# 國立交通大學

## 資訊科學與工程研究所

## 碩士論文

# 一個適合 802.11(p) 無線網路的多段轉送協定

# Supporting Multi-Hop Forwarding over 802.11(p) Networks

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# 摘要

車間通訊在未來的車輛以及交通管理上將會扮演很重要的角色。因此，為了在車間通訊網路中達到車與車之間的小範圍通訊，制定了 IEEE 802.11(p)/1609 標準；它是從 802.11-2007 標準修改而來，而且定義了專屬車間通訊環境的運行模式。

然而，在 IEEE 802.11(p)/1609 標準中，並沒有制訂封包的多段轉送協定，因此，在本篇論文中，我們提出了一個以收端為中心的多段轉送協定；為了要衡量其效能，我們將其與以送端為中心的多段轉送協定來比較。

我們的模擬結果顯示，在 802.11(p)1609 的車間通訊網路的環境中，與以送端為中心的多段轉送協定比較之下，我們提出的以收端為中心的多段轉送協定可以大幅的增加端點到端點之間的傳輸效能，並且減少封包的延遲時間。

**關鍵字：車間通訊、802.11(p)/1609、多段轉送協定、繞徑**

# ABSTRACT

Inter-vehicle communication will play an important role in future aotomobiles and traffic management in general. Therefore, the IEEE 802.11(p)/1609 standard is designed for vehicular communication networks in order to provide Dedicated Short Range Communication (DSRC) for future vehicle-to-vehicle (V2V) communication. It amends the IEEE 802.11-2007 standard and defines a new operational mode for vehicular environments (referred to as the WAVE mode in the standard).

However, in the 802.11(p)/1609 standards, multi-hop packet forwarding mechanism remains un-standardized. In this paper, we propose a receiver-centric multi-hop forwarding scheme for the 802.11(p)/1609 network. To evaluate the efficiency of our proposed receiver-centric forwarding scheme, the performances of our proposed scheme are compared with those of a sender-centric forwarding scheme.

Our simulation results show that, as compared with a sender-centric design, our proposed receiver-centric forwarding scheme can greatly increase end-to-end forwarding goodputs and reduce end-to-end packet delay time for an 802.11(p)/1609 vehicular network.

**Keywords:** intervehicle communications, 802.11(p)/1609 networks, multi-hop packet forwarding, routing.

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# Chapter 1

# Introduction

The IEEE 802.11(a)(b)(g) standard family has been widely used in the indoor and outdoor wireless networks nowadays. However, such traditional 802.11 protocols cannot operate well in the vehicular enviroment, which is characterized by high node mobility and highly-changing link conditions. As such, the IEEE 802.11 working group is working on defining the 802.11(p) standard [8], which is a new network specification designed for wireless communications in vehicular networks.

The 802.11(p) standard amends the IEEE 802.11-2007 standard [9], defining a new MAC-layer operational mode for wireless accesses in vehicular environments (referred to as the WAVE mode). It is designed to cooperate with the IEEE 1609 standard family [13], [10], [11], [12], which defines the application layer and network layer for a WAVE-mode network. In this paper, we call such a network as an IEEE 802.11(p)/1609 network.

The 802.11(p) standard [8], IEEE 1609.3 [11] and 1609.4 [12] together define the operation of a WBSS in vehicular networks. The communication in a WBSS is carried out in a one-hop manner, i.e., data exchanges are only allowed between a WBSS user and the WBSS provider or between two neighboring WBSS users. In addition, the 802.11(p)/1609 standard suite also regulates an 802.11(p) node cannot simultaneously join two WBSSs. This means that, for an 802.11(p) node, maintaining multiple WBSSs at the same time to carry out multi-hop packet forwarding is not allowed in this network. As such, the multi-hop packet forwarding mechanism in the 802.11(p)/1609 network remains un-standardized.

To allow 802.11(p)/1609 networks to efficiently support multi-hop packet forwarding, in this paper we propose a receiver-centric multi-hop forwarding scheme for the 802.11(p)/1609 network. To evaluate the efficiency of our proposed receiver-centric forwarding scheme, the performances of our proposed scheme are compared with those of a sender-centric forwarding scheme. Our simulation results show that, as compared with a sender-centric design, our proposed receiver-centric forwarding scheme can greatly increase end-to-end forwarding throughputs and reduce end-to-end packet delay time for an 802.11(p)/1609 vehicular network.

The rest of this thesis is organized as follows. The related work is discussed in Chapter 2. In Chapter 3, the standards of the IEEE 802.11(p)/1609 are introduced. Our proposed multi-hop routing schemes are explained in Chapter 4. In Chapter 5, we present the simulation results and performance evaluation. Finally, we propose possible extensions to our work in Chapter 6 and conclude the thesis in Chapter 7.

