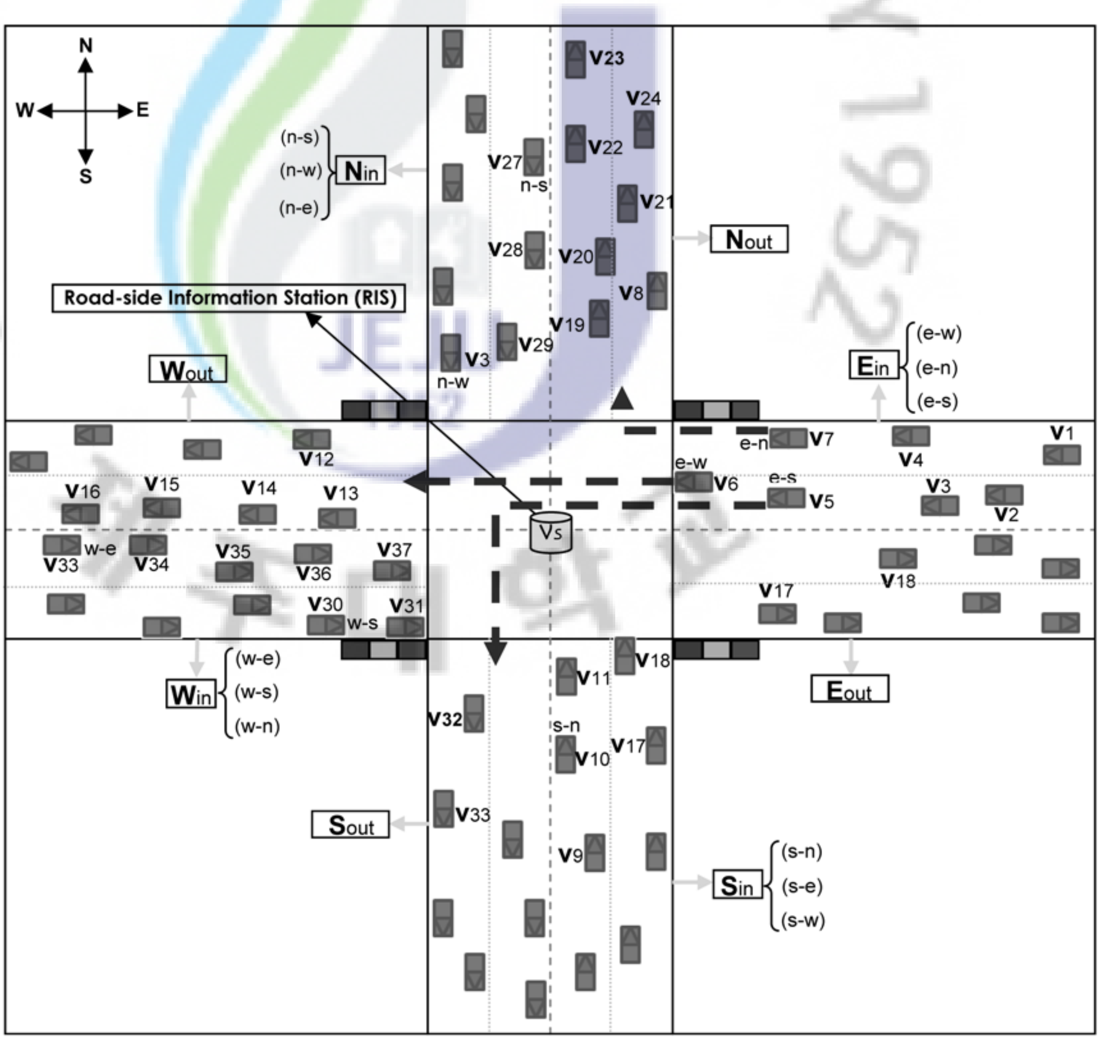

Figure 4.5.1 Caching data effectiveness in RIS area

Figure 4.5.2 illustrates the entire procedure of RIS model data disemination with intelligent routing.

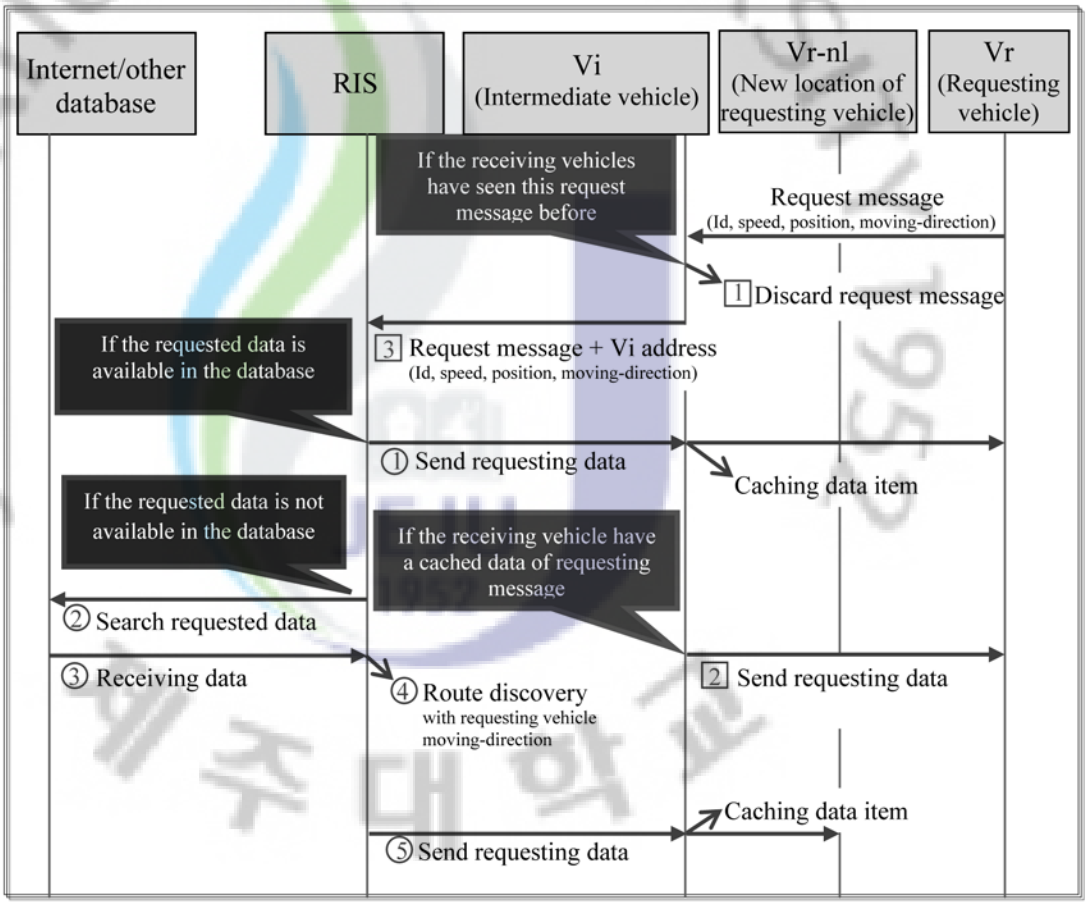

Figure 4.5.2 The entire process of RIS model data dissemination with intelligent routing

Chapter 5

Performance Evaluation

In order to demonstrate the effectiveness of cache scheme and routing protocol, we have conducted simulation using the network simulator ns-2 [55], version 2.31. At the moment we have performed comparative analysis with four well-known ad hoc routing protocols; three reactive (or on demand) routing protocols (DYMO, AODV, and DSR) and one proactive routing protocol (DSDV) are considered.

