Part 1. A Study on Delay Tolerant Network Algorithm for VANET

Part 2. An Efficient MU-MIMO Precoding Operation with ZF and MMSE

A Thesis Presented

by

Taek Keun Lyu

to

The Graduate School

in Partial Fulfillment of the

Requirements

for the Degree of

Master of Science

in

Electrical Engineering

Stony Brook University

August 2016

Stony Brook University

The Graduate School

Taek Keun Lyu

We, the thesis committee for the above candidate for the

Master of Science degree, hereby recommend

acceptance of this thesis.

Dr. Xin Wang – Thesis Advisor
Associate Professor, Electrical and Computer Engineering

Dr. Fan Ye – Second Reader
Assistant Professor, Electrical and Computer Engineering

This thesis is accepted by the Graduate School

Nancy Goroff
Interim Dean of the Graduate School

Abstract of the Thesis

Part1. A Study on Delay Tolerant Network Algorithm

for VANET

and

Part 2. An Efficient MU-MIMO Precoding Operation

with ZF and MMSE

by

Taek Keun Lyu

Master of Science

in

Electrical Engineering

Stony Brook University

2016

Part 1. In this paper, we learn how to select the Delay Tolerant Network (DTN) routing protocols according to dynamic network environment in wireless ad hoc network. Basically, providing access to the Internet or other network services with low mobile density is quite difficult for disconnection and long delay. One of the solutions in this problem is using Vehicular Ad-hoc Networks (VANET) with DTN. There are a variety of DTNs, relying on the different

network environment. We categorize the DTNs routing protocols. Also, we use simulations to compare that DTN routing protocols lead to reduce end-to-end delay and higher message delivery ratio. For example, Epidemic takes disadvantages in terms of longer delay time and many bundle duplicate copies in high node density. It can lead into collisions and retransmissions. We simulate Binary Spray and Wait, and ProPHET (Probability routing protocol using history of encounters and transitivity) which has shorter delay time and less duplicated bundle receipt. We used the Network Simulator 2 (NS-2) to implement DTN protocols as Epidemic, Binary Spray and Wait and ProPHET to compare in different network environments. This simulation result presents that which routing protocol gives better performance.

Part 2. Multi-user multiple-input multiple-output (MU-MIMO) system provides higher capacity gain if the transmitter knows the channel state information (CSI). Precoding techniques require each antenna to transmit a pre-coded data. Particularly, the precoding techniques such as zero forcing (ZF) and minimum mean square error (MMSE) have been provided for optimal capacity in the system. In this paper, we compare the capacity based on different antennas numbers with ZF and MMSE. We apply the two types of precoding to multiple antennas, considering MU-MIMO downlink with varying number of users. The optimal precoding scheme is different depending on the relative relationship between the transmitter number and the receiver number. The simulation results demonstrate that different combinations of transmitting and receiving antennas have different effect on the capacity. Based on the observations from the simulation results, we propose adaptive precoding scheme for down link (DL) transmissions in order to achieve the capacity-approaching performance in different operational environments.

Dedicated to those whom I love and those who love me

Have I not commanded you? Be strong and courageous. Do not be afraid; do not be discouraged, for the Lord your God will be with you wherever you go. Joshua 1:9

Table of Contents

List of Figures

Figure **Page**

List of Tables

Tables **Page**

Acknowledgments

When I arrived at Stony Brook in January 2013, I was caught with concerns without specific reason for doubts when I can graduate from the school. However, I completed Master degree after 3 years and half already passed. I would like to express appreciation for whom I love and who loves me.

First of all, I really want to express gratitude to my advisor Professor Xin Wang during senior year and master degree. She instructed me to research by asking acuter questions and advices. Even if when I was going to opposite direction against her expectation, she did her best to teach me.

Besides my undergraduate advisor during junior year, I am grateful to Professor Petar Djuric. He guided me how to approach the research and organize a paper. Also, he allowed me to teach student in his recitation class as Teaching Assistant. Through the experience I could improve my English skills as well as teaching skills.

I would like to thank Pastor Seok who is preaching in Nanume church for giving me spiritual word from Bible. Whenever I was disappointed myself and faced obstacles from harsh study abroad such as culture difference, language barrier and lonely, he always encouraged me to recover my heart. Thus, I could be refreshed and study hard every week.

I want to greatly thank all of colleagues majoring in Electrical Engineering and from International Student Organization. I always used to get new energy by hanging out them. Moreover, I could endure all hard circumstances for their hard bondage and team spirit.

Lastly, I thank my parents and younger brother who were used to handle my questions. They always help, encourage and trust me by believing that I can overcome hardness and finally I will accomplish the final goal.

Chapter 1. A Study on Delay Tolerant Network Algorithm for VANET

1.1 Introduction

1.1.1 Motivation

Delay Tolerant Network (DTN) can be composed of occasionally-connected network for partition and with one or more set of routing protocols. The architecture of DTN network is based on high delay environment such as space communication outside earth such as Interplanetary Internet [45], that is, sensor network, wireless network, satellite network, and sonar network. They have some features/qualities such as changeable delay time, frequent disconnection and partition, high bit error rate, and unbalance data rate.

In DTN, bundle layer, which is different from Open Statement Interconnection (OSI) 7 layer, is used to organize overlay network in end-to-end message. It is called DTN node as figure 1. The bundle layer offers the functions of continuous storage to cope with abrupt network disconnection, hop-by-hop transmission with reliability, end-to-end acknowledgment, diagnosis and management of bundle packet transmission. For possible interconnection, naming function is used including different naming and addressing, and it also has security model to protect a network from an alien network without permission [44].

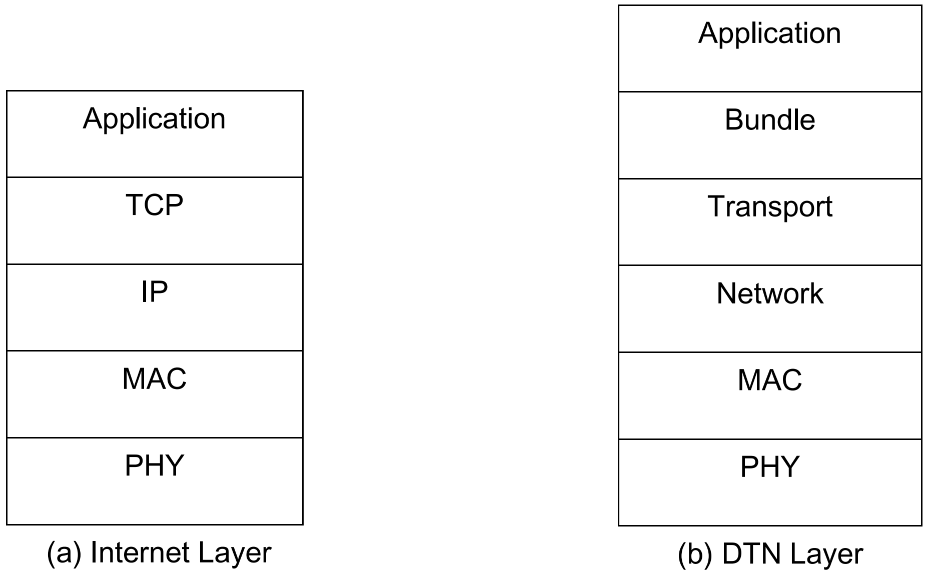


Fig. 1 Comparison between DTN and Internet layer

1.1.2 Outline

This paper is as follows organized. In Section 2, we will introduce a meaning of VANET, and its structure and features are explained. In section 3, VANET routing protocols are overviewed. In section 4, DTN is introduced with routing protocols we have simulated. In section 5, we show the simulation results with different routing protocols by using NS-2 (Network Simulation Tool). In section 6, we overview the hot issue of VANET.

1.2. VANET

Over the world, VANET study has been studied by many countries. For example, there are Vehicle Safety Consortium in the USA, Car to Car Communication Consortium in Europe, and Advanced Safety Vehicle in Japan [1]. Vehicular Ad Hoc Networks (VANETs) is a type of Mobile Ad-Hoc Network (MANET), and Ad-Hoc Network that is established by vehicles with wireless communication skills. Each vehicle is defined as communication node. The car exchange information through car to car and Road Side Unit (RSU). The purposes of the VANET study guarantee driver's safety, and offer traffic efficiency and convenience to drivers. VANET is performs communication through Multi hop between nodes without Infrastructure like MANET. However, network disconnection and frequency topology change are happened for high mobility. Thus, VANET is difficult to guarantee reliable routing. Many solutions about the problem have presented [21-30].

1.2.1 VANET features

We show differences between MANET and VANET with different aspects as follows [6].

Mobility Pattern: Mobile nodes are sending a message about the mobility pattern which is presented by the restricted vehicle's movement by the road topology, speed limit, and traffic signals. Conversely, the MANET does not consider the conditions like arbitrary pattern in VANET.

Flooding Operation: It is regarded to be the basis operation in MANET for reactive routing protocols where the route to the destination is specified by using the flooding operation. However, in VANET, in proactive routing protocols, messages are sent periodically but the destination can be changed and cannot be anticipated. It causes the wasted bandwidth and reduces the network performance in large network with a huge number of nodes.

Scalability: MANET is serving only a limited number of nodes such as 1-2 hundreds by using the routing protocols that are using to compute the path. It is not possible to store routes to other nodes in the network, as in reactive and proactive routing protocols.

Disconnective path: VANET can avoid the link breakage with the aid of the mobility pattern knowledge for neighboring nodes. However, the information is not suitable for the MANET routing protocol. It uses the periodic messages and path creating to conduct the problem of path breakages.

Non-local Function: MANET requires that all nodes participate in the operation of routing path establishment and maintenances, to create a routing table in proactive routing protocols and contribute in performing the primary flooding needs. Nevertheless, VANET requires the localization routing solution to collect information from their neighboring nodes to deal with overheads and scalability.

Using Supported Knowledge: Mobile nodes in VANET have the ability to provide vehicles with useful information that improves the performance of the routing protocols such as the predicted path, velocity, direction, and road topology in digital maps.

VANET has three different network structure types. First, WLAN/Cellular structure makes every vehicle communicate with RSU and base station but it requires expensive cost. Second, Ad Hoc structure performs car to car communication without RSU. In the case of car accident the network structure make a car send the accident information to another cars around the accident car. Thus, it can be applicable in many VANET applications. Third, hybrid structure combines

WLAN/Cellular with Ad Hoc. Even if hybrid structure is impossible to cover all street, but it can offer improved service by some of the streets that have RSU. Especially, this structure is fit to infotainment application more. The car that is not covered by RSU can communicate through Ad Hoc network [1].

Also, VANET has different features. First of all, High mobility and limited move pattern-The high speed vehicle has high mobility but the movement pattern can be expected for limited road. Second, frequent network disconnection-In rush hour, lots of vehicles are driven in the specific road for high mobility but network disconnection would arise in certain street if the street has no car. A variety of communication environment-Communication environment may be changed by traffic condition and location. GPS sensor or different sensor-Most vehicle has GPS by improved technology. Also, other traffic sensor to analyze road condition is presented.

1.2.2 Geographic-Based Routing protocols (Position-Based)

This routing protocol is very suitable for VANET for mobile nodes move depends on the Global Position System (GPS). When the data is conveyed from source node to destination node based on this protocol, the procedure is as follows. The source node primarily takes the decision of forwarding the packet; first, the destination's position is maintained by the source node in the packet header. Second, it takes the one-hop neighbor's position into consideration. The information about this position is obtained by the beacons sent periodically. Each node included in the radio range of another node is considered to be a neighbor to this node, and the geographic-based routing protocols work under the assumption that each node has information about its position, especially, with the aid of the Global Position System (GPS) unit fitted on-board unit and navigation system [45], which provides the source node with sufficient knowledge about the position of the destination node. In conclusion, geographic-based routing protocols are considered to be stronger and more suitable for a high mobility environment as in VANET.

1.3. Routing Protocols in VANET

1.3.1 Classification of Routing Protocols

VANET Routing protocol can be separated in three parts as follows: Broadcast, Geocast, and Unicast. Also, each routing protocol can be separated in different types.

1.3.1.1 Broadcast

It is forwarding data to all vehicles from a transmitter vehicle. It can be used in traffic information, emergency, road condition, and advertisement. Broadcast does not sustain routing table, and do need neighbor nodes information. It is ideal for highly mobility environment for a high reliability. Flooding is basic broadcast principle. It means that nodes receive packets broadcasts packets to all nodes. However, it wastes bandwidth by transmitting many data, and it has a less throughput by collision and errors. Thus, it is not fit to VANET has lots of node. For example, not all node broadcast but only specific node (delivery node) broadcast. Rest of the node does not broadcast when it hears that the specific node broadcast. However, the reliability can be degraded. Many alternatives have suggested overcome flooding problems as following the ways to choose forwarding node. Broadcast's different type is as follows.

A. UMB (Urban Multihop Broadcast) chooses a forwarding node depends on a distance [2].

B. Weighted p-persistance is to calculate forwarding probability p according to the distance between a node and transmission node, and determine whether it broadcast rely on p [3].

Slotted 1-persistance determines delay time, and node which has less delay time (it is far node) is selected as forwarding node, and it broadcast [3].

C. Slotted p-persistance determines broadcast probability rely on forwarding probability p [3].

D. UV-CAST (Urban Vehicular Broadcast) consider disconnected network condition [4].

1.3.1.2 Geocast

Geocast is location based multicast routing, which means a transmitter vehicle broadcast data to all vehicle in specific region. Geocast is suitable to VANET's application. For example, when car accident is happened ahead, the accident information is conveyed to only vehicles affected by the accident not all vehicles. It can grow up network efficiency. Generally, geocasting routing protocol defines the data as Zone of Relevance (ZOR). It uses flooding make all nodes receive messages in the zone. Also, it uses broadcasting by using forwarding node.

A. IVG (Intervehicle Geocast) selects critical regions according to driving direction and a car accident location. It uses distance based broadcasting to deliver a data [5].

B. DRG (Distributed Robust Geocast) establishes ZOR to receive a data, and it defines Zone of Forwarding (ZOF) to guarantee connection [6].

C. Mobicast adds time element with the spatial element of Geocast [7].

1.3.1.3 Unicast

Unicast routing conveys a data from a transmitter vehicle to the objective car. Unicast Routing protocol can be divided by four parts

A. Position-based routing

It has only location information without overhead for route maintenance process.

First of all, GPSR (Greedy Perimeter Stateless Routing) is the basic location based routing. It has the objective's location and neighbor's location by greedy forwarding. For instance, if it is deadlocked, it performs packet forwarding by Perimeter Routing. However, if it finds much closer node to the objective node, it changes the forwarding way as greedy forwarding again [8].