# Chapter 2

# Related Work

As metioned in Section 1, in the 802.11(p)/1609 standards ([8][13][10][11][12]), multi-hop packet forwarding mechanism remains un-standardized. Thus, we proposed a new scheme to allow 802.11(p)/1609 networks to efficiently support multi-hop packet forwarding.

In the literature, many previous work (e.g., [2], [6], [1]) on the multi-hop routing techiques and evaluates the performance in the MANET (Mobile Ad-Hoc Networks) or VANET (Vehicular Ad-Hoc Networks). However, which are not suitable for the 802.11(p)/1609 networks due to the new operational mode. Our proposed receiver-centric multi-hop forwarding scheme use the position-based routing which is amended from [5].

We take the driver model [4] in our simulation platform in order to simulate real traffic. [7], [3] prodivdes us some useful information, thus we could verify the accuracy of our 802.11(p)/1609 module and then simulate more accurate results.

# Chapter 3

# Background

The IEEE 802.11(p) standard [8] is a draft amendment to the IEEE 802.11-2007 standard [9] to add wireless access in the vehicular environment (reffered to as the WAVE mode). It defines the enhancements to that 802.11 specification that are required to support Intelligent Transportation Systems (ITS) applications. The enhancements include data exchange between high-speed vehicles and between the vehicles and the roadside unit in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz).

The IEEE 802.11(p) standard is designed to collaborate with the IEEE 1609 standard suite, which defines the resource management [13], security services [10], networking services [11], and multi-channel operation [12] for a 802.11(p) WAVE-mode network. Fig. 3.1 shows the architecture of an IEEE 802.11(p)/1609 network. As one sees, the new network type supports the TCP/UDP/IP protocol suite and a new WAVE-mode short message protocol (WSMP). The former is used to accommodate existing IP-based network applications while the latter is used to disseminate small-sized packets that carry emergent road safety, location service, or traffic information.

The IEEE 802.11(p)/1609 MAC layer manages link bandwidth in a combined FDMA/TDMA manner. Fig. 3.2 illustrates how an IEEE 802.11(p)/1609 network utilizes its bandwidth resource. As Fig. 3.2 shows, the WAVE mode divides link bandwidth into a control channel (CCH) and multiple service channels (SCH). The

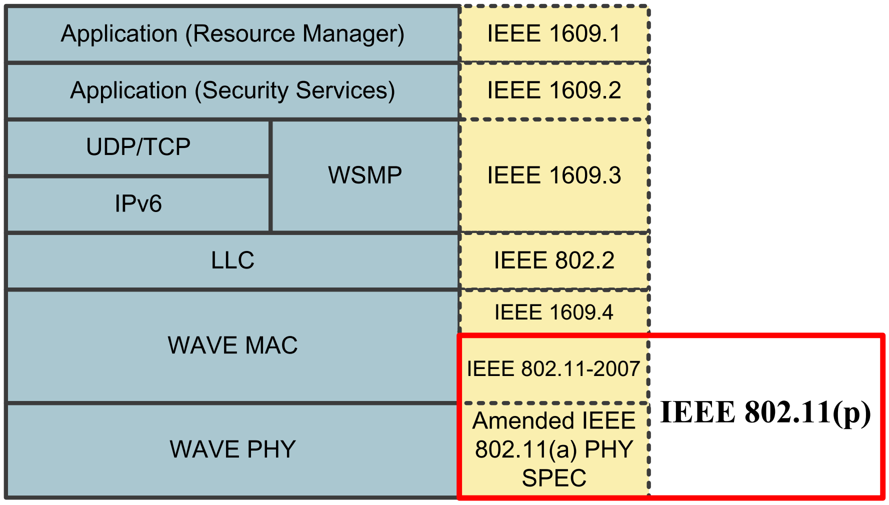

Figure 3.1: The protocol stack of an IEEE 802.11(p)/1609 network

CCH is dedicated for nodes to transmit WAVE-mode short messages (WSM) and announce WAVE services, while SCHs are used by nodes to transmit application data packets.

The link bandwidth of these channels are further divided into transmission cycles on the time axis, each comprising a control frame and a service frame. These two types of frames are represented by the black blocks and gray blocks, respectively in Fig. 3.2. In the IEEE 1609.4 draft standard [12], it is suggested that the duration of a frame (either a control or a service frame) is set to 50 milliseconds. In a transmission cycle, the control frame must be on CCH whereas the service frame can be on a specific SCH. The operation of the WAVE mode is briefly explained below.