5.1 Simulation Environment

In this section, simulation scenario, environment settings, and simulation metrics are explained.

5.1.1 Simulation Scenario

The simulation scenario used for the simulation is shown in figure 5.1. The road intersections of downtown area, each with two lanes, are selected for the numerical experiment. There are fifty vehicles in total placed randomly in two-intersecting-roads scenario. An RIS is placed at the center of the intersection roads. We set a special node (SN) near the RIS to make the performance evaluation more accurate. SN interacts with another database that is wire-connected with the RIS. All vehicles move (with the speed of 5-15 ms) from one side to another side of the road during the simulation time. To generate the movement patterns, we used *setdest* utility of ns-2, developed by the Monarch Project from CMU [56]. When a vehicle reaches the end of the road, it is considered as outside-vehicle of the RIS area, and the data it has requested to the RIS will be dropped.

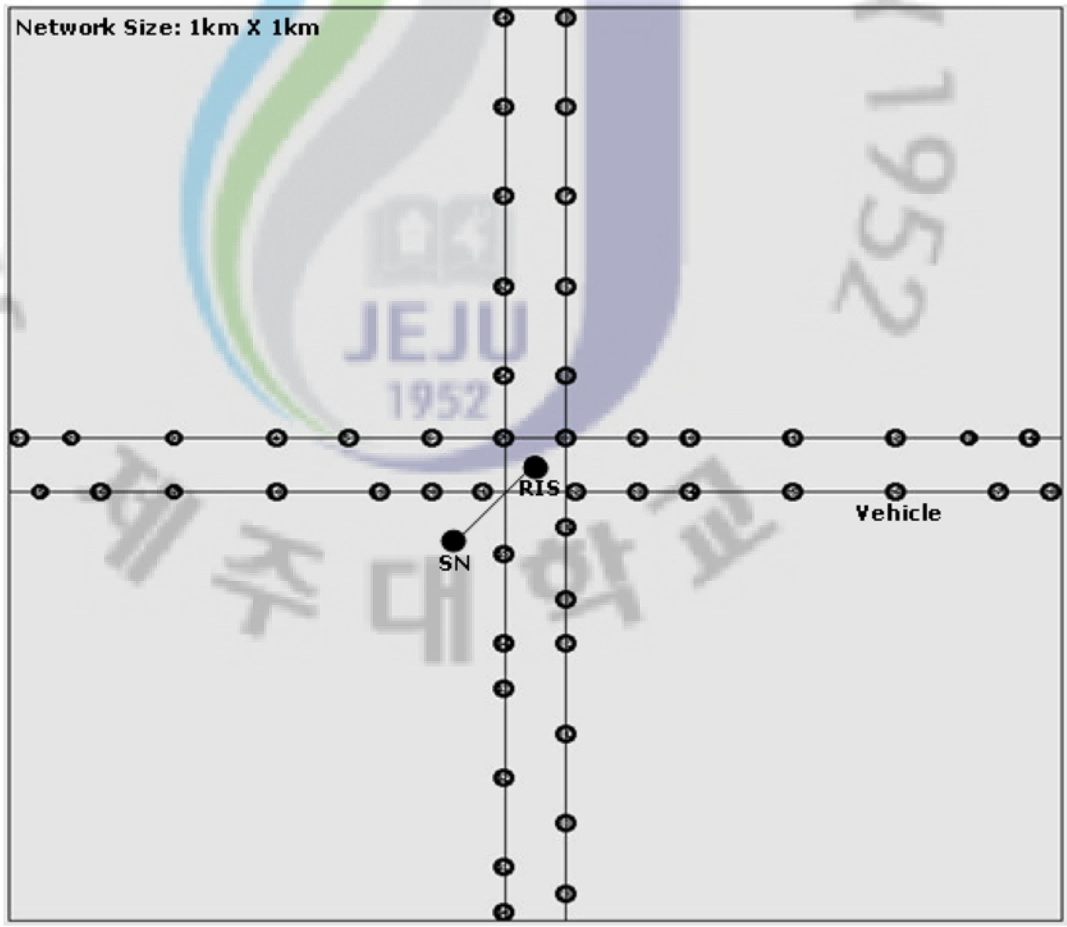

Figure 5.1 Simulation scenario of road intersection

5.1.2 Environment Settings

The basic settings of the simulation are defined for each routing protocols. These settings are fixed for all experiment. Requesting vehicles options are handle. Those options can be modified easily editing the configuration file. The environment settings are explained in table 5.1.

Table 5.1 The setup parameters used for the ns2 simulations

Parameter	**Value**
Simulator	ns-2.31
Antenna type	Omnidirectional
Propagation model	TwoRayGround
Transmission range	200m
MAC protocol	802.11 with RTS/CTS
Interface queue type	Drop-tail priority queue
Max. IFQ length	50
Vehicle count	50
Vehicle speed	5-15ms
Network size	1km × 1km
Requesting vehicles	5, 10, 15, 20, 25, 30
Simulation time	150s

We have used our own RIS application (by utilizing UDP application) as traffic generation source. Vehicles send the request message to the RIS. If the requested data is not available in the RIS, RIS sends the request to SN and collects the data. RIS data items are transmitted to the requesting vehicles and data item passing by the intermediate vehicles makes the data cached. If the cache data matches with the requested data, the cached vehicle transmits that to the requesting vehicle instead of sending it to the RIS.

5.1.3 Simulation Metrics

The following metrics are used in this dissertation to evaluate the performance of IR-RIS, DYMO, AODV, DSR, DSDV and the proposed cache scheme.

- **Packet Delivery Ratio (PDR):**
    - This metric gives the ratio of the data packets successfully received at the destination and total number of data packets generated at source. The following equation is used to calculate the PDR

      PDR = (DPr / DPs) * 100

      Where DPr is total data packet received, and

      DPs is the total data packet sent.