Second, GPCR (Greedy Perimeter Coordinator Routing) is based on that a city street and crossroad forms flat graph. Thus, it forwards packet by limited greedy routing protocol depends on street node [9].

Third, GSR (Greographic Source Routing) is when it investigates a path, it gets the location of destination by using the request and response message. It is to get the location by using street information, and dijkstra short path algorithm measures the shortest path to destination based on the lists of crossroad [10].

B. Connectivity-based Routing

In Connectivity routing protocol, the connectivity is estimated by the density of car, the pattern of space of vehicle, and wireless channel quality. Connectivity-based Routing is divided by three parts. First, LOUVRE (Landmark Overlays for Urban Vehicular Routing Environment) calculates car density by measuring neighbor node numbers meet a street node. A car density estimated deliver to another node. Second, GyTAR (Improved Greedy Traffic Aware Routing Protocol) scores at the crossroad by using car density and the distance to destination when it selects next crossroad. It forwards a packet to the crossroad with highest score [12]. Third, RBVT (Road-based Routing using Vehicular Traffic) forwards a packet through crossroad by Route Discovery (RD) and Connectivity Packet (CP) [13].

C. Stability-based Routing

To decrease overhead by frequent topology change, many metric routing protocols with stability have been suggested. Stability-based Routing has three different type routing protocol. First, MOPR (Movement Prediction based Routing) combines with general location based routing protocol and stability. It expects link's stability by neighbor node's location, speed, and direction [14]. Second, PBR (Prediction-Based Routing) also expects link's lifetime by a location, speed, and direction. Through this procedure, it expects path's lifetime [15, 16]. Third, ERBA (Energy-efficient Routing using movement) uses response mechanism for stable route investigation. When it investigates a path, it considers the location of car, direction, next direction, and the distance to crossroad to get LRS (Link Reliable Significance) [17].

D. RSU (Road Side Unit)-aided

RSU has large transmission distance and buffer. Thus, it conveys packet with more reliability. Moreover, using wire backbone get different information by interworking road side unit and traffic server. It has three different types of routing protocol. First, Infrastructure-Assisted Geo-Routing forwards a packet to road side unit nearby transmit vehicle when vehicular communicates, delivering the packet through wire routing between road side units nearby objective vehicle, and the road side unit convey the packet to the vehicle [18]. Second, SADV

(Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks) considers all crossroads with road side unit [19]. Road side unit periodically estimates delay time with neighbor road side unit by car density and speed. Third, SPRING (Social-based Privacy-preserving Packet Forwarding protocol for vehicular Delay Tolerant Networks) suggest that road side unit is installed in only crossroad with high social degree not all cross road. The high social degree means the crossroad that many vehicles pass [20].

1.4 Delay Tolerant Network (DTN)

1.4.1 Overview of Delay Tolerant Networks

Delay-tolerant networking (DTN) architecture offers support for communication scenarios where nodes are sparse and the contacts between them are short-lived, e.g., due to high node mobility. The DTN approach allows the intermediate nodes to store messages for extended period of time (i.e., carry), and to deliver messages towards destination when opportunity to forward a message becomes available. Thus, in contrast to MANET approach, the DTNs can deliver messages also when instantaneous end-to-end path between the nodes does not exist. However, many DTN routing protocols aim to ensure delivery by creating multiple message copies, which can lead to congestion and decreased performance, especially in dense networks [9].

A. Architecture and Standards

To support the heterogeneity of different networks the DTN architecture is designed to run as an overlay network over the network layer (IP in the case of the Internet). To do so, two new layers are added: The bundle layer, and the convergence layer [10]. The bundle layer encapsulates application data units into bundles, which are then forwarded by DTN nodes following the bundle protocol. The convergence layer abstracts the characteristics of lower layers to the bundle layer. The convergence layer does not need to run over the Internet protocol stack, thus allowing for the implementation of DTNs over any type of network [10].

B. Bundle Protocol

The bundle protocol stores and forwards bundles between DTN modes. Instead of end-to-end forwarding, the Bundle Protocol performs hop by hop forwarding. To deal with network disruption, the Bundle Protocol can store bundles in permanent storage devices until a new transmission opportunity appears. The concept of reliable custody transfer ensures that a DTN node will not remove a bundle from its buffer until another node has taken custody of it.

The Bundle Protocol operation depends on contact. A contact occurs when a connection between two DTN nodes can be established. The contact type depends on the type of operating network: it may be deterministic, as in Interplanetary networks, opportunistic, as in Vehicular Network (VN), or persistent, as in the Internet.

Where the size of a bundle exceeds the maximum transferred data of contacts, the bundle protocol must perform fragmentation. Fragmentation is supported in two different schemes: proactive, where a DTN node may fragment an application message into different bundles and forwards every bundle independently, and reactive, where bundles are fragmented during transmissions between nodes [10].

Why DTN Networks?

Most of the routing protocols that have been developed for VANET are assumed that there are a high number of nodes available in the network to act as intermediate nodes. However, this assumption is considered to be unrealistic because in many situations number of nodes will be very low either along the road or in some sections of the road. This will reduce the packet delivery ratio [47].

1.4.2 DTN Routing protocols for VANET

1.4.2.1 Epidemic Routing

Epidemic routing is to distribute application messages to hosts, called carriers, within connected portions of ad hoc networks. In this way, messages are quickly distributed through connected portions of the network. The routing protocol relies upon carriers coming into contact with another connected portion of the network through node mobility. At this point, the message spreads to an additional island of nodes. Through such transitive transmission of data, messages have a high probability of eventually reaching their destination. The goal of Epidemic routing is to maximize message delivery rate and minimize message delivery latency, while also minimizing the aggregate system resources consumed in message delivery [36].

In DTN, epidemic routing is a sparse network routing protocol. Each node has infinity storage space and bandwidth. It means that all node store transmitted messages during “contact” phase. This uses the concept of database replication. For example, a relay node can exchange the entire message during “contact” phase. Each node maintains list of messages in the database called summary vector. This vector is exchanged first and then only those messages are exchanged that are absent in the other’s summary vector. This epidemic strategy is practically possible in sparse network and small size message. Epidemic routing is very simple and so it is proposed to work when no better method is available. However, the epidemic strategy is that the messages continue to propagate even if the message is delivered to the destination [37].

1.4.2.2 Spray and Waiting routing

Spray and wait approach consists of two phases, spray phase and wait phase. During spray phase, each node will flood (spray) each message to L number of relay nodes when they come in subsequent contact in with each other. L is initialized by source node. If destination is encounter, message transmission is successfully terminated. Unless, wait and spray started and then relay node can deliver message only during contact phase. This strategy is controlled by parameter L which is function of node density [37].

Spray and wait routing consists of the following two phases:

A. Spray Phase: for every message originating at a source node, L message copies are initially spread – forwarded by the source and possibly other nodes receiving a copy – to L distinct “relays”.

B. Wait Phase: if the destination is not found in the spraying phase, each of the L nodes carrying a message copy performs direct transmission.

Spray and Wait combines the speed of epidemic routing with the simplicity and thriftiness of direct transmission. It initially “jump-starts” spreading message copies in manner similar to epidemic routing. When enough copies have been spread to guarantee that at least one of them will find the destination quickly (with high probability), it stops and lets each node carrying a copy perform direct transmission. In other words, Spray and Wait could be viewed as a trade-off between single and multi-copy schemes. Surprisingly, as we shall shortly see, its performance is better with respect to both number of transmissions and delay than all other practical single and multi-copy schemes, in most scenarios considered [38].

C. Binary Spray and Wait. The source of a message initially starts with L copies; any node A that has n>1 message copies (source or relay), and encounters another node B (with no copies), hands over to B $\lfloor n/2 \rfloor$ and keeps $\lceil n/2 \rceil$ for itself; when it is left with only one copy, it switches to direct transmission [38].

1.4.2.3 PRoPHET

In ProPHET (probability routing protocol using history of encounters and transitivity) protocol, delivery predictability between two nodes is calculated based on contact history between them, where higher delivery predictability implies a higher probability of future contacts between them. In PRoPHET protocol, a message is copied to a contact node only when the delivery predictability to a destination node of the contact node is larger than that of the transmitting node. By doing this, PRoPHET protocol achieves good delivery probability as well as satisfying low overhead [8].

To be specific, PRoPHET protocol uses nonrandom mobility and contact patterns in real application scenarios to copy messages to other nodes in order to improve routing performance. That is, the PRoPHET protocol is based on the fact if a node has visited a location or contacted with a node frequently, the probability of visiting the location and contacting the node is higher. To achieve, "delivery predictability" is defined at a node for every other contacted node. The delivery predictability of node A to node B is denoted by $P_{A,B}$ and the range of delivery predictability value is defined as $0 \leq P_{A,B} \leq 1$. If node A with a message to a destination node D contacts with node B, node A and node B exchange summary vectors and delivery predictability. Then, node A compares $P_{A,D}$ and $P_{B,D}$. If $P_{B,D} > P_{A,D}$, the message to destination node D is copied to node B. Otherwise, the message is not copied to node B [40].

1.4.2.4 GEODTN+NAV Algorithm

Delay Tolerant Networks (DTNs) is used in the network environment where discontinuous end to end connectivity. The routing protocols based on a store-and-carry forwarding strategy. In vehicle to vehicle (V2V) communication, the vehicles keep the packet instead of dropping the packet in communication disorder. They move and wait until appropriate mobile node appears to carry and forward the packet. Through this process, the packet can be forwarded to final destination. For longer delay and lower packet delivery ratio by store-carry-forward strategy, it is hot issue for a vehicle with packet to find the next mobile node to deliver the packet to another node which can deliver it to its destination. Specifically, GPSR which is position-based routing can be suitable in VANET environment. By fast topology change, local maximum is often happened that that mobile node cannot find the closer node than own node. Thus, delivery delay occurs. DTN is introduced with carry and forward strategy. At first, packet is delivered to its destination by greedy mode. When it reaches local maximum, it operates by using perimeter mode. As the network is disconnected in perimeter mode, the packet is sent in DTN. If hop counter is bigger than specific threshold in perimeter mode, network can be assumed as disconnection. Figure 2 depicts the transition diagram between three modes [32].

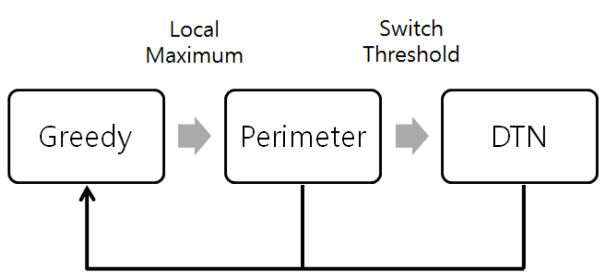


Figure 2. Switch between greedy, perimeter, and DTN mode.

A. Limited GPSR routing protocol

Greedy Perimeter Stateless Routing (GPSR) is proposed by [8]. This routing protocol has Greedy and perimeter mode. The packet is forwarded in Greedy mode from source node to neighbor node which is closest node in its boundary. Greedy mode operates as long as source node finds the neighbor node to its destination but if there is no the node in coverage area, the mode fails [8].

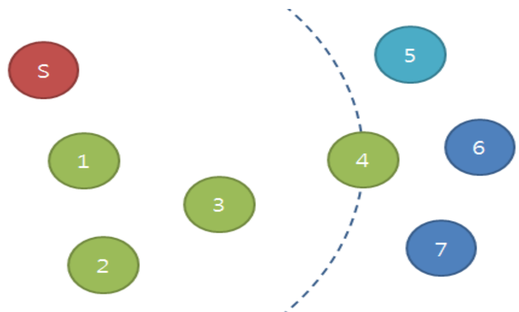


Figure 3. Greedy mode

B. Perimeter mode

Perimeter mode operates when greedy mode fails. This mode is based on right hand rule. The rule is defined as traversing the edges of the void area. The local maximum problem is happened when the source node do not find next closet neighbor node. Picking the next anticlockwise edge and continues to do the same till it reaches its destination. A node can be considered as remembering the location information of all nodes maintained at every other node followed by other geographical routing protocols [8].

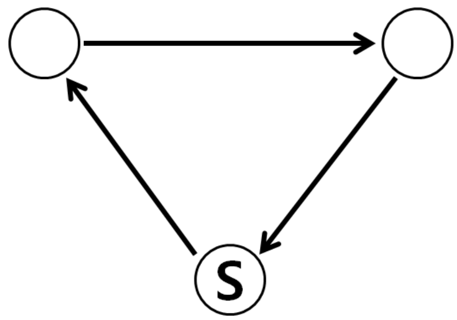


Figure 4. Perimeter mode

C. Position-Based and DTN Forwarding

1. Assumption

The research of VANET routing protocol have based on position-based routing protocol in [8],[9],[10]. In [8] GPSR is representative position-based routing protocol by using greedy forwarding. It periodically sends beacon message to neighbors node as one-hop broadcast to collect theirs position information. Greedy forwarding has to gather correct position information about its neighbor node. Also, the neighbor node has to be positioned in various directions. Thus, the forwarding is good evaluation in less mobile environment. Thus, GPSR is not suitable in city foundation for fast topology change by vehicular density.

2. MOTIVATION

Let us consider an example in Fig.5. A vehicle A node sends a packet to the destination D at the cross road C4. In terms of GPSR, vehicle C sends a data to other node but it does not have neighbor node. At the time the mode is changed to perimeter mode. However, C still does have any closer node. Vehicle C is going towards the destination D by much shorter time than the way of C1→C2→C3→C4. Vehicle B receives a data from A by GPRS. The data packet is delivered from the route of C1→C2→C3→C4 to the destination [33].

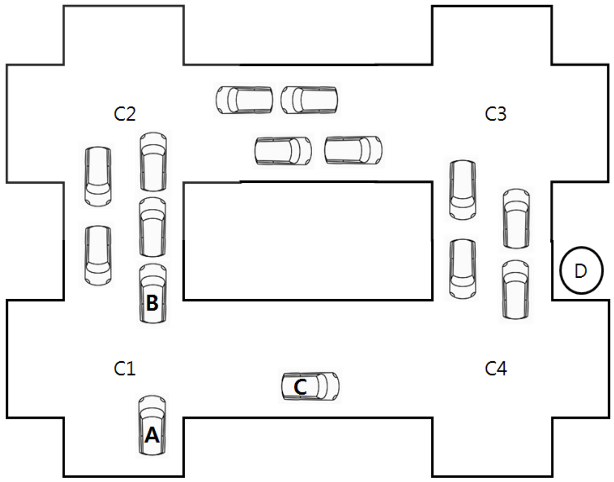


Figure.5 An example of routing problem in VANETs

D. Geographical Opportunistic Routing for Vehicular Networks (GeOpps)

We present GeOpps: geographical delay tolerant routing algorithm that exploits information from the vehicles' navigation system to route messages to a specific location. To select the next packet carrier, there are patterns as follows [34].