In the WAVE mode, data packet transmissions are only allowed to occur within a Wave-mode Basic Service Set (WBSS). A node that initiates a WBSS is called a WBSS provider and nodes that join a WBSS are called WBSS users. After a mobile node joins a WBSS, it can start exchanging data frames with the provider of this WBSS. To establish a WBSS, as shown in Fig. 3.3, a WBSS provider has to

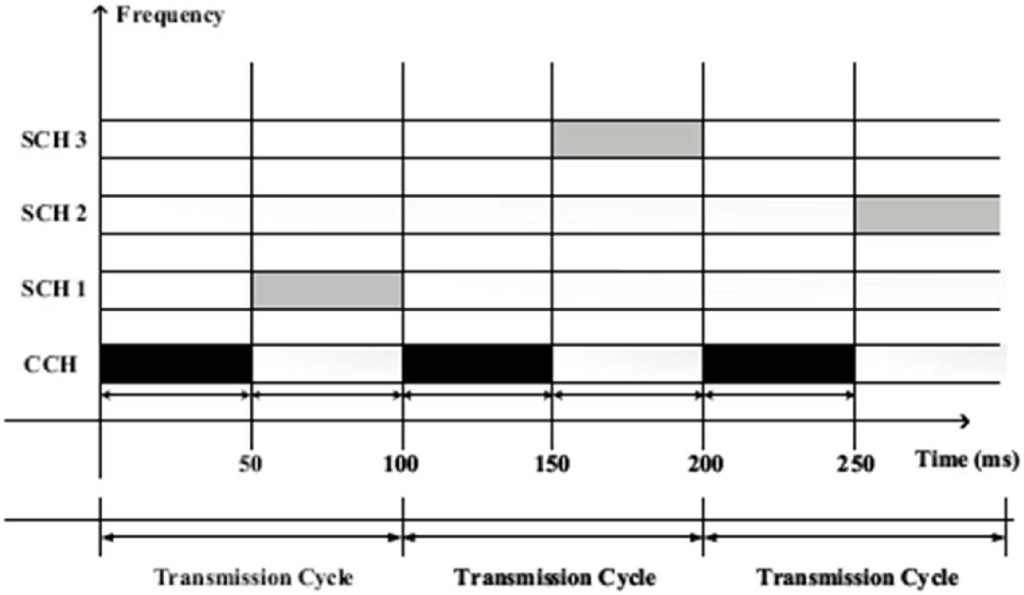

Figure 3.2: The operation of an IEEE 802.11(p) network

periodically broadcast a WAVE service advertisement (WSA) for this WBSS on the CCH during a control frame. A WSA consists of the operational information of a WBSS (e.g., the ID of this WBSS and the channel ID of the SCH that is chosen by this WBSS for data transmission).

After receiving the WSA message broadcasted by the WBSS provider, the node can join this WBSS by switching its operational channel on the SCH indicated by the WSA message. As such, on service frames the WBSS provider and its user nodes can exchange data packets on a specific SCH during service frames. The WBSS provider can periodically broadcast its WSA message on control frames to let users that are interested in its WBSS can know how to join this WBSS or to let users that has joined its WBSS can periodically update the operation paramters, such as operation SCH ID.

One should note that a WBSS user need not perform the authentication and association procedures to join a WBSS. (Note: these two procedures are necessary for a node to join an infrastructure BSS in the infrastructure mode of IEEE 802.11(a/b/g) networks.) The reason is that in a high-mobility environment, such as a vehicular communication network, wireless link connectivity among vehicles is very fragile. In such a condition, the chance for a high-speed vehicle to join a WBSS is much smaller than a fixed/nomadic computer to join an infrastructure BSS. With this design, a vehicle can quickly utilize the bandwidth of a WBSS after detecting its existence. However, the only drawback of this design is that a WBSS provider cannot detect whether any network node has joined its WBSS.

The physical-layer specification of the IEEE 802.11(p)/1609 network is an amended version of the IEEE 802.11(a) physical-layer specification based on the orthogonal frequency division multiplexing (OFDM) technology. Table 3.1 shows the main parameters used in the 802.11(p) physical layer.