- **Control Traffic Overhead (CTO):**
    - The total number of routing packets transmitted during the simulation. For packets sent over multiple hops, each transmission of the (each hop) counts as one transmission. Since end-to-end Network Throughput (data routing performance) is defined as the external measure of effectiveness, efficiency is considered to be the internal measure. To achieve a given level of data routing performance, two different protocols can use differing amounts of overhead, depending on their internal efficiency, and thus protocol efficiency may or may not directly affect data routing performance. If control and data traffic share same channel and the channel capacity is limited, then excessive control traffic often impacts data routing performance.

- **Network Throughput**

    - It is defined as total number of packets received by destination. It is a measure of effectiveness of a routing protocol. Finally what matters it the number of packets delivered successfully.

- **Response Time:**

    - One important metric is the Round Trip Time (RTT). Response time is the average Round Trip Time (RTT) of successful request transactions. This is the time taken to send a packet from one end of the connection to the other and back.

- **Average Hop Count:**

    - The average hop count is the number of hops a message traverses from its source to destination.

5.2 Simulation Results

After the simulation run on the given scenario (Figure 5.1), performance metrics mentioned above are measured on DYMO, AODV, DSR, DSDV, and IR-RIS. To display results obtained by simulation we have used the program GNU Plot. The simulation results are presented in this section.

5.2.1 Packet Delivery Ratio

Packet delivery ratio is achieved by the total number of packets sent by the total number of packets received. This provides a good measure of the reliability and robustness of a routing protocol. We investigate the packets delivery ratio for 5, 10, 15, 20, 25, and 30 requester vehicles, one at a time, in case of DSDV, AODV, DSR, DYMO, and IR-RIS. Figure 5.2 (c) shows that IR-RIS outperforms the other protocols, achieving up to 17% increase compared with DSDV, 12% increase compared with AODV, 10% increase compared with DSR, and 7% increase compared with DYMO. Generally, the fewer the number of request flows, the better the protocol performance in terms of delivery ratio. Therefore, we observe a decrease in the average delivery ratio as the number of request flows increases in the RIS area. DSDV is most affected by the number of vehicles or streams, showing 24% decrease from the 5 request-flow simulation to the 30 request-flow simulation, whereas DSR has 20%, AODV and DYMO both have 15% decreases. Clearly, IR-RIS delivery ratio is higher and has the minimum decrease (10%) in the delivery ratio among the simulated protocols. In figure 5.2 (a), we can observe that when the requester vehicles are less (5 to 15), all the simulated protocols are performing well. On the other hand, when requester vehicles become higher (20 to 30 in figure 5.2 (b)), IR-RIS outperforms other protocols significantly. The reason behind the good performance of IR-RIS is that, RIS selects more reliable paths for packet forwarding exploiting the requesting vehilcle's moving-direction. It significantly reduces the probability of link breakage, packet loss is reduced accordingly.