- Neighbor vehicles that follow suggested routes to their driver's destination calculate the nearest point that they will get to the destination of the packet.
- Afterwards, they use the nearest point and their map in a utility function that expresses the minimum estimated time that this packet would need in order to reach its destination.
- The vehicle that can deliver the packet quicker/closer to its destination becomes the next packet carrier.

Let us assume that a vehicle has a calculated route to its destination. When this vehicle is given a data packet for a specific geographical location D, it is able to calculate a nearest point (NP) on its suggested route that is its nearest point to D. In other words, it calculates the closet point to the destination of the packet that this vehicle is going to reach.

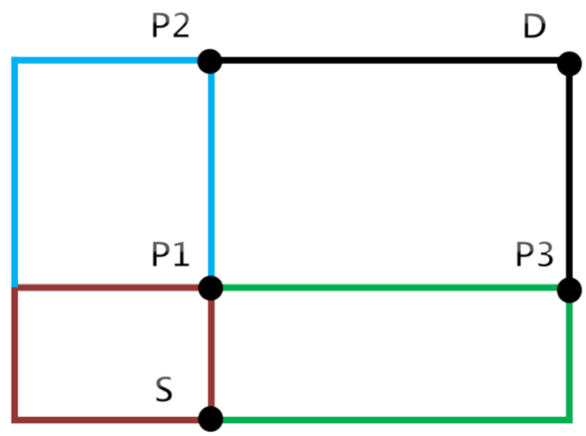


Figure 6. The calculation of the Nearest point (NP) from packet's destination.

To find NP, we assume that there are three mobile nodes which has designated route. For example, mobile node 1's route is S->P1 and round to anticlockwise. In this case, the nearest point is P1. Mobile node 2's route is S->P2 and round to anticlockwise. The nearest point is P2. Finally, mobile node 3's route is S->P1->P3, and round to clockwise. P3 is the nearest point in this case.

1.5 Performance Evaluation

We evaluate different DTN routing protocols with Binary Spray and wait (Bi-Spray and Wait), PRoPHET, and Epidemic with different range of simulation and routing parameters. The simulation result shows different delivery ratio, delay time, hop count results based on a number of nodes, velocity, packet size, and simulation width [41]. The simulation environment follows [41], and we simulate by adding another ProPHET routing protocol for it reduces end-to-end delay.

1.5.1 Mobility Types

We simulate the protocols in different mobility cases to compare them. We select random waypoint which is main mobility model in this simulation since this model is suitable to sparse environment for the mobile nodes are randomly moved. We generate random waypoint node mobility using setdest program. We have 4, 20, 40, 80 mobile nodes that choose a random direction and a random speed is from 1.5m/s to 25m/s. Area range is from 10m times to 10 m to 2500m times 2500m. In the random waypoint scenarios, the simulation time is 700 seconds [41].

We simulate the DTN routing protocols with more realistic environment with wider area, more mobile nodes and a variety of velocity. This environment is assumed to be real traffic road [41].

1.5.2 Data Packet Types

Traffic model is setting with different message sizes 10kB messages at a random time with 200 seconds intervals [t, t+200s] to another, randomly selected, node. In the DTN case, the bundles are fragmented to 1500-byte IP packets before sending them to the MAC layer. A retransmission mechanism providing reliable delivery of IP packets is implemented [41].

1.5.3 DTN

In DTN mode, the hello messages are sent in every 100ms to advertise to their buffer content to each other. In this simulation, we assume that the message have enough room for the identifiers of buffered bundles and return receipts. If the node has sufficient buffer space, a bundle can generated. For example, we select 100 MB buffer space as enough storage. Bundle life time is set to 650 seconds after all copies of the bundle will be deleted. If the sending node does not receive a return receipt within 500 seconds, it will retransmit the bundle. Antipacket (AP) lifetime is the minimum retransmission timeout (500 seconds) less bundle forwarding time and bundle life time (650 seconds) [41].

1.5.4 Wireless Channel Type

The library provides support for different transmission rates, modulation methods and coding schemes that are defined in the IEEE802.11b/g standards.

A signal-to-interference-and-noise ratio (SINR) based packet level error model is introduced. The reception threshold (RXThresh_) variable, which is used in the default 802.11 implementation, has been removed. Instead, packet error rate (PER) is used to determine random packet losses. PER is calculated using pre-determined curves of PER vs. SINR and packet size. SINR is calculated using received signal strength, noise and interference. Interference is calculated using a Gaussian model to account for all transmissions that happen simultaneously to the one which is considered for reception. Finally, strength of noise is fixed in all simulations.

The capture model, i.e., the determination of whether a packet can be received when there are other concurrent transmissions, is embedded in the aforementioned interference model. The 802.11 parameters are chosen to model 802.11g and they are listed in Table 1. Noise is set according to

$$\mathrm{Pn} = KTB,$$

Where k is Boltzmann's constant (1.38e-23 J/K), T is room temperature (290 K), and B is bandwidth (2.437 GHZ) [41].

Table 1: IEEE 802.11g related simulation parameters

Parameter	**Value**
Noise_	9.75e-12W
CSThresh_	1e-10W
Pt_	0.0178W
Freq_	2.437e6 Hz
L_	1.0
useShortPreamble_	True
gSyncInterval_	0.00001s
CWMIN_	15
CWMAX_	1023
RTSThreshold_	0B
ShortRetryLimit_	7
LongRetryLimit_	4
SlotTime_	0.000009s
SIFS_	0.000016s

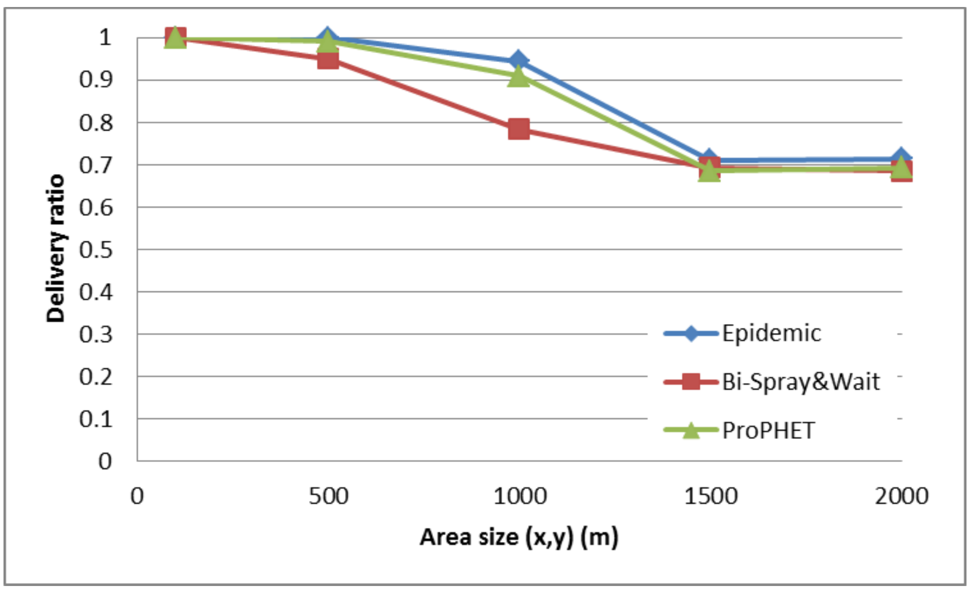
1.5.5 Simulation Results

1.5.5.1 Mobility: 40 Nodes, 10kB Messages

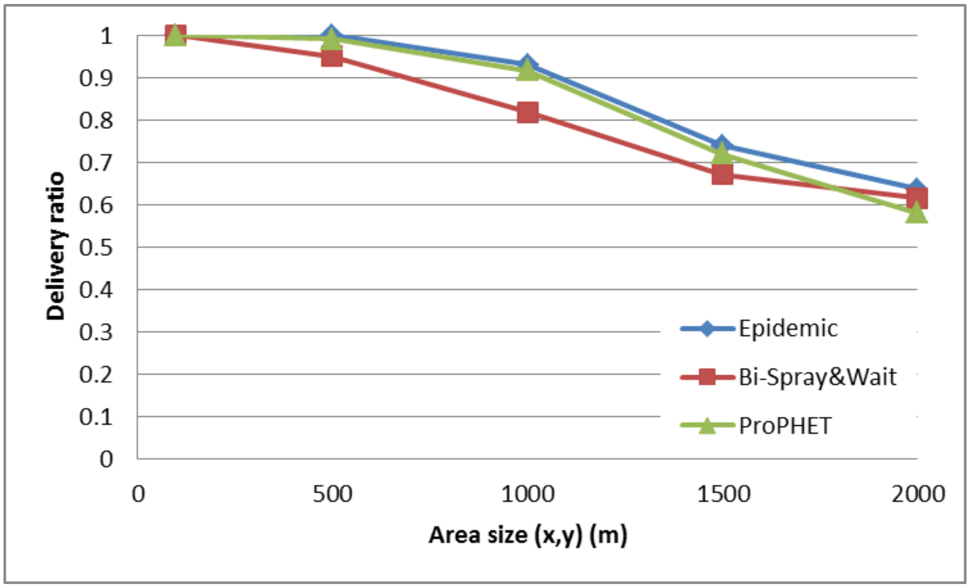
We analyze three different routing protocols with 40 mobile nodes based on random generated point, 10kB, slow mobility (Average speed: 5m/s) and fast mobility (Average speed: 20m/s). In Figure 7 (a) and (b), it shows that the routing protocols tend to have low delivery ratio in large area. It means mobile nodes have frequently dropped packets in sparse mobile environment for the large area and slow velocity. Mobile nodes store packets until theirs (Time to Live) TTLs expire. The nodes have less probability to face another node to convey the packet for slow velocity in low mobile density. However, the high mobile nodes have relatively more faced another node to transfer the packets. For example, Epidemic protocols entirely outperform other two protocols over the size of area as 15 percent higher at 1000 x 1000m. Conversely, the delivery ratio is not a problem in smaller are size for all nodes often communicate each other. Thus, most of packets sent are transferred within TTL.

Figure 7. (c), (d) show how end-to-end delay is changed over area. Theoretically, the larger size, the longer delay because enlarged size make a mobile node take a longer delay time. For example, source node routinely meets the intermediate node to transfer a packet to destination node in small area but the mobile nodes are widespread in large are size. We have the same result as theoretic expectation. From those figures, epidemic gives the best performance in terms of end to end delay. For example, in low velocity, a source node transfers its packet to a destination node for shorter time as 40 seconds by using epidemic routing protocol at 1000 x 1000m.

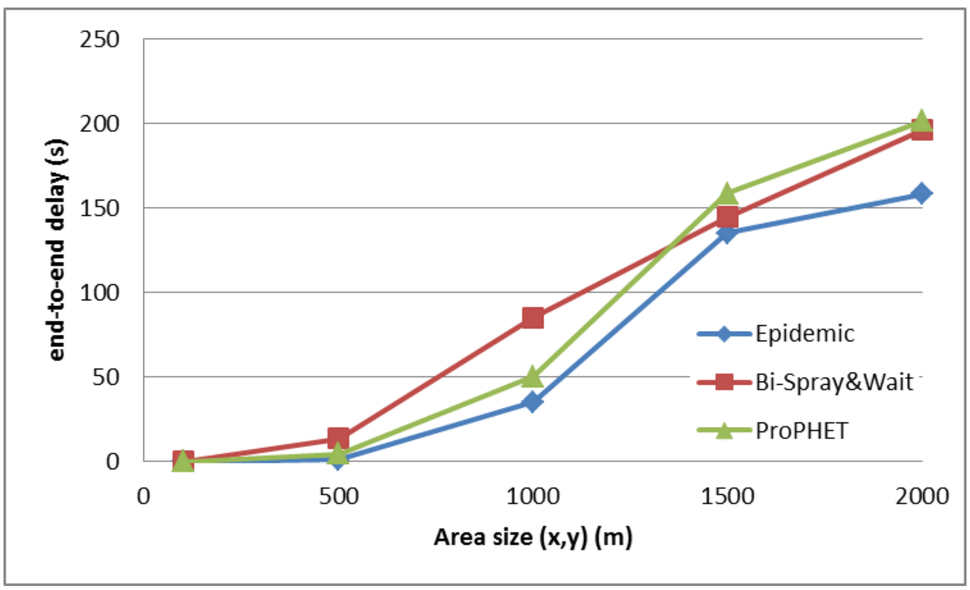
A hop is portion of the path between source and destination. In hop count figure 7. (e), (f) demonstrate that the hop count is increasing and decreasing in different area. Increasing hop count means a number of nodes passed between intermediate nodes are increasing. The hop count is increasing until 1000m time 1000m but the count is decreasing over enlarged area. In sparse environment, it is hard for mobile nodes to find another node to give its packet. Thus, even if a source node has a packet till TTL, the node drops the packet after the time. Thus, the hop count is decreasing.