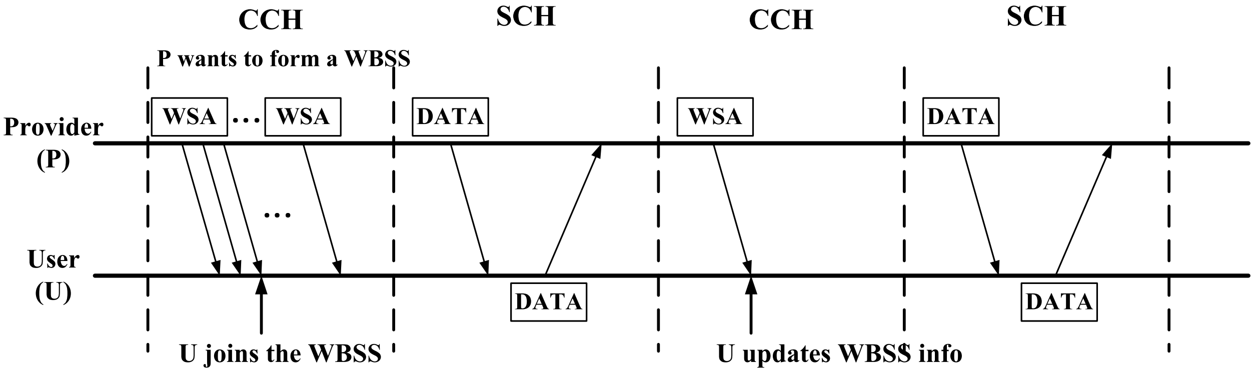

Figure 3.3: The WBSS establishment

Table 3.1: Main parameters of the IEEE 802.11(p) physical layer

| **Parameters** | **Details** |
|---|---|
| Data Rate | 3, 4.5, 6, 9, 12, 18, 24 |
| Modulation | BPSK, QPSK, 16-QA, 64-QAM |
| Coding Rates | 1/2, 2/3, 3/4 |
| Number of Subcarriers | 52 |
| Number of Pilot Tones | 4 |
| OFDM Symbol Duration | 8 msec |
| Guard Interval | 1.6 msec |
| Subcarrier Spacing | 156.25 KHz |
| Signal Bandwidth | 10 MHz |

# Chapter 4

# Multi-hop Forwarding over 802.11(p) Networks

In this chapter, we present the design of our proposed receiver-centric multi-hop forwarding scheme (RMFS). To show the advantages of our proposed receiver-centric approach, we compare the performances of our proposed scheme with those of a basic sender-centric multi-hop forwarding scheme (SMFS). The remainder of this chapter is organized as follows. In Section 4.1, we first present the schematic design of a sender-centric forwarding scheme, and in Section 4.2 we explain the design of our proposed receiver-centric forwarding scheme in detail.

## 4.1 SMFS

The design of a sender-centric multi-hop forwarding scheme is explained as follows. As shown in Fig. 4.1, when an 802.11(p) OBU node intends to send packets to another OBU node, it first checks if this intended receiving node is within its transmission range. If it is, it will form a WBSS for its data packet transmission. After listening to the WSA of the WBSS, the intended receiving OBU node can join this WBSS and then receive data packets sent from the transmitting OBU node. However, if the intended receiving OBU is two or more hops away from it, the transmitting node will first send its data packts to the RSU that is nearest to itself. Upon receiving data packets, a RSU should forward these received packets to 1) the backbone network (if the destination node is located in the Internet) or 2) a RSU that is closest to the destination node (if the destination node is in the same 802.11(p) network).

The rationale of this RSU-aided design is explained as follows. In a vehicular network, the communication link between two OBUs is fragile and volatile due to the high mobility of moving vehicles. As such, forwarding data packets in such a highly-mobile network using multiple vehicle-to-vehicle (v2v) links is unreliable.

In addition, forwarding packets in such a way is very time-consuming in an IEEE 802.11(p)/1609 network, because, in this type of network, a pair of nodes have to establish the WBSS provider-user relationship before they can exchange data packets. Under this limitation, $N$-hop data forwarding requires the time overheads for establishing $N$ WBSSs, which greatly increases the end-to-end packet delay times experienced by the source and destination nodes.

Due to these reasons, exploiting fixed RSU nodes to increase the packet forwarding performances is effective to increase the reliability of forwarding data packets in 802.11(p) vehicular networks. Fig. 4.2 shows an example scenario of SMFS. In this example scenario, the source and destination OBU nodes cannot directly communicate with each other. As such, the source OBU node first creates a WBSS for seeking a neighboring OBU node to relay its data packets to the nearest RSU node. After receiving these data packets, the RSU node shall forward them towards the destination node.

Fig. 4.3 illustrates the one-hop forwarding process of SMFS and is explained here. Using SMFS, a source OBU should create a WBSS (and thus act as a WBSS provider), before it can transmit its data packets out. After broadcasting the WSA message for the created WBSS on a control frame, the source OBU node assumes that a neighboring node has attached to its WBSS and thus starts to broadcast its data packets in its WBSS on subsequent service frames.