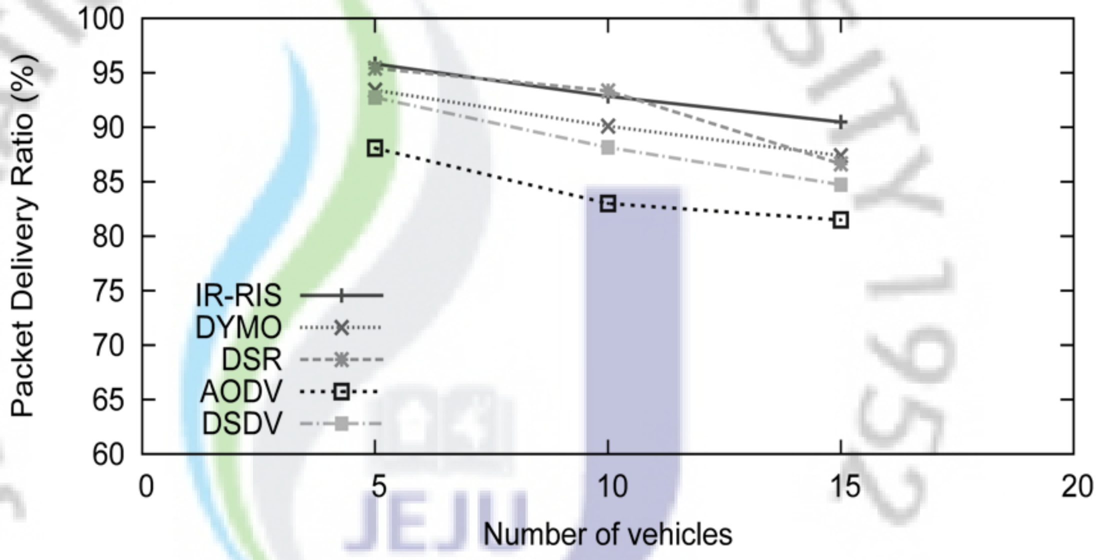

Figure 5.2 (a) PDR for 5 to 15 requester vehicles

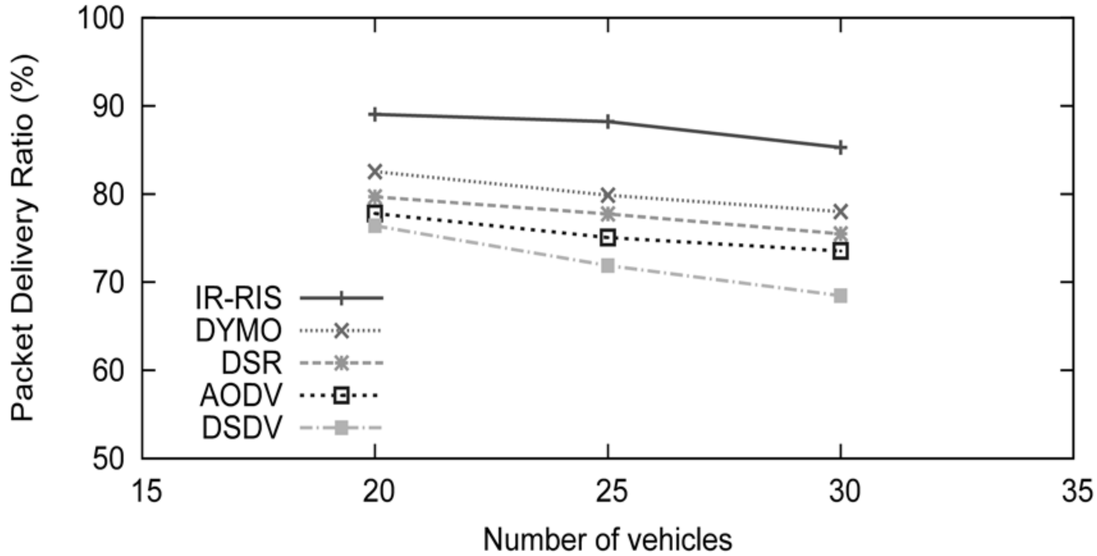

Figure 5.2 (b) PDR for 20 to 30 requester vehicles

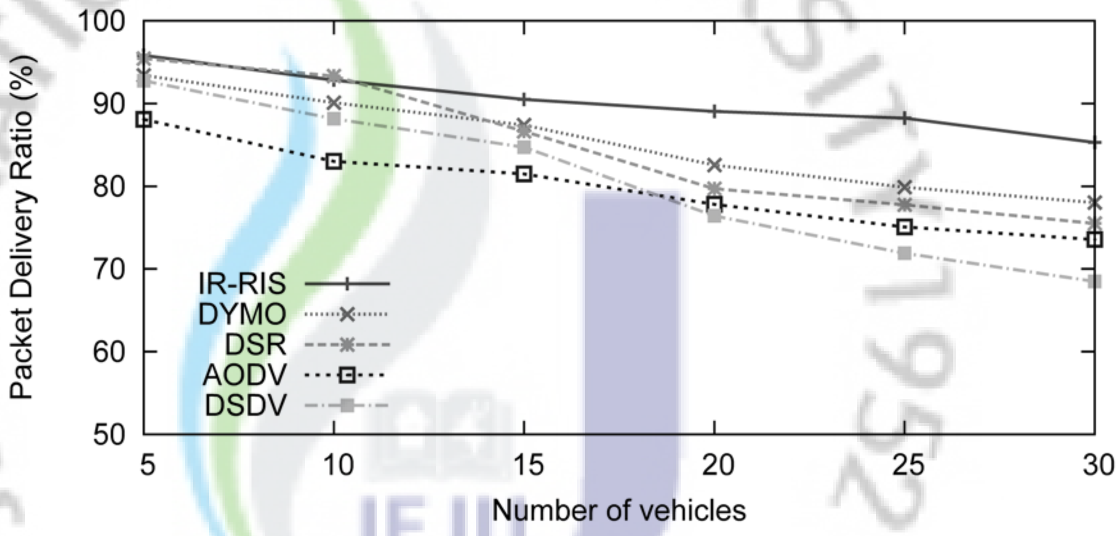

Figure 5.2 (c) PDR for 5 to 30 requester vehicles

Figure 5.2 Average packet delivery ratio for IR-RIS, DYMO, DSR, AODV, and DSDV

5.2.2 Control Traffic Overhead

Control traffic overhead or routing overhead is illustrated by the cumulative sum of routing packets generated in order to route data packets from the requesting vehicle to RIS and RIS back to the requesting vehicle throughout the duration of the simulation. Figure 5.3 shows the routing overhead of IR-RIS is significantly lower than DYMO, DSR, AODV, and DSDV. The cumulative packets at the end of simulation time is 8729 for DSR, 8410 in DSDV, 7895 in AODV, 7137 in DYMO, whereas, IR-RIS creates just 6665 packets, which is comparatively less than the other mentioned protocols. IR-RIS certainly reduces the control traffic overhead, the reduction stems from the fact that the route discovery mechanism in IR-RIS is highly optimized. Actually, in IR-RIS, RIS does not need to send a large number of RREQ and RERR packets to fix route breakages. It exploits the intersecting roads layout and the awareness of vehicle's moving direction allows establishing more stable paths with much lower overhead.

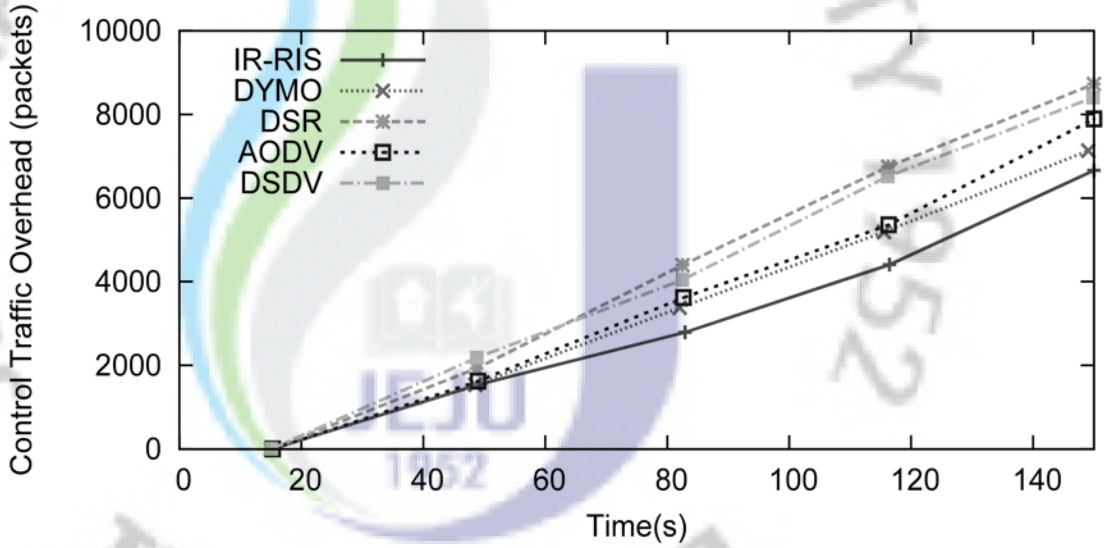

Figure 5.3 Comparative control traffic overhead for IR-RIS, DYMO, DSR, AODV, and DSDV

5.2.3 Network Throughput

Throughput is measured by the amount of pure data transferred from vehicles to a RIS as requests and from the RIS to vehicles as responses during the simulation interval. We measure the average throughput for different number of requester vehicles (5, 10, 15, 20, 25, and 30) for DSDV, AODV, DSR, DYMO, and IR-RIS. The curves in figure 5.4 show the network performance varies with the different number of requester vehicles and mobility for all mentioned protocols. The comparative analysis shows that the throughput of IR-RIS is better than those of DSDV, AODV, DSR, and DYMO. When the requester vehicle is higher in RIS area, (by comparing figure 5.4 (a) and (b)) we can observe that IR-RIS average throughput is much better compare with other simulated protocols. It is because in case of high speeds, the link breakage is highly likely to take place, when vehicles turn at the intersection in the RIS area. DSDV, AODV, DSR, and DYMO then take a long time to re-establish the route break. On the other hand, using the vehicle's moving-direction and speed, the RIS can presume the current location of the requesting vehicle and rebuild another route immediately. This reduces the number of packet drops and eventually increases the overall throughput.