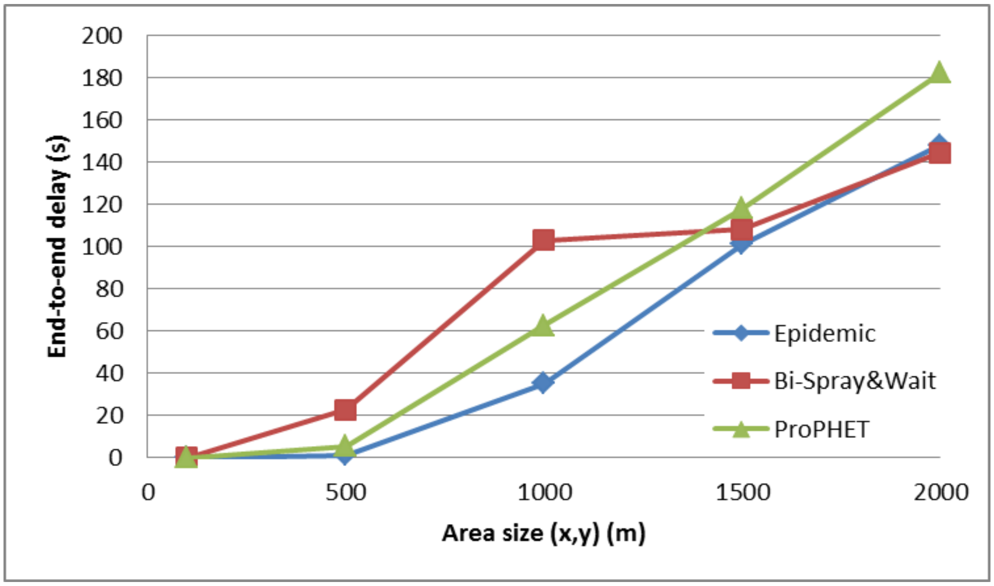
(a) Delivery ratio, Slow mobility (5m/s)



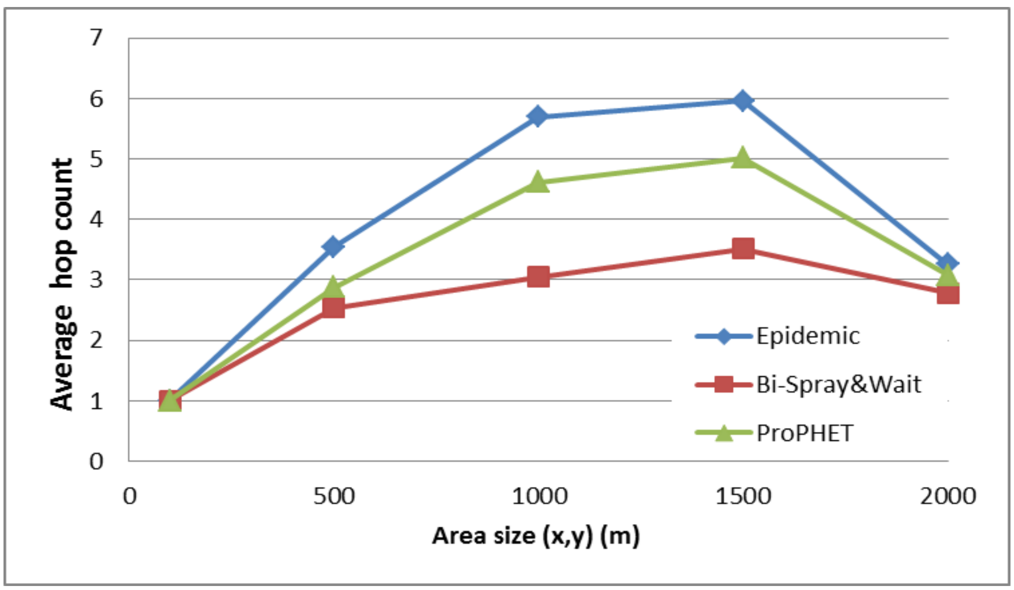
(b) Delivery ratio, Fast mobility (20m/s)



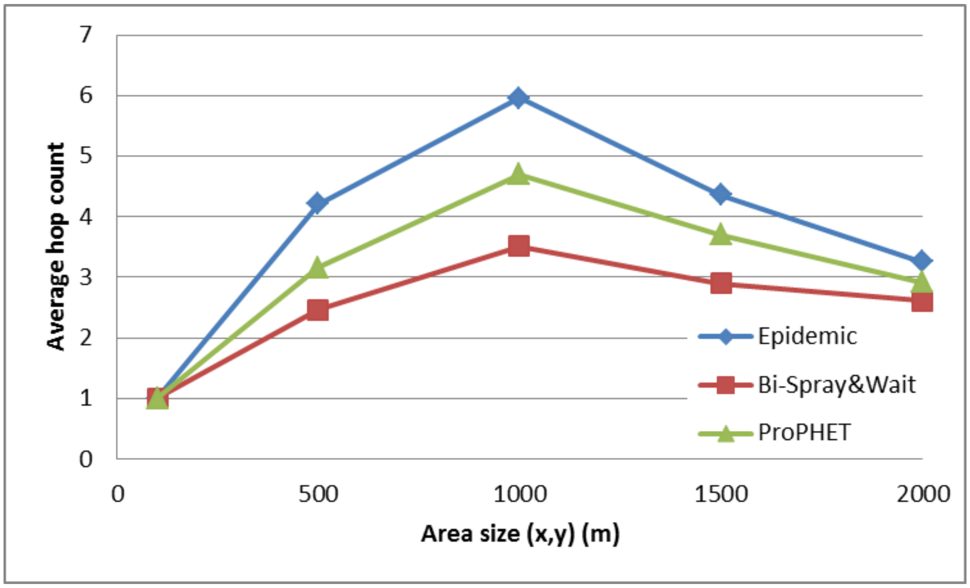
(c) End-to-end delay, Slow mobility (5m/s)



(d) End-to-end delay, Fast mobility (20m/s)



(e) Average Hop count, Slow mobility (5m/s)



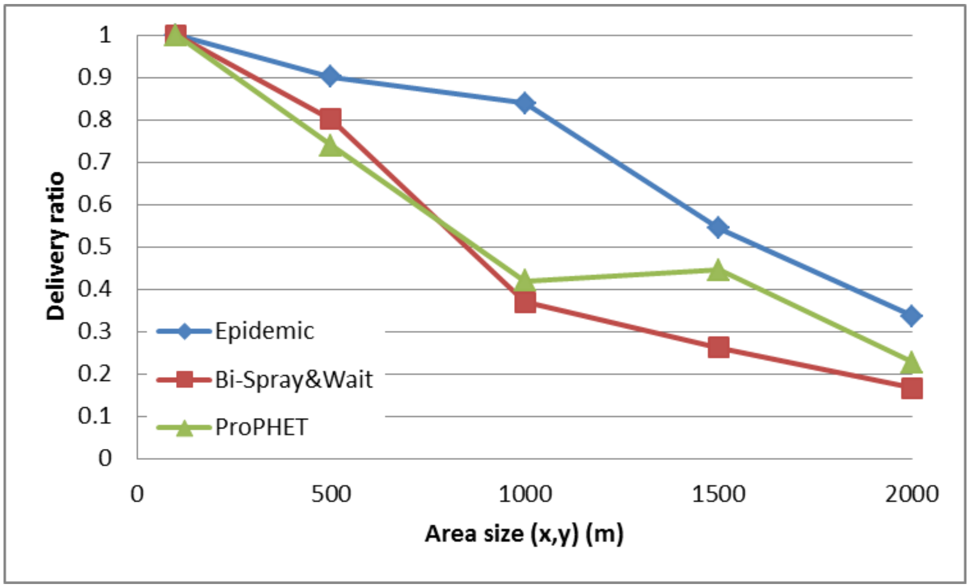
(f) Average hop count, Fast mobility (20m/s)

Figure 7: Random waypoint: 40 nodes, 10kB messages

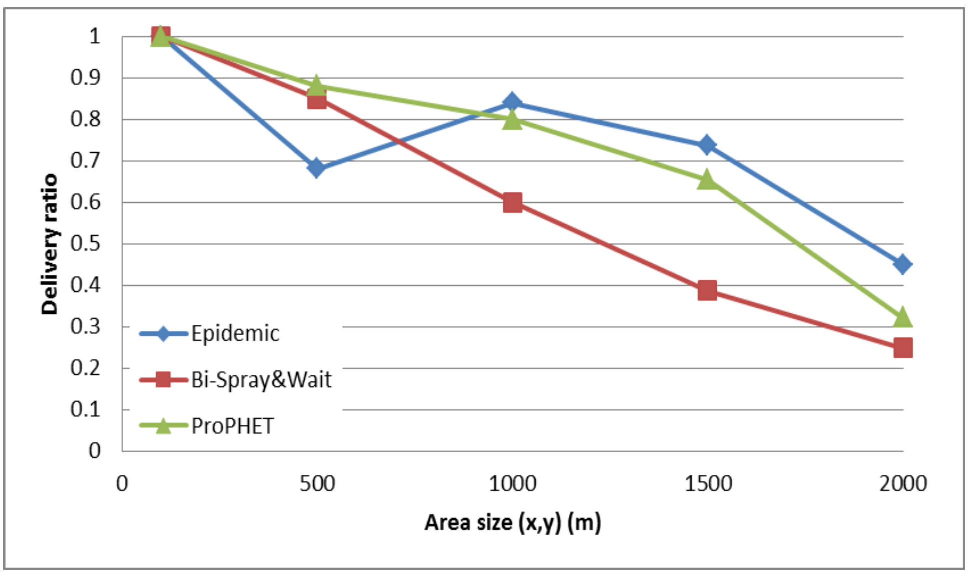
Slow mobility (max. 5m/s), Fast mobility (max. 20m/s)

1.5.5.2 Mobility: 80 Nodes, 10kB Messages

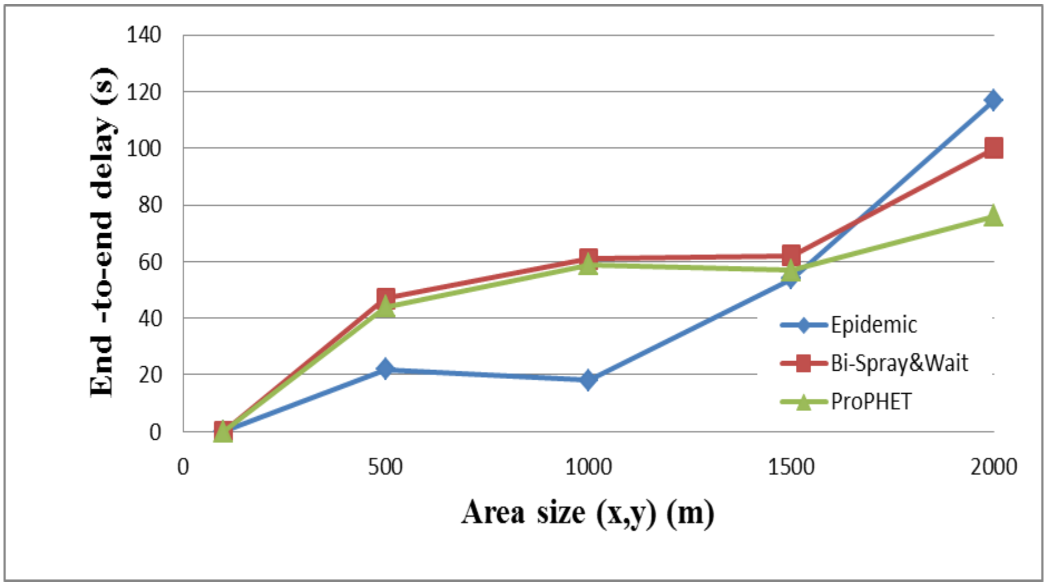
We simulate three routing protocols in high node density. Figure 8 shows the result obtained with 80 mobile nodes and 10kB in size. In Figure 8 (a), (b), it shows that the delivery ratio of routing protocols is decreased in large area. The difference of ratio is larger than that of previous section. We found out that which routing protocol has high delivery ratio. Epidemic outperforms other two routing protocols. End-to-end delay is relatively decreased in high mobile density because the nodes frequently communicate with their neighbors. Also, mobile nodes with high velocity have shorter delay time. In high mobile density, PRoPHET gives best performance. For example, in large area 2000m times 2000m, it has shorter delay time as 20 sec and 40 sec. Moreover, the hop count is increasing and decreasing over area. Epidemic has larger hop count than that of others but the count is decreasing again in the larger area.



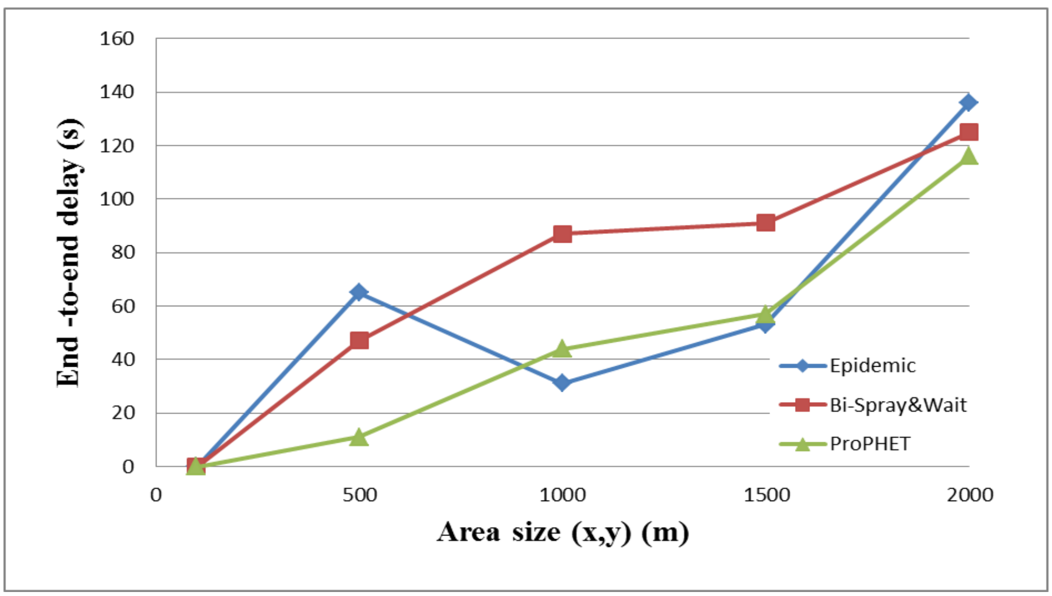
(a) Delivery ratio, Slow mobility (5m/s)



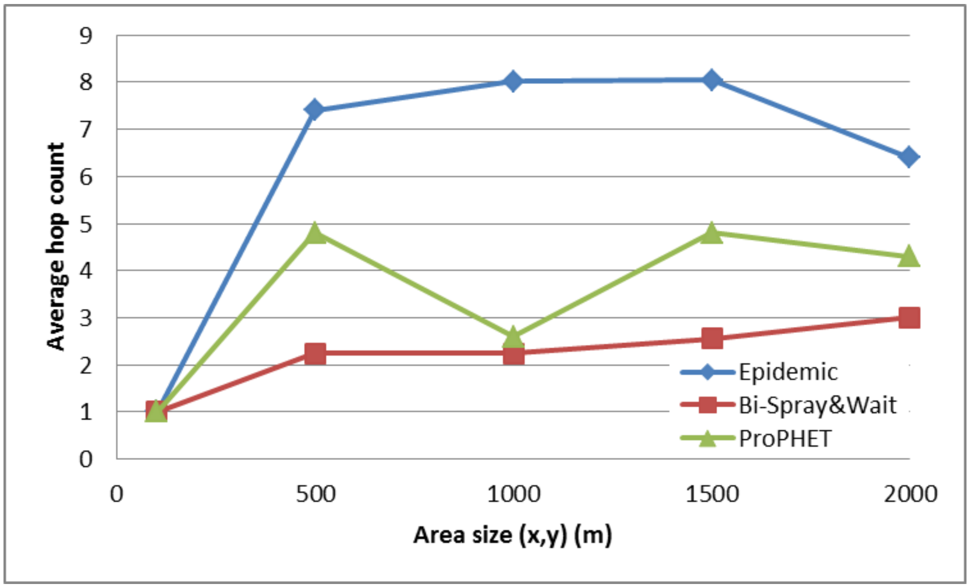
(b) Delivery ratio, Fast mobility (20m/s)