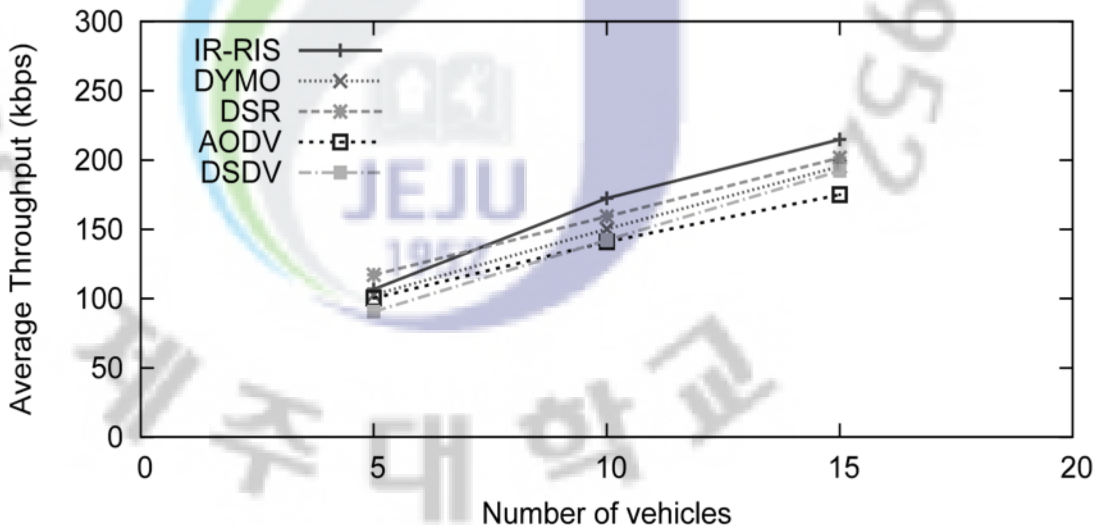

Figure 5.4 (a) Average throughput for 5 to 15 requester vehicles

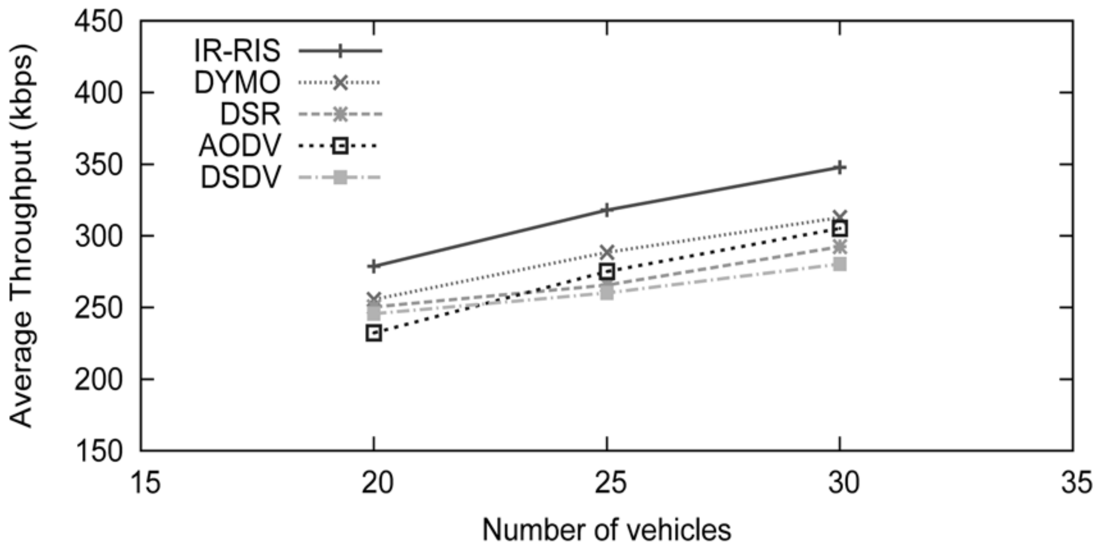

Figure 5.4 (b) Average throughput for 20 to 30 requester vehicles

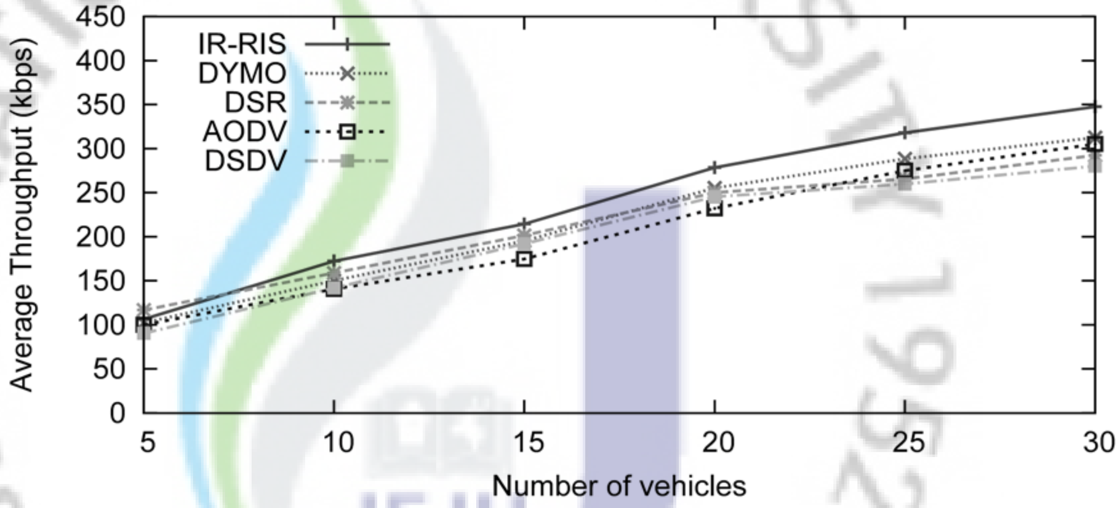

Figure 5.4 (c) Average throughput for 5 to 30 requester vehicles

Figure 5.4 Comparative throughput for IR-RIS, DYMO, DSR, AODV, and DSDV

5.2.4 Average Response Time

Response time is the average Round Trip Time (RTT) of successful request transactions. Figure 5.5 shows the comparative response time for DSDV, AODV, DSR, DYMO, and IR-RIS in case of without-cache (WoC) scheme (Figure 5.5 (a), (b), and (c)) and with-cache (WC) scheme (Figure 5.5 (d), (e) and (f)). In the both cases, we evaluate the average response time for 5, 10, 15, 20, 25, and 30 requester vehicles among simulated protocols, one at a time. In case of RIS WoC scheme, we can discover from the figure 5.5 (c) that when the number of requests increases in the RIS, response time also increases rapidly for all the simulated protocols. Actually, when the number of requests increases, the RIS starts to drop some of the packets. On the other hand, the RIS WC combination enhances the response time remarkably. In figure 5.5 (f), we can observe that DSDV, AODV, DSR, DYMO, and IR-RIS protocols perform quite well in WC scheme, compared with the WoC scheme. The reason behind this performance is that cached data in the intermediate vehicles enhances the probability that the requested data item is found nearby the requesting vehicle. Moreover, If we look after the WoC scheme (Figure 5.5 (a) and (b)) and WC scheme(Figure 5.5 (d) and (e)) graphs, it can be easily observe that simulated MANETs routing protocols are performing well in WC scheme compare with WoC scheme. In WoC scheme, IR-RIS outperforms the existing protocols because the RIS has the ability to take advantage of the vehicle's moving information for sending the requested data to the requesting vehicle, enhancing the response time. On the other hand, in WC scheme IR-RIS performance is much better because controlled forwarding in IR-RIS increases the packet delivery ratio in the RIS area and therefore, cached data items can be used more often than those of DSDV, AODV, DSR, and DYMO.