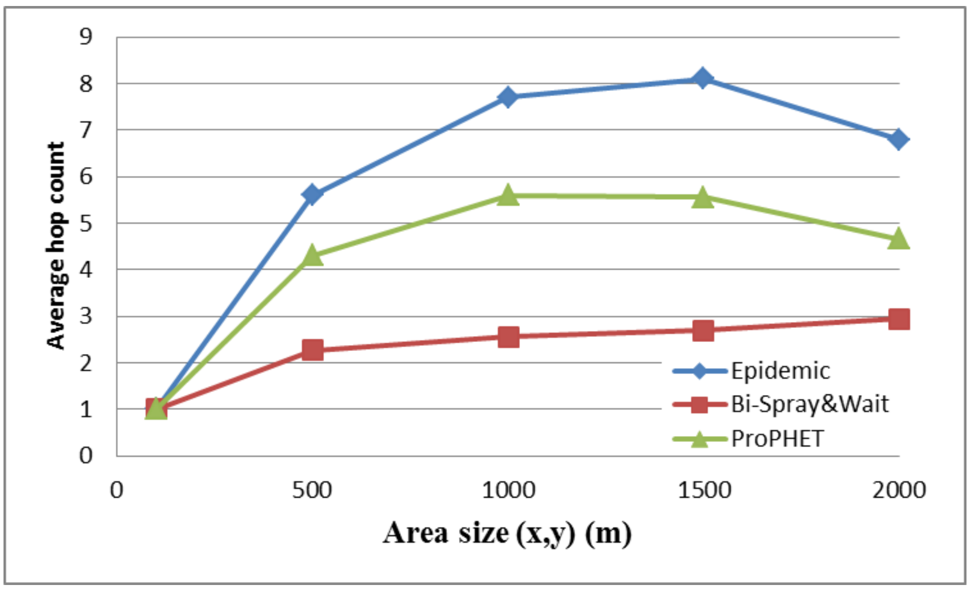
(c) End-to-end delay, Slow mobility (5m/s)



(d) End-to-end delay, Fast mobility (20m/s)



(e) Average Hop count, Slow mobility (5m/s)



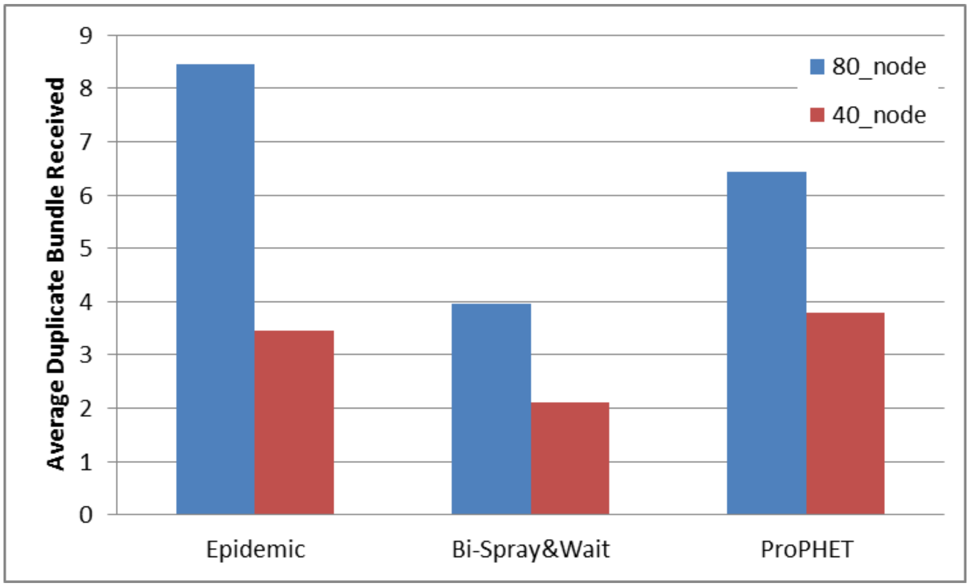
(f) Average hop count, Fast mobility (20m/s)

Figure 8: Random waypoint: 80 nodes, 10kB messages

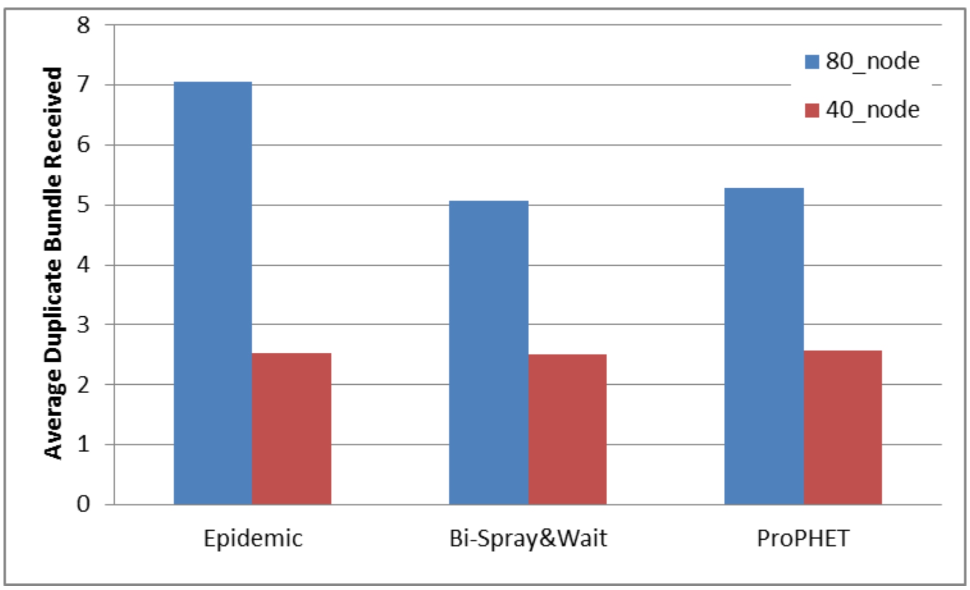
Slow mobility (max. 5m/s), Fast mobility (max. 20m/s)

1.5.5.3 Duplicate Bundle Received

In this section, we compare duplicate bundle received with three different routing protocols in different node density. We simulate the routing protocols at 1000m X 1000m with 5m/s and 20m/s velocity. Other conditions are the same as 1.5.5.2. In fact, in case of low stressed environment, each vehicle does not receive the duplicate message from other vehicles [46]. Figure 9 (a) and (b) shows that the duplicated message is forwarded in high mobile nodes. It is frequent that each node transfers a packet to neighbor nodes. However, the messages are less produced in low mobile density as we mention it in section 1.5.5.1 Thus, the average duplicate bundle received rate is increased from 40 nodes to 80 nodes. Epidemic has larger rate than that of other two routing protocols in two mobility cases. However, PRoPHET and Binary Spray and Wait have less duplicate bundle receipts than Epidemic.



(a) Slow mobility (5m/s)

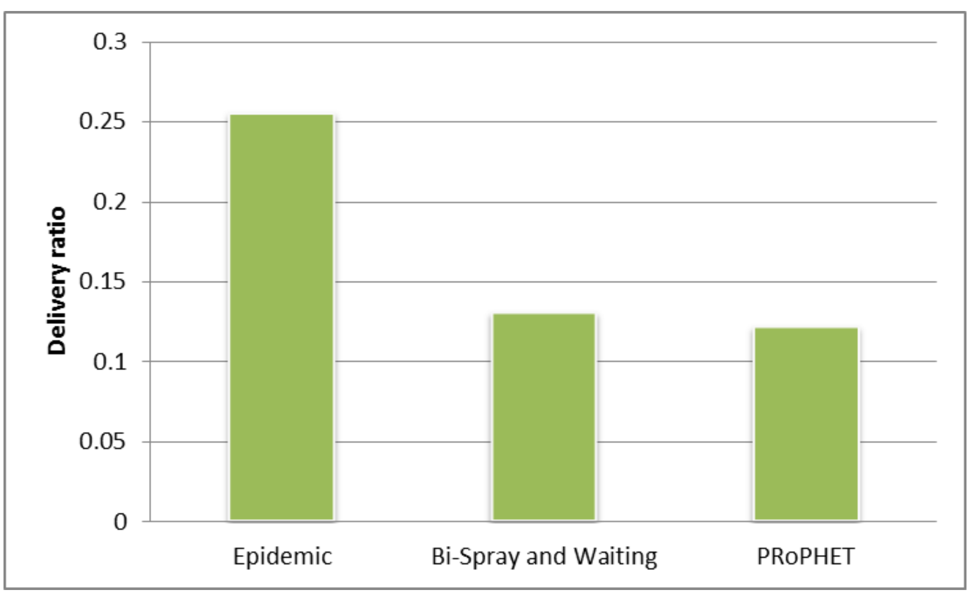


(b) Fast mobility 20m/s

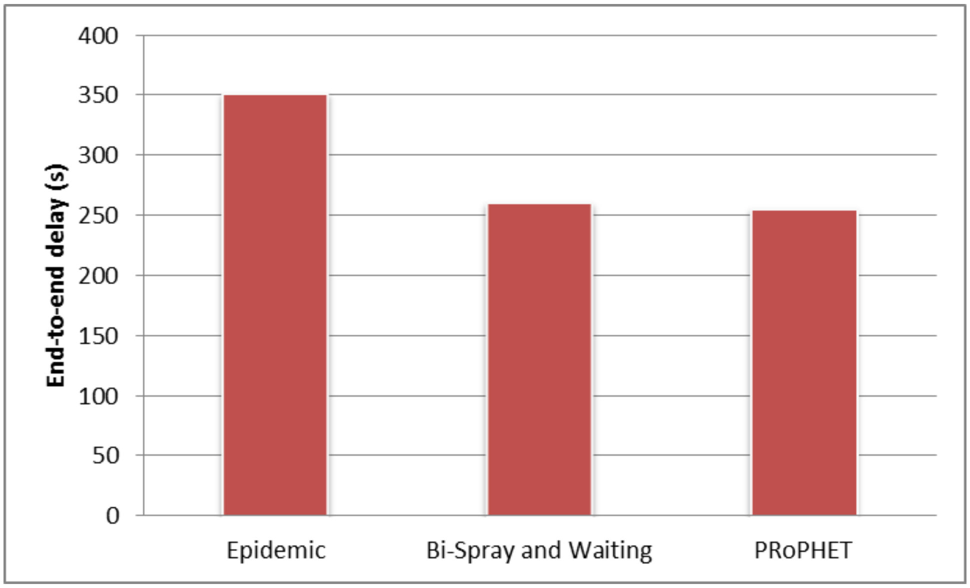
Figure 9. Average Duplicate Bundle Received

1.5.5.4 Real Scenario

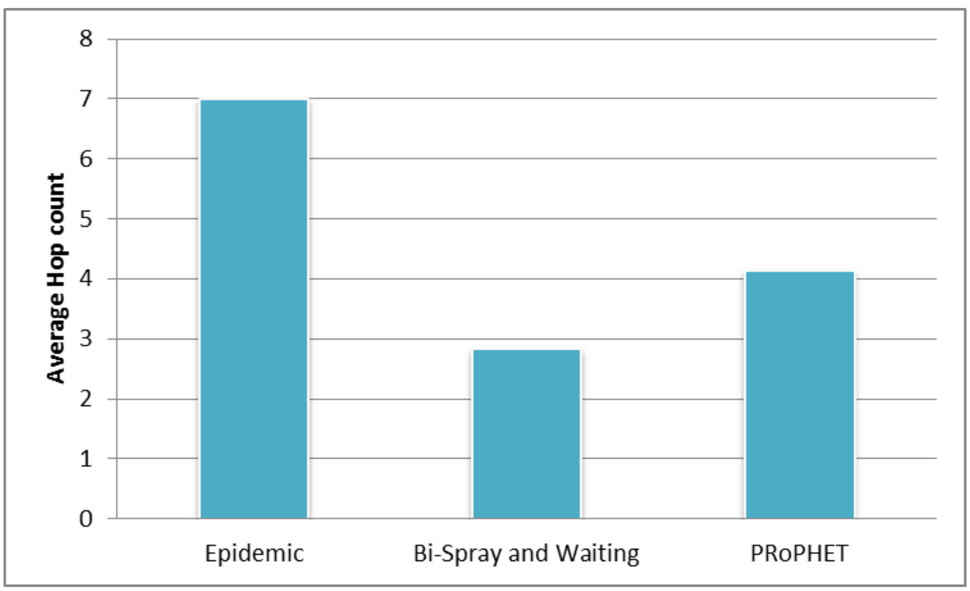
We simulate the different routing algorithms in real environment. We assume the area is small town as much as 4000m times 3400m. The mobile node 116 is set to be more density environment from 2m/s to 25m/s. The message size is 100kB and simulation time is 1000s and other condition is the same as section previous simulation. In Figure 10 (a) it shows results with delivery ratio. When we compare the ratio in the small area, the delivery ratio is decreased but the epidemic routing protocol is still higher delivery ratio than that of others. The end-to-end delay is postponed for enlarged area. As the same result in previous section, the delay is longer in large area where mode density is sparse. From (b) in Figure 10, ProPHET routing protocol gives best performance in terms of delay time. In low mobile density, the duplicate bundle received rate is relatively very low for only a few mobile nodes forward the messages to neighbor nodes. Epidemic routing protocol has the higher duplicate rate than others as that of previous sections.



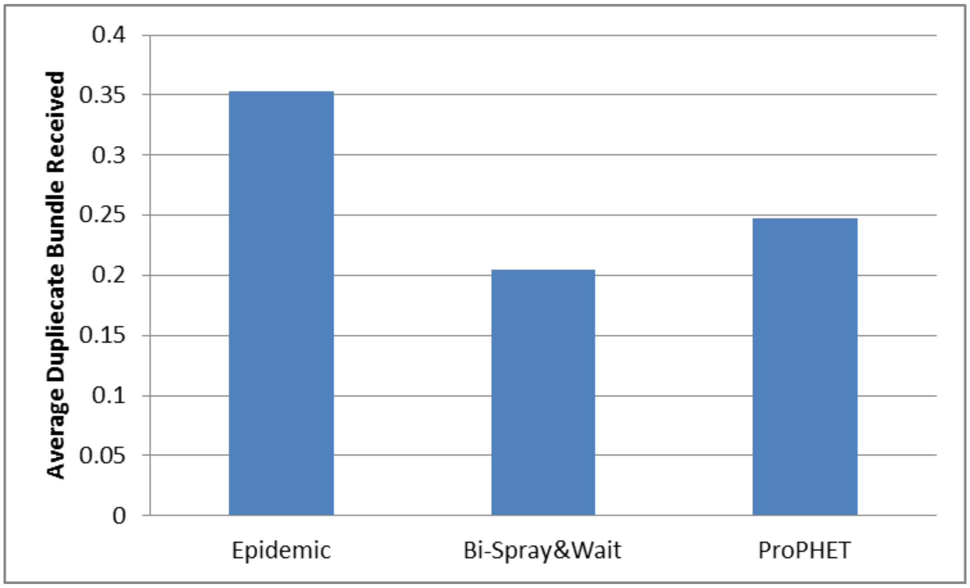
(a)


400
350
300
250
200
150
100
50
0
End-to-end delay (s)
Epidemic
Bi-Spray and Waiting
PRoPHET

(b)


8
7
6
5
4
3
2
1
0
Average Hop count
Epidemic
Bi-Spray and Waiting
PRoPHET

(c)



(d)

Figure 10. Real scenario, 100kB messages, 116 nodes

1.6 Related Works

1.6.1 Newest Issue

1.6.1.1 The accuracy of location information

VANET perform location based routing by using GPS, and most of the routing assumes that a vehicles' location is correct. However, if the location information is incorrect, it takes a long delay time for investigating wrong path, and the performance is degraded. To solve the problems many improved routing protocols are presented.