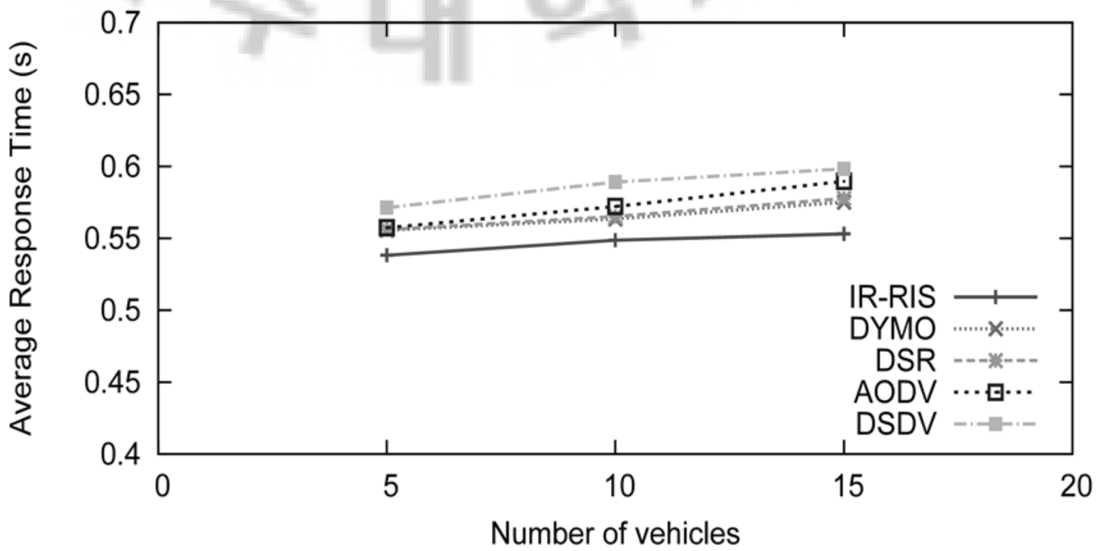

Figure 5.5 (a) Response time for 5 to 15 requester vehicles without cache

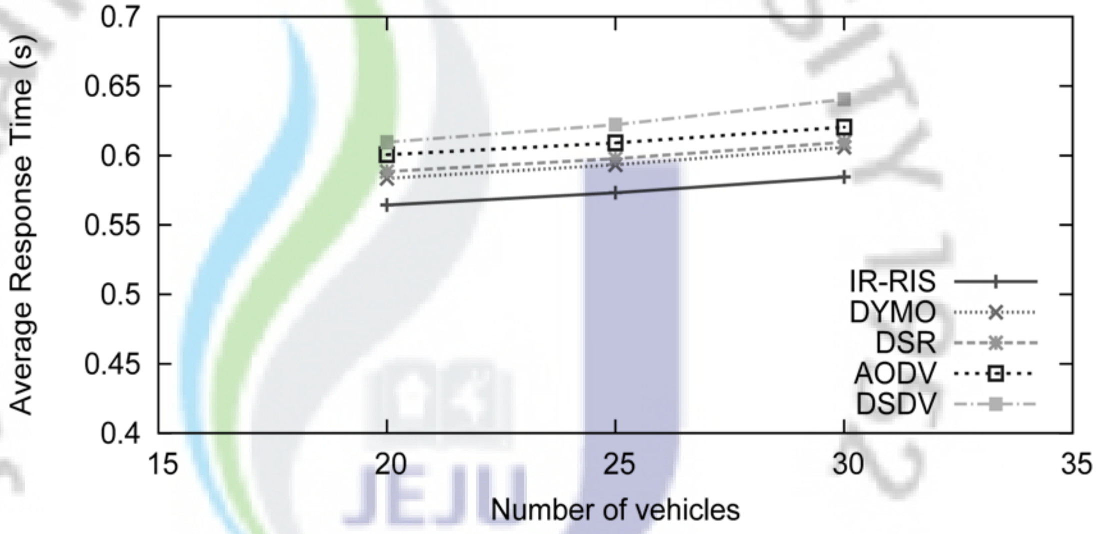

Figure 5.5 (b) Response time for 20 to 30 requester vehicles without cache

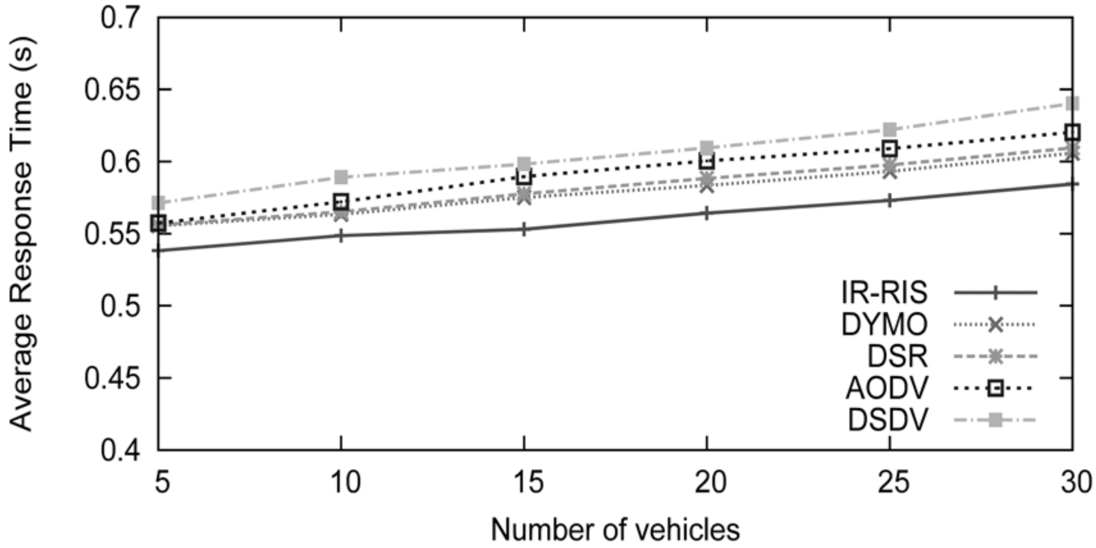

Figure 5.5 (c) 5 to 30 requester vehicles without cache

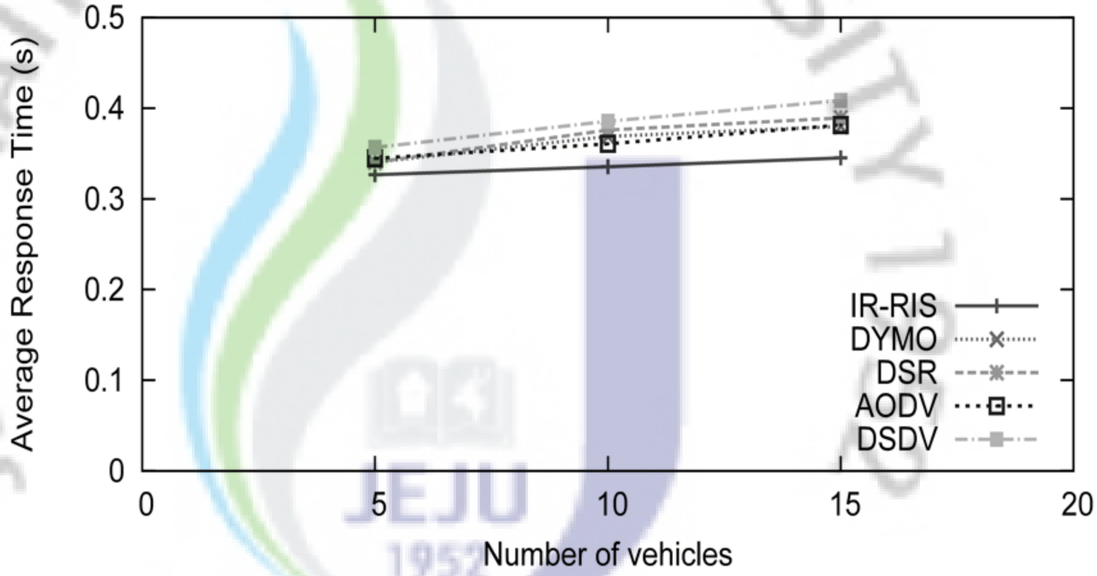

Figure 5.5 (d) Response time for 5 to 15 requester vehicles with cache

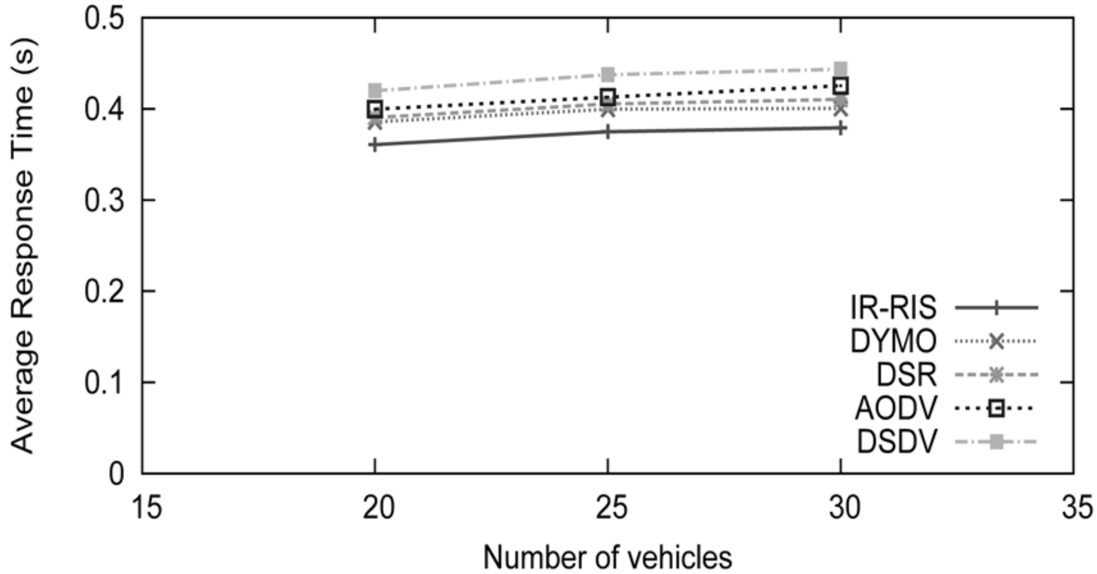

Figure 5.5 (e) Response time for 20 to 30 requester vehicles with cache

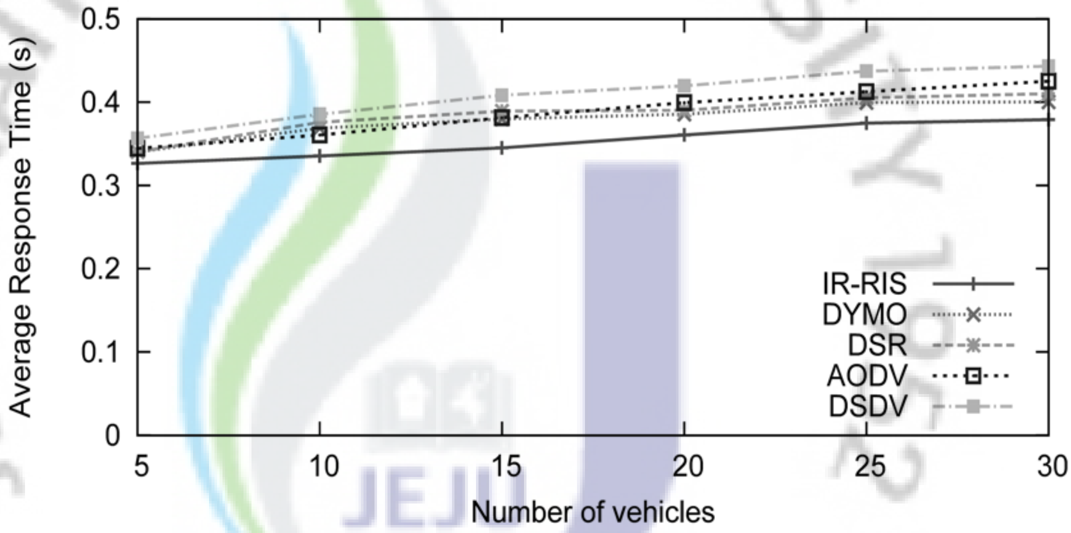

Figure 5.5 (f) Response time for 5 to 30 requester vehicles with cache

Figure 5.5 Comparative response time without cache and with cache for IR-RIS, DYMO, DSR, AODV, and DSDV

5.2.5 Average Hop Count

By average hop count, we mean the number of hops from the time when the request is issued until the requested data item is received. We have used IR-RIS with 5 to 30 requester vehicles and measured the average hop counts in 5 different simulations run for both of WoC scheme and WC scheme. Figure 5.6 clearly shows that WC scheme outperforms WoC scheme. WoC scheme illustrates the steady graph progress, as its hop counts depend on the requesting vehicles distance from the RIS. In WC scheme, when the data items are cached at the intermediate vehicles, future vehicles have the possibility to get the requested data item in the nearby requesting vehicles, therefore hop counts decreases as expected. All in all, we can summarize that IR-RIS showed the best performance in the simulated scenario. Caching scheme significantly improves response time, and reduces average hop count, wherein IR-

RIS have the lowest overhead, highest throughput, and quite fast packet delivery compared with those of DSDV, DSR, AODV, and DYMO.