First, hybrid routing protocol combines ad hoc on-demand distance vector expected transmission vector (AODV-ETX) to solve the location information problem. It forwards route search message through location based routing. If the routing fails, it performs flooding with AODV [21]. Second, Back-Bone-Assisted Hop Greedy Routing (BAHG) suggests a hop greedy routing protocol that aims to reduce the end-to-end delay by yielding a routing path that includes the minimum number of intermediate intersections [22].

1.6.1.2 Security

Security problem have to be solved because if a vehicle with malicious purpose forwards wrong routing information, the car accident message cannot be sent, and many vehicles would be driven into congestion road by the incorrect information.

To upgrade security, Secure Position-Based Routing for VANETS (PBR) has presented. It guarantees node authentication, data integrity by combining signatures/certificates, plausibility checks, and rate limitation [23]. Geographical Secure Path Routing (GSPR) offers node authentication and data integrity by Public-Key security algorithm [24].

1.6.1.3 Cross-Layer

Cross-Layer's research is combined with physical layer or link layer with network layer. It expects serviceable routing in VANET routing by physical, and link layer information. It studies the effect of cooperative transmission on the routing decision for vehicular ad-hoc networks. Two different types of routing optimization are investigated to understand the effects of improved link cost to the routing decision [25]. In [26], the proposed algorithm is that if when greedy is sent, the algorithm excludes the node that is more than certain length, considering specific node that is congested.

1.6.1.4 Various combination of information

VANET can get a variety of information by GPS, navigation system, and sensor. Trajectory-based Statistical Forwarding (TSF) is that using navigation calculates driving direction with car density, and other information. It selects optimal path by using distribution of packet transmission delay, and car moving delay [27]. Shortest-Path-Based Traffic-Light-Aware Routing (STAR) forwards packet at crossroad by traffic signal information [28].

1.6.1.5 Multimode protocol

Routing protocol is established to fit specific environment. For example, crossroad based routing protocol can be applied in downtown, but it is not suitable in country road, and highway. Distribution-Adaptive Distance with Channel Quality (DADCQ) determines distance critical value, considering car density, distribution pattern of vehicle space, and quality of wireless channel [29].

1.6.1.6 Quality of Service (QoS)

Data has to be sent in certain period after car accident. However, the data cannot guarantee a quality for high mobility of VANET. RMRV (Road-based Qos-aware Multipath Routing Protocol for Urban VANET) suggests that multipath routing to meet delay requirements, considering expected path lifetime and transmission time [30].

CHAPTER 2. An Efficient MU-MIMO Precoding Operation with ZF and MMSE

2.1. Introduction

Next generation mobile communication system requires high capacity and reliability for supporting bandwidth intensive applications such as multimedia services. For a given spectrum channel, multiple-input Multiple-output (MIMO) technology can efficiently increase the transmission rate by increasing the antenna numbers at both the transmitter and the receiver. With the potential of increasing the spectrum usage efficiency, MIMO technique has been introduced into 802.16, 3GPP for mobile communications [48].

The emerging Fifth Generation (5G) mobile communication is considering the use of large-scale antenna systems (LSAS) and Massive MIMO, where each Base Station (BS) is equipped with orders of magnitude more antennas, e.g, 100 or more [49]. A MIMO system relies on multiple antennas to transmit multiple streams of data in wireless communication systems [50]. Multi-User MIMO (MU-MIMO) system serves several user terminals at the same time [51]. For example, with MU-MIMO, a base station can transmit data to a set of single-antenna users at the same time and the spatial channels can be shared by all users [49]. The transmission rate can be improved by using smart antenna, antenna array, and Beam Forming technologies. To increase the performance of MU-MIMO systems, precoding techniques are often applied based on the channel state information (CSI). Denoting the number of antennas on a base station as M, and the number of users in a cell as K, we would like to study the performance of MU-MIMO in three operational scenarios: K (Users) >M (Antennas) <, K =M, and K< M.

Generally, when the number of users increases, the sum rate also increases for a large antenna number M. Also, the sum rate will be different if a BS applies different linear precoders or uses different number of antennas.

Two candidate precoders are often used, Minimum Mean Square Error (MMSE) precoder and Zero-Forcing (ZF) precoder. Different from the conventional belief that MMSE is optimal in all cases, in this paper we first show that performance of the precoders depends on the complexity and the throughput and can vary in different application scenarios. For example, a ZF precoder has lower complexity but also lower sum rate at certain antenna numbers, while the relationship between the two precoding schemes changes under other scenarios. Based on the observations, we propose an algorithm to efficiently select the precoder in a practical network with different number of users. .

The rest of the paper is organized as follows. In section 2, we introduce the spatially multiplexed MIMO system and the capacity rate in downlink transmissions. Also, the need of massive MIMO system is introduced with latest technology trend. To be specific, MU-MIMO system is overviewed with four advantages. In section 3, we introduce the linear precoding scheme. In section 4, the simulated empirical results are displayed to be analyzed. In section 5, we introduce our scheme for precoder selection. Finally, we conclude the paper in Section 6.

2.2 System Model

Spatially multiplexed MIMO(SM-MIMO) systems can transmit data at a higher speed than MIMO systems using antenna diversity techniques.

H denotes a channel matrix with its (j,i)-th entry h_{ji} representing the channel gain between the i-th transmit antenna, i=1,2,…., N_T and the j-th receive antenna, j=1,2,….., N_R. The spatially-multiplexed user data and the corresponding received signals are represented by $x = [x_1, x_2, \dots, x_{Nt}]^T$ and $y = [y_1, y, \dots, y_{Nr}]^T$, where x_i denote the transmit signal from the i-th transmit antenna and y_j denote the received signal at the j-th receive antenna. Let z_j denote the white Gaussian noise with a variance of σ_z^2 at the j-th receive antenna, and h_i denote the i-th column vector of the channel matrix H. $N_R X N_T$ MIMO system is represented as

$$Y = Hx+z, \tag{2.1}$$

$$= h_1 x_1 + h_2 x_2 + \dots + h_{Nt} x_{Nt} + z, \tag{2.2}$$

where z=$[Z_1, Z_2, \dots, Z_{Nr}]^T$ [56].

MU-MIMO is considered for downlink transmission between the base station and the users, where a Base station (BS) equipped with M antennas communicates with K users with $M \geq K$. The received signal $y_{k,m,q} \in C^{N\,X\,1}$ represents the k-th user channel response at time m and frequency q is can described as

$$y_{k,m,q} = H_{k,m,q} x_{m,q} + n_{k,m,q} \text{ for k=1,…,K} \tag{2.3}$$

where $H_{k,m,q} \in C^{N\,X\,M}$ represents the k-th user channel response at time m and frequency, $x_{m,q} \in C^{M\,X\,1}$ is the vector of transmitted symbols at time m and frequency q, *and* $n_{k,m,,q} \in C^{NX\,1}$is circularly symmetric additive complex Gaussian noise with zero mean and variance σ^2,∀k [52].

A. Point to Point MIMO

A-1 Basic Model

Point-to-point MIMO link is installed with N_t and N_r antennas. The narrow band channel with H ∈ $C^{N_r X N_t}$, and has the following equation as

$$Y=\sqrt{\rho}Hx+n, \tag{2.4}$$

where here y ∈ $C^{N_r X1}$, *and* x ∈ $C^{N_t X1}$ are respectively the received signal vector and the transmit signal vector, and n ∈ $C^{N_r X1}$ represents the noise and interference. We assume that the total power of the transmit signal is normalized, E{ $\|x\|^2$}=1, and the noise is zero-mean circularly symmetric complex Gaussian with an identity covariance matrix I. The scalar ρ is the transmit power [49].

A-2 Capacity Rate

With independent and identically distributed (i.i.d.), Gaussian transmit signals and that perfect CSI is available at the receiver, the instantaneous achievable rate can be expressed as

$$\mathrm{C} = \log_2 \det(I + \frac{\rho}{N_t} HH^H) \text{ bits/s/Hz.} \tag{2.5}$$

where Nt is the number of antenna and ρ is transmit power [49].

When the propagation coefficents in the channel matrix H are normalized as Tr$(HH^H) \approx$ $\mathrm{N}_t\mathrm{N}_r$, upper and lower bounds the capacity are derived in [53] with the help of Jensen's inequality:

$$\log_2(1 + \rho\mathrm{N}_r) \leq \mathrm{C} \leq \min(\mathrm{N}_t, \mathrm{N}_r) \log_2(1 + \rho\frac{\max((\mathrm{N}_t,\mathrm{N}_r)}{\mathrm{N}_t}) \quad (2.6)$$

1) $\mathrm{N}_t \gg \mathrm{N}_r$ and $\mathrm{N}_t \to \infty$: When the number of transmit antenna goes to infinity while the number of receive antennas is constant $\mathrm{N}_t \gg \mathrm{N}_r$, $\mathrm{N}_t \to \infty$, the row vectors of H are orthogonal, and hence we have $\frac{(HH^H)}{\mathrm{N}_t} \approx I_{N_r}$.

In this case, the capacity rate in (2.4) can be approximated as

$$\mathrm{C} \approx \mathrm{N}_r \log_2(1 + \rho) \text{ bits/s/Hz}, \quad (2.7)$$

which achieves the upper in (2.5).

2) $\mathrm{N}_r \gg \mathrm{N}_t$ and $\mathrm{N}_r \to \infty$: Using similar derivations as in 1)

$$\mathrm{C} \approx \mathrm{N}_t \log_2(1 + \rho\frac{\mathrm{N}_r}{\mathrm{N}_t}) \text{ bits/s/Hz}, \quad (2.8)$$

B. MU-MIMO Advantages

Multi-User Multiple Input Multiple Output (MU-MIMO) is a group of improved MIMO. It can make the streams of data conveyed to lots of devices at the same time. This technology has four major advantages. First, data rate increases as more antennas are used at the transmitter, so more independent data streams can be sent out and the more terminals can be served simultaneously [51]. Second, there is a higher reliability as the more antennas the more independent paths that can convey the radio signal propagated. Third, it improves the energy efficiency as the base station can focus its emitted energy into the spatial directions where it knows that the terminals are located [51]. Fourth, it reduces the interference, as MU-MIMO uses massive MIMO in base station, and it prevents the interference signal from others base station. In other words, the signal efficiency can be improved.

C. Downlink

Denote $y_d \epsilon C^{KX1}$ as the received signal vector at all K users:

$$y_d = \sqrt{\rho_d} H x_d + n_d \quad (2.9)$$

where $x_d \in C^{NX1}$ is the signal vector transmitted by the BS, $n_d \in C^{KX1}$ is additive noise defined as before, and ρ_d is the DL transmit power. The overall achievable rate of all users becomes

$$C = {}^{max}_{p} log_2 \det(I_n + \rho_d H P H^H) \quad (2.10)$$

$$= {}^{max}_{p} log_2 \det(I_k + \rho_d N P D) bits/\text{s/Hz}$$

where P is a positive diagonal matrix with the power allocations $(p_1, \dots, p_k)$, and N is the number of antennas [49].

2.3 Linear Precoding

Linear precoding requires each antenna to transmit a data stream that is the linear combination of K data streams with K beamforming weights [54]. This design choice conveniently allows all of the radios to share a common data bus for downlink transmission [54].

A. DESIGN

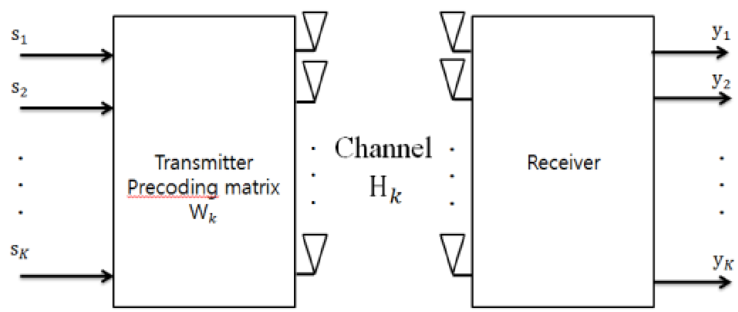


Figure 11. Linear precoding scheme in MIMO

Let $S_k \in C^{NX1}$ denote the k-th user transmit symbol vector. Under linear precoding, the transmitter multiplies the data symbol for each user k by a precoding matrix $W_k \in C^{MXN}$ so that the transmitted signal is a linear function $x = \sum_{K=1}^{K} W_k S_k$. The resulting received signal vector for user k is given by

$$y_k = H_k W_k S_k + \sum_{j \neq \mathrm{K}} H_k W_j S_j + n_k \tag{2.11}$$

where the second-term in (2.11) represents the multi-user interference. We assume that each user will decode $S \leq N$ streams that constitute its data. The goal of linear precoding is to design $\{W_k\}_{K=1}^{K}$ based on the channel knowledge, so a given performance metric is maximized for each stream [52].

B. ZF PRECODING

The ZF scheme intends to completely eliminate the Co-Channel Interference (CCI). To ensure this is possible, the number of antennas equipped at the relay should be greater than the number of interferes [55]. Zero forcing (ZF) is a technique of linear equalization algorithm. Measuring the channel information can be estimated at the receiver, the process of the ZF algorithm detection can be explained as follows:

$$\mathrm{W}_{ZF} = (H^H * H)^{-1} * H^H, \tag{2.12}$$

where ZF technique cancels the interference.

Assuming equal power allocation over the users and user codes drawn from an independent identically distributed Gaussian distribution, the achievable sum rate is given by

$$R_{ZF} = \sum_{k=1}^{k} log_2(1 + \frac{P}{K\sigma^2}|h_k W_k|^2) \tag{2.13}$$

$(H)^H$ denotes a function of Hermitian transpose of H. It demonstrates the inverse effect of channel as follows [56].

C. MMSE PRECODING

The ZF scheme completely eliminates the CCI at the relay, which however causes an elevated noise level. In contrast, the MMSE scheme does not fully eliminate the CCI, instead, it provides the optimum trade-off between interference suppression and noise enhancement [55].