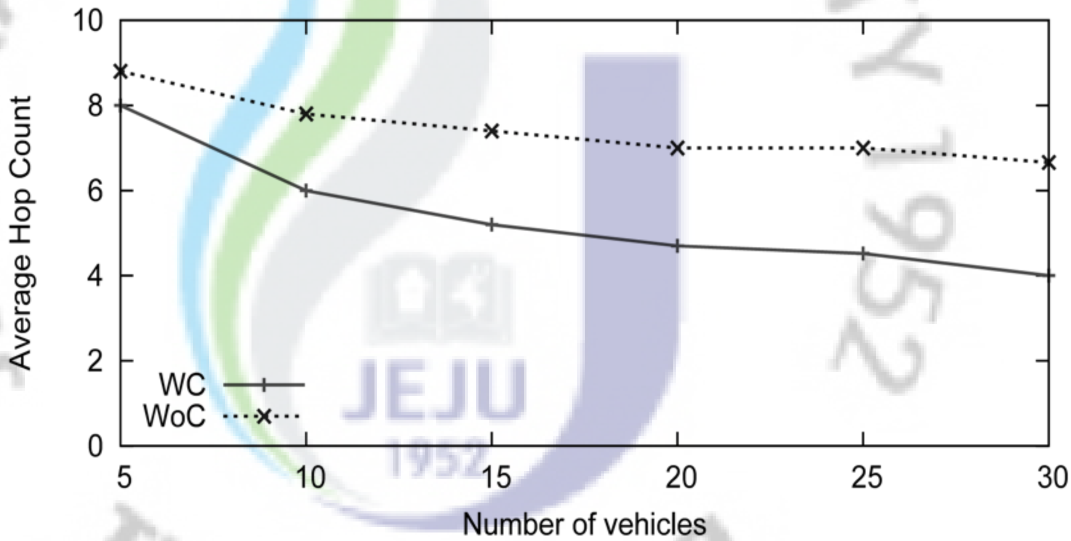

Figure 5.6 Comparative hop count for WoC and WC schemes

Chapter 6

Conclusions

6.1 Summary

In vehicular ad hoc networks data transfer is typically done with the help of multihop communication in which the high speed vehicles are acting as the data carrier. The vehicles are constrained to move on definite path depending on the road layout and the traffic conditions. In vehicular ad hoc network multihop data delivery is very complicated job because of the high mobility and frequent disconnections occurring in the vehicular networks. Recently, a lot of research articles have been published for road-side data access in vehicular environment. Most of them reflect on the city scenarios for routing or data disseminating, wherein a number of access points are needed to meet the network requirements for accessing data items from database/Internet.

Our goal is to select some specific road intersection points in the city areas, where accessing data items are extremely needed, and giving the RIS only to those of specific points. In our application-based proposed work, we don't need to set up any extra access points apart from RIS. Therefore, the number of access points can be reduced significantly in the city areas. Our proposed routing protocol is designed according to the specific application demand. The grouping roads layout from RIS allows requesting vehicle to send the vehicle moving-direction with the request message, and RIS takes the advantage of the additional information on position, speed, moving-direction, etc. to find the reliable paths for packet forwarding. After designing the protocol, we find out a combined simple cache scheme with our proposal can improve the response time greatly, and take a vital rule to reduce the burden of the RIS.

6.2 Conclusions

In this dissertation, we have proposed a cache-augmented data distribution scheme based on the Road-side Information Station (RIS) model, after designing a routing protocol referred to as Intelligent Routing protocol for Road-side Information Station (IR-RIS) for road-side data access in road intersections of downtown area in Vehicular Ad Hoc Networks (VANETs). The proposed data dissemination process in the downtown area is first investigated and after that a cache scheme is proposed for RIS model to enhance the data accessibility. The grouping roads layout from RIS allows requesting vehicle to send the vehicle moving-direction with the request message, and RIS takes the advantage of the vehicle's moving-direction to find the stable paths for packet forwarding. In the proposed protocol, RIS takes the routing decision based on the requested data availability in RIS database or other database/Internet. This decision making procedure reduces the disturbance of the RIS services, packet collisions, control traffic overhead, and increases packet delivery ratio and overall network performance. We evaluate the performance of the proposed scheme and protocol using ns-2 simulator. Simulation results show that the proposed RIS cache scheme improves the response time, and reduces average hop count, wherein the control traffic overhead, packet delivery ratio, and network performance of the proposed protocol are more efficient than those of DSDV, DYMO, AODV, and DSR.

6.3 Future Work

Vehicular Ad hoc network (VANET) is the current and near future hot topic for research, that has been targeted by many researchers for developing some applications and protocols specifically for the VANET. It is becoming a rather absorbing concept in wireless communications. This means that there is much research going on and many issues that remains to be solved. Due to limited time, research work only focuses on MANET routing protocols for comparing with the proposed protocol, and a simple cache scheme is considered for improving the data dissemination in RIS area. However, there are many issues that could be subject to future studies. Some of them are explained as follows:

- More research and development effort is required for vehicular network and traffic simulators. The available techniques have made it possible to explore and model complex simulation scenarios, but as of now these techniques are far from perfect. Real experiments are needed such as equip vehicles with wireless devices and observe dissemination performance, obtain real movement traces, design and test sample applications. Real experiments might invalidate many of the available design. With the real observation, it is possible to redesign the schemes.

- A number of studies have been conducted for improving the data access by deploying various caching and replication scheme in wireless ad hoc network. In this dissertation we utilized a simple cache scheme for improving the data access in road intersections. Performance analysis shows that caching scheme improves response time and network performance significantly in road intersections of RIS area. Cache and replication schemes need to be considered broadly for data dissemination in VANETs as they are very constructive for improving response time.

- There is not much literature on V2I/I2V communication. Some open problems are: How to deal with the cross-traffic in the pull scheme? How to utilize scheduling transmissions? How to combine push and pull model or hybrid dissemination in vehicular networks? These open problems need to be considered mostly to improve the data dissemination in VANETs.

- A very important issue that has to be considered is the security in VANETs. Routing protocols are prime targets for impersonation attacks. Security must be handled in a distributed fashion.

- What are the needs for Quality of Service in VANETs? This is related to what the vehicular networks actually will be used for.

We hope that the results contained in this dissertation will prompt further research in the field of protocol design and analysis for Road-side Information Station (RIS) in Vehicular Ad hoc Networks (VANETs), and eventually lead to the deployment of practical networks which can serve to enable intelligent transportation systems that improve road intersections data dissemination, safety and reduce the expenses associated with traffic congestion.

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