MMSE estimator is an estimator which follows an estimation method, through which it minimizes the mean square error [57]. In order to maximize the post-detection signal-to-interference plus noise ratio (SINR), the MMSE weight is given as

$$\mathrm{W}_{MMSE} = (H^H * H + {\sigma_z}^2 * I)^{-1} * H^H \tag{2.14}$$

Note that the MMSE receiver requires the statistical information of noise ${\sigma_z}^2$. Note that the i-th row vector $W_{i,MMSE}$ of the weight matrix in Equation (2.14) is given by solving the following optimization equation [56].

$$W_{i,MMSE} = \underset{w = (w1, w2, \ldots, w_{N_T})}{argmax} \frac{|wh_i|^2 * E_x}{E_x * \sum_{j=1, j\neq i}^{Nt} \left|wh_j\right|^2 + \|w\|^2 * {\sigma_z}^2} \quad (2.15)$$

Using the MMSE weight in Equation (2.15) obtains the following relationship.

$$\widetilde{X_{MMSE}} = W_{MMSE} * y = \tilde{x} + \widetilde{z_{MMSE}} \quad (2.16)$$

The achievable sum rate is given by

$$R_{MMSE} = \sum_{k=1}^{k} log_2\left(1 + \frac{|h_k W_k|^2}{\sum_{j\neq k}|h_k W_k|^2 + \frac{K\sigma^2}{P}}\right), \quad (2.17)$$

where W_k is the normalized k-th column of the precoder [52]. Similarly to MMSE equalization, a non-zero β value results in a measured amount of multi-user interference. The amount of interference is determined by β>0 and an optimal tradeoff between the condition of the channel matrix inverse and the amount of crosswalk ought to be found. In practice, the regularization factor is commonly chosen as $\beta = \frac{M * \sigma^2}{P}$ motivated by the results in [56] that show that it approximately maximizes the SINR at each receiver, and leads to linear capacity growth with M. The performance of MMSE is certainly significantly better at low SNR and converges to that of ZF precoding at high SNR. However, MMSE does not provide orthogonal channels and thus power allocation techniques cannot by performed in a straightforward manner [52].

2.4 Simulation Results

In this section, we present numerical results in terms of capacity with the two precodings, MMSE and ZF, in two different environments. For example, the number of antennas is arranged as $N_T\ (Tranmitters\colon M) \times N_R\ (Receivers\colon K)$in MIMO in fast fading Rayleigh channels. We compare the capacity with two types of precoding, ZF and MMSE. Overall, the throughput increases when the transmitters and receivers become larger. We assume other elements are perfect equalization. If there are N_T maximum transmitter antennas, the capacity has to be maximized with maximum channels.

The total throughput was analyzed based on a variety of antenna pairs such as K>M, K=M, and K<M. In Figure 2, we observe that the sum rates of MMSE precoding systems are always higher than those of ZF systems when K=M and K>M, but a ZF precoding system produces higher capacity in some case of K<M. To be specific, if the number of receivers is less than one plus a half of transmitters, ZF precoding systems have better performance. That is, in the other case of 10×5 combination, the ZF precoding system performs better. In order to analyze that case of K<M, we show more results in the figure 3 and also in the table 1, with different SNR values and K values, in the case of M=10.

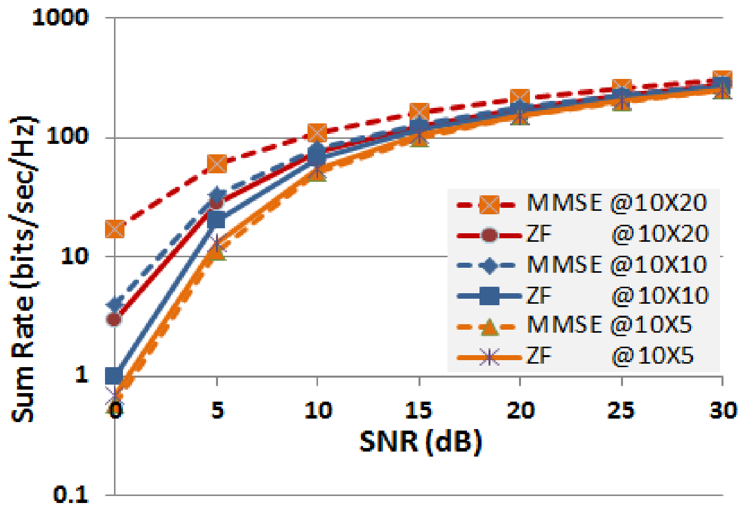


Figure 12. The comparison of capacity of ZF and MMSE (M=10; K<M, K=M, and K>M)

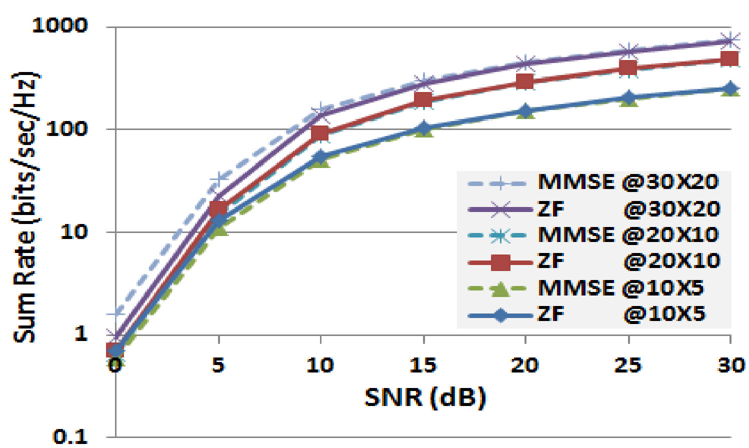


Figure 13. The comparison of capacity of ZF and MMSE (M > K)

We assume that the total antennas numbers has effect on the sum rate but only the receiver numbers impacts the total output as [48]. When we compare two capacities in different MIMO systems, the sum rate of MMSE is higher than that of ZF (up to four times at 0dB) when the antenna numbers are the same as [48]. In figure 3, the sum rate of MMSE is higher than ZF when 30x20 only, while the other way around otherwise.

Table 2. The comparison of capacity of ZF and MMSE (K<M, K=M, and K>M) (Unit: bits/sec/Hz)

SNR(dB)	0	5	10	15	20	25	30
MMSE@10X1	0	0	8	38	84	134	183
ZF @10X1	0	4	29	75	125	174	224
MMSE@10X2	0	2	21	64	114	164	214
ZF @10X2	0	7	41	89	139	189	239
MMSE@10X4	0	7	42	91	141	191	241
ZF @10X4	1	11	52	101	151	201	251
MMSE@10X6	1	15	58	108	157	207	257
ZF @10X6	1	15	58	108	157	207	257
MMSE@10X8	2	24	71	120	170	220	270
ZF @10X8	1	18	62	112	162	212	262
MMSE@10X10	4	33	81	131	180	230	280
ZF @10X10	1	20	66	116	165	215	265
MMSE@10X12	6	40	89	139	189	239	289
ZF @10X12	2	22	69	118	168	218	268
MMSE@10X14	9	47	96	146	196	246	296
ZF @10X14	2	24	71	121	170	220	270
MMSE@10X16	11	52	102	152	202	251	301
ZF @10X16	2	26	73	123	172	222	272
MMSE@10X18	14	57	107	157	206	256	306
ZF @10X18	2	27	75	124	174	224	274
MMSE@10X20	17	61	111	161	211	260	310
ZF @10X20	3	28	76	126	176	226	275

The exact values in the table 1 show the change of throughput. That is, the light yellow part shows that ZF precoding give better throughput than MMSE. The yellow part presents the transition combination of antennas. The other part indicates that MMSE precoding gives better throughput than ZF.

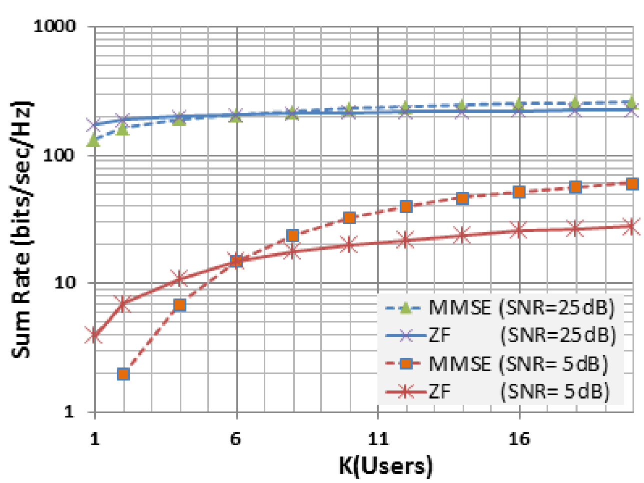


Figure 14. A comparison of capacity of ZF and MMSE (M=10; K<M, K=M, and K>M)

In figure 14 obtained from the table 2, we analyze the capacity rate with the fixed transmitter antenna numbers M=10, and a variety of receiver antenna numbers at lower and higher SNR (5dB and 25 dB), respectively.

For both cases, the MMSE performance is better when the number of users is larger than 6, while the opposite is observed when the number of users is smaller than 6. When SNR = 5 dB, the sum rate of ZF is up to 71% larger than that of MMSE when K< 6. On the other hand, the sum rate of MMSE is up to 46% higher when K> 6.

When SNR = 25dB, , the result is similar to that in the lower SNR (5dB) case, but the difference between the two reduces. MMSE has up to 15% higher sum rate compared to ZF when there are more than 6 users. The sum rate of ZF has up to 30% larger sum rate compared to MMSE when the number of users is less than 6.

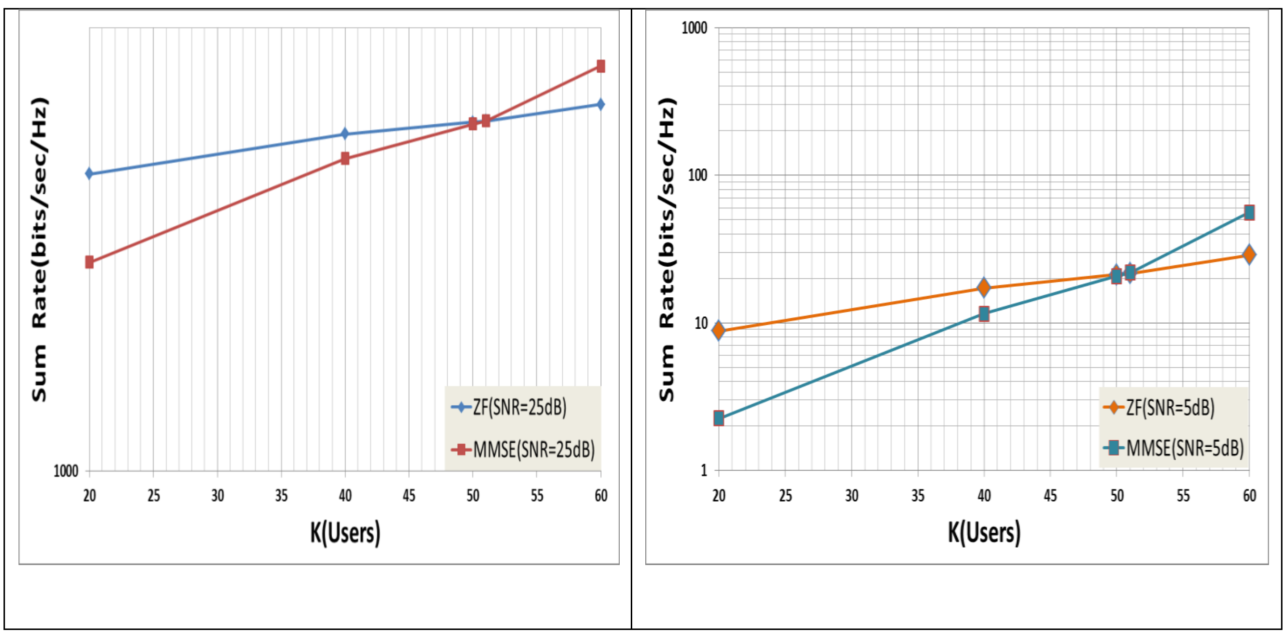


Figure 15. A comparison of capacity of ZF and MMSE (100 of Transmitter Ant. x N of Receiver Ant)

In figure 15, we analyze the capacity rate with the fixed transmitter antenna numbers 100, and a variety of receiver antenna numbers at lower and higher SNR (5dB and 25 dB), respectively. We found out that ZF and MMSE capacity are exchanged at receiver antennas 51 in larger antenna numbers than Figure 14.

In conclusion, MMSE can be used for better precoding with a higher sum rate when $K > M$, *and* K = M. ZF gains a higher sum rate when K<$\frac{M}{2}$+1. The difference between the two is larger when the SNR is lower. Also, MMSE outperforms ZF in larger antenna size which is called Massive MIMO (Antenna numbers >=100).

2.5 An Efficient Precoding Operation

From the simulation result in section 2.4, we propose that the base station and the mobile station support both ZF and MMSE precoding schemes and the precoding scheme to select for a given transmission is determined based on the operational scenarios as follows.

Figure 5 displays an algorithm of precoding selection in data channel block of an implemented MIMO system. An operation scenario of the base station is as follows. The logic of computing $Nr > \frac{Nt}{2} + \alpha$ (α =1, in Table 2) is determined, because the base station knows both the number of its own antennas and the number of mobile stations (users) transmitting and receiving data through the data channel. The base station informs the mobile station which precoder of the data channel to use through the control channel in DL, when they begin to set up the call. The value of system parameter, α, is optimized according to the system conditions.

For example, in case of $Nr \leq \frac{Nt}{2} + \alpha$ (e.g., midnight), both the base station and the user equipments operate with ZF precoder for better throughput in DL. Then, when it is converted into the case of $Nr > \frac{Nt}{2} + \alpha$ the MMSE decoder of a new user equipment begins to operate for a new call, according to the direction of the base station. On the one hand in the base station, some data channel units keep on operating the ZF precoder for the continued call from previous time, while other channel units start the MMSE precoder for the new call for better throughput in DL. Namely, the base station applies both ZF and MMSE precoders simultaneously. If the mobile environment keeps the condition of $Nr > \frac{Nt}{2} + \alpha$, finally channel units of the base station run the MMSE precoder only, because they stop operating the ZF precoder in terminating the previous calls

Conversely, if the number of users converts into the case of $\mathrm{Nr} \leq \frac{\mathrm{Nt}}{2} + \alpha$, the previous terminal keeps its MMSE decoding for continued call. A new terminal begins to use its ZF decoder for new call. As the same above, channel units of the base station maintain MMSE precoding for previous calls, while it starts the ZF precoder for the new calls for better throughput.

In conclusion, if the condition of $\mathrm{Nr} \leq \frac{\mathrm{Nt}}{2} + \alpha$ lasts, finally channel units run the ZF precoder only, because they stop operating the MMSE precoder in terminating the previous calls.

As mentioned above, the performance of DL has improved efficiently, although the hardware complexity of DL in base station and terminals increases.

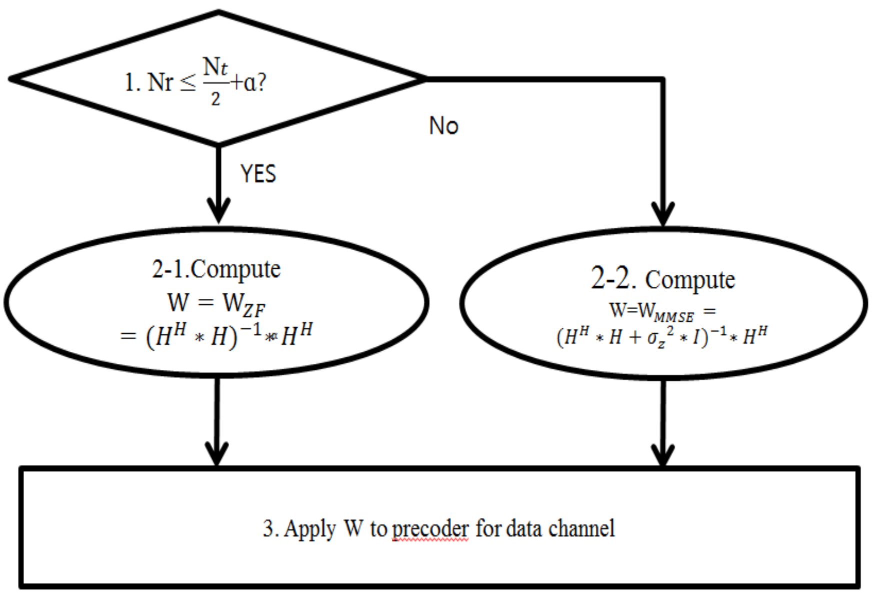


Figure 16. An algorithm of precoding selection

2.6 Conclusion

In this paper, we have presented the analysis of latest MIMO system capacity based on different precoding. The new technology offers diversity advantages in terms of power efficiency, interference, and throughput. Especially, the spatially multiplexed model transmits much more data and achieve higher transmission rate. We simulated with the two different coding techniques based

Reference

[1] Daehee Kim and Sun Shin Ahn, "VANET routing research and trend," Journal of Korean Institute of Communications and Information Sciences, Vol. 30, No. 5, pp.95-105, May 2013.

[2] G. Korkmaz et al., "Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems," Proc. of the 1st ACM International Workshop on Vehicular Ad Hoc Networks, pp.76-85, 2004.

[3] N. Wisitpongphan, et al., "Broadcast Storm Mitigation Techniques in Vehicular Ad Hoc Networks," IEEE Wireless Communications, Vol.14, No.6, pp.84-94, Dec. 2007.

[4] W. Viriyasitavat, et al., "UV-CAST: An Urban Vehicular Broadcast Protocol," IEEE Communications Magazine, Vol.49, No.11, pp.116-124, Nov. 2011.

[5] A. Bachir, et al., "A Multicast Protocol in Ad hoc Networks Inter-Vehicle Geocast," Proc. of the 57th IEEE Semiannual Vehicular Technology Conference, Vol.4, pp.2456-2460, 2003.

[6] H. P. Joshi, et al., "Distributed Robust Geocast Multicast Routing for Inter-Vehicle Communication," Proc. of WEIRD Workshop on WiMax, Wireless and Mobility, pp.9-21, 2007.

[7] Y. Chen, et al., "A Mobicast Routing Protocol in Vehicular Ad-Hoc Networks," ACM/Springer Mobile Networks and Applications, Vol.15, No.1, pp.20-35, Feb. 2010.

[8] B. Karp, et al., "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," Proc. of the ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), 2000.

[9] C. Lochert, et al., "Geographic Routing in City Scenarios," ACM SIGMOBILE Mobile Computing and Communications Review, Vol.9, No.1, pp.69-72, Jan. 2005.

[10] C. Lochert, et al., "A Routing Strategy for Vehicular Ad Hoc Networks in City Environments," Proc. of IEEE Intelligent Vehicles Symposium, pp.156-161, June 2003.

[11] K.C. Lee, et al., "LOUVRE: Landmark Overlays for Urban Vehicular Routing Environments," Proc. of IEEE Vehicular Technology Conference, pp.1-5, 2008.

[12] M. Jerbi, et al., "An Improved Vehicular Ad Hoc Routing Protocol for City Environments," Proc. of IEEE International Conference on Communications, pp.3972-3979, 2007.

[13] J. Nzouonta, et al., "VANET Routing on City Roads Using Real-Time Vehicular Traffic Information," IEEE Transactions on Vehicular Technology, Vol.58, No.7, pp.3609-3626, Sept. 2009.

[14] H. Menouar, et al., "Movement Prediction-Based Routing (MOPR) Concept for Position-based Routing in Vehicular Networks," Proc. of IEEE Vehicular Technology Conference, pp.2101- 2105, 2007.

[15] V. Namboodiri and L. Gao, "Prediction-Based Routing for Vehicular Ad Hoc Networks," IEEE Transactions on Vehicular Technology, Vol.56, No.5, pp.2332-2345, July 2007.

[16] N. Sofra, et al., "Route Construction for Long Lifetime in VANETs," IEEE Transactions on Vehicular Technology, Vol.60, No.7, pp.3450-3461, Sept. 2011.

[17] D. Zhang, et al., "An Energy-Efficient Routing Protocol Using Movement Trends in Vehicular Ad Hoc Networks," The Computer Journal, Vol.56, No.4, March 2013.

[18] D. Borsetti and J. Gozalvez, "Infrastructure-Assisted Geo-Routing for Cooperative Vehicular Networks," Proc. of IEEE Vehicular Networking Conference, pp.255-262, 2010.

[19] Y. Ding and L. Xiao, "SADV: Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks," IEEE Transactions on Vehicular Technology, Vol.59, No.5, pp.2445-

2455, June 2010.
[20] R. Lu, et al., "SPRING: A Social-based Privacy Preserving Packet Forwarding Protocol for Vehicular Delay Tolerant Networks," Proc. of IEEE INFOCOM, pp.1-9, 2010.
[21] M. Al-Rabayah and R. Malaney, "A New Scalable Hybrid Routing Protocol for VANETs," IEEE Transactions on Vehicular Technology, Vol.61, No.6, pp.2625-2635, July 2012.
[22] P.K. Sahu, et al., "BAHG: Back-Bone-Assisted Hop Greedy Routing for VANET's City Environments," IEEE Transactions on Intelligent Transportation Systems, Vol.14, No.1, pp.199-213, March 2013.
[23] C. Harsch, et al., "Secure Position-Based Routing for VANETs," Proc. of IEEE Vehicular Technology Conference, pp.26-30, 2007.
[24] V. Pathak, et al., "Securing Location Aware Services Over VANET Using Geographical Secure Path Routing," Proc. of IEEE ICVES, pp.346-353, 2008.
[25] Z. Ding and K. Leung, "Cross-Layer Routing Using Cooperative Transmission in Vehicular Ad-hoc Networks", IEEE Journal on Selected Areas in Communications, Vol.29, No.3, pp.571- 581, March 2011.
[26] W. Wang, et al., "Small-Scale and Large-Scale Routing in Vehicular Ad Hoc Networks, " IEEE Transactions on Vehicular Technology, pp.5200-5213, Nov. 2009.
[27] J. Jeong, et al., "Trajectory-Based Statistical Forwarding for Multihop Infrastructure-to-Vehicle Data Delivery," IEEE Transactions on Mobile Computing, Vol.11, No.10, pp.1523-1537, Oct. 2012.
[28] J. Chang, et al., "Intersection-Based Routing for Urban Vehicular Communications with Traffic-Light Considerations," IEEE Wireless Communications, Vol.19, No.1, pp.82-88, Feb. 2012.
[29] M. Slavik and I. Mahgoub, "Spatial Distribution and Channel Quality Adaptive Protocol for Multihop Wireless Broadcast Routing in VANET," IEEE Transactions on Mobile Computing, Vol.12, No.4, pp.722-734, April 2013.
[30] Y. Hsieh and K. Wang, "A Road-based QoS-aware Multipath Routing for Urban Vehicular Ad Hoc Networks," Proc. of IEEE GLOBECOM, 2012.
[31] H. Song and H. S. Lee, "Decentralized Congestion Control Protocols for V2V Communications and Their challenging Issues," Proc. IEEE ICTC 2014, BUSAN, South Korea, Oct. 2014.
[32] P. C. Cheng, K. C. Lee, M. Gerla, and J. Härri, "GeoDTN+Nav: geographic DTN routing with navigator prediction for urban vehicular environments," Mobile Networks and Applications, vol. 15, no. 1, pp. 61–82, 2010.
[33] Lei Zhao, Fan Li, and; Yu Wang, "Hybrid Position-Based and DTN Forwarding in Vehicular Ad Hoc Networks", IEEE International Conference , 2012.
[34] I. Leontiadis and C. Mascolo, "GeOpps: geographical opportunistic routing for vehicular networks," Proc. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks 2007 (WoWMoM 2007), Espoo, Finland, pp. 1–6, June 18–21, 2007.
[35] NS tutorial. http: //www.isi.edu/nsnam/ns/tutorial/index.html.
[36] Amin Vahdat and David Becker, "Epidemic routing for partially-connected ad hoc networks.Technical Report CS-2000, Duke University, July 2000.
[37] R. S. Mangrulkar and Dr. Mohammad Atique "Routing Protocol for Delay Tolerant Network: A Survey and Comparison," IEEE Internatioanl Conference on Communication Control and Computing Technologies (ICCCCT), pp.210-215, 2010.

[38] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, “Spray and Wait: an efficient routing scheme for intermittently connected mobile networks,” ACM SIGCOMM workshop on Delay-tolerant networking, pp. 252-259, 2005.

[39] Olariu S and Weigle MC, “Vehicular networks: from theory to practice”, Chapman & Hall/CRC, 2009.

[40] Seung Deok Han and Yun Won Chung, “An Improved PRoPHET Routing Protocol in Delay Tolerant Network,” Hindawi The Scientific World Journal, vol. 2015, Article ID 623090, 7pages, 2015.

[41] Jani Lakkakorpi, Mikko Pitkanen, and Jorg Ott, “Adaptive routing in mobile opportunistic networks,” Proc. of the 13th ACM international conference on Modeling, analysis, and simulation of wireless and mobile systems, Bodrum, Turkey, October 17-21, 2010.

[42] Sergio M Tornell, Carlos T Calafate, Juan – Carlos cano and pietro Manzoni “DTN Protocols for Vehicular Networks: An Application Oriented Overview”, IEEE Communication Survey and Tutorials, Vol. 17, Issue 2, pp.868-887, 2015.

[43] A. Sérgio de Sousa Vieira, J. Gonçalves Filho, J. Celestino Jr., and A. Patel, “VDTN- ToD: routing protocol VANET/DTN based on trend of delivery,” Proc. of the 9th Advanced International Conference on Telecommunications (AICT '13), pp. 135–141, 2013.

[44] Sang Ho So, “*Study of Delay Tolerant Network Routing Algorithm Considered Movement Pattern of Mobile Node*”, Thesis, Chungnam National University, Feb 2009. (Publication No. KDMT 1200912857)

[45] R. Flury and R. Wattenhofer, “MLS: an efficient location service for mobile ad hoc networks,” Proc. of 7th ACM International Symposium on Mobile Ad Hoc Networking and Computing, pp. 226-237, 2006.

[46] Makoto Ikeda, Taiki Honda, Seiichiro Ishikawa, and Leonard Barolli “Performance comparison of DTN Routing Protocols in Vehicular DTN Environment”, Ninth International Conference on Broadband and wireless Computing, Communication and Applications, pp.247-252, 2014

[47] Moath Muayad Al-Doori, “*Directional Routing Techniques in VANET*,” PhD Thesis, Software Technology Research Laboratory, De Montfort University, Leicester United Kingdom, November 2011.

[48] Samarendra Nath Sur, Dr. Rabindranath Bera, and Dr. Bansibadan Maji,“Channel Capacity Analysis of MIMO System in Correlated Nakagami-m Fading Environment,” International Journal of Engineering Trends and Technology, Vol. 9, no. 3, pp.101-105, 2014.

[49] L. Lu, G. Y. Li, A. L. Swindlehurst, A. Ashikhmin, and R. Zhang, “An Overview of Massive MIMO: Benefits and Challenges,” IEEE Journal of Selected Topics in Signal Processing, Vol. 8, No. 5, pp.742-758, October 2014.

[50] Taek Keun Lyu and Xin Wang, “Capacity of Precoding for MU-MIMO Systems,” Proc. ICTC2015, pp. 405-407, October 2015.

[51] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, “Massive MIMO for Next Generation Wireless Systems,” IEEE Communication Magazine, pp.186-195, 2014.

[52] Florian Kaltenberger, L. S. Cardoso, M. Kountouris2, R. Knopp and D. Gesbert, “Capacity of Linear Multi-user MIMO Precoding schemes with measured Channel Data,” in Proc, IEEE Workshop on Sign. Proc. Adv. in Wireless Comm.(SPAWC), pp.580-584, Recife, Brazil, July 2008.

[53] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, “Scaling up MIMO: Opportunities and challenges with very large arrays,” IEEE Signal

Process. Mag., Vol. 30, no. 1, pp.40–46, January 2013.
[54] Clayton Shepard, Hang Yu, Narendra An, Erran Li, Thomas Marzetta, Richard Yang, and Lin Zhong. "Argos: Practical Many-Antenna Base Stations," Proc. ACM Int. Conf. Mobile Computing and Networking (MobiCom), pp.53-64, August 2012.
[55] Guangxu Zhu, Caijun Zhong, Himal Suraweera, Zhaoyang Zhang,Chau Yuen, and Rui Yin, "Ergodic capacity comparison of different relay precoding schemes in dual-hop AF systems with co-channel interference," IEEE Transactions on Communications, Vol. 62, no. 7, pp. 2314-2328, July 2014.
[56] Yong Soo Cho, Jaekwon Kim, Won Young Yang, and Chung-Gu Kang, MIMO-OFDM Wireless Communication with MATLAB, John Wiley & Sons (Asia), Singapore, 2010.
[57] Swetamadhab Mahanta and Ankit Rajauria, "Analysis of MIMO system Through ZF & MMSE Detection Scheme," Proc. IJECT Vol. 4, pp. 84-87, June 2013.