As such, if an OBU node has attached to this WBSS and successfully received the packets transmitted from the provider, it can forward these packets towards

Figure 4.1: A SMFS scenerio in which the source node can directly communicate with a RSU node

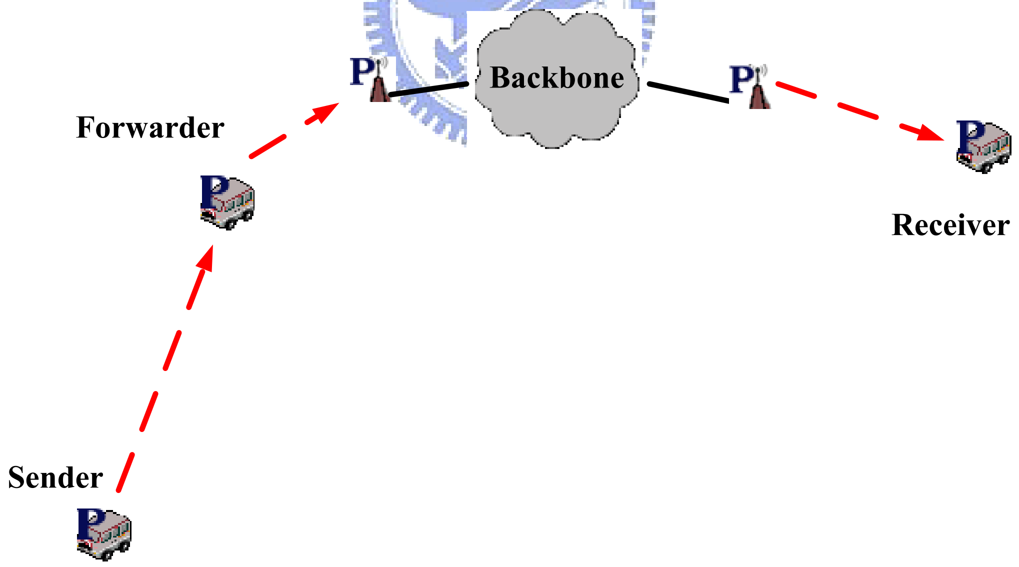

Figure 4.2: A SMFS scenerio in which the source node cannot directly communicate with a RSU node

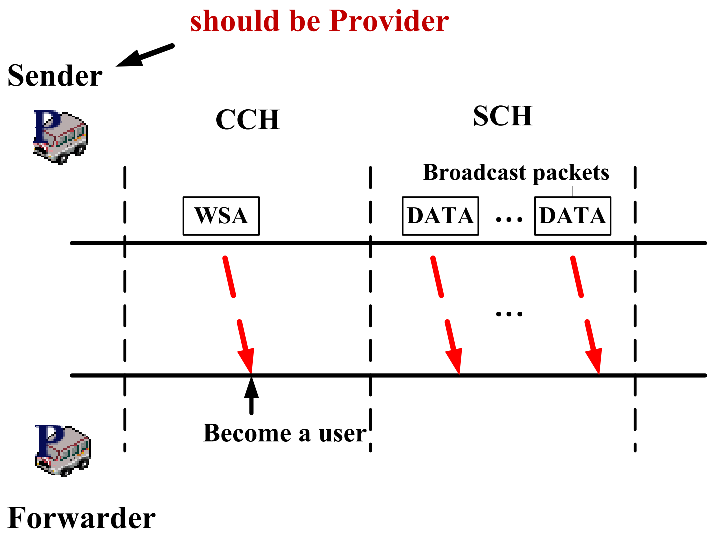

Figure 4.3: The procedure of SMFS

the RSU specified by the source node. Fig. 4.4 shows the timing diagram of the SMFS's forwarding procedure. As shown in Fig. 4.4, each node should maintain a channel utilization table based on received WSA messages broadcasted on control frames. The channel utilization table is used by a 802.11(p) node to keep track of the number of active users on each SCH. With the information of channel utilization, each 802.11(p) node can choose a least-used channel to create its own WBSS for packet forwarding, which can balance the load of each SCH.

## 4.2 RMFS

The design of SMFS is simple. However, SMFS has a drawback that signicantly decreases its packet forwarding performances and is explained below. As explained previous, using SMFS each transmitting node should assume that, after it announces the WSA message of its WBSS, potential receiving nodes will always switch their operational frequencies into the SCH indicated by the WSA message and join the WBSS. Nonetheless, this is not always true at all time. For example, suppose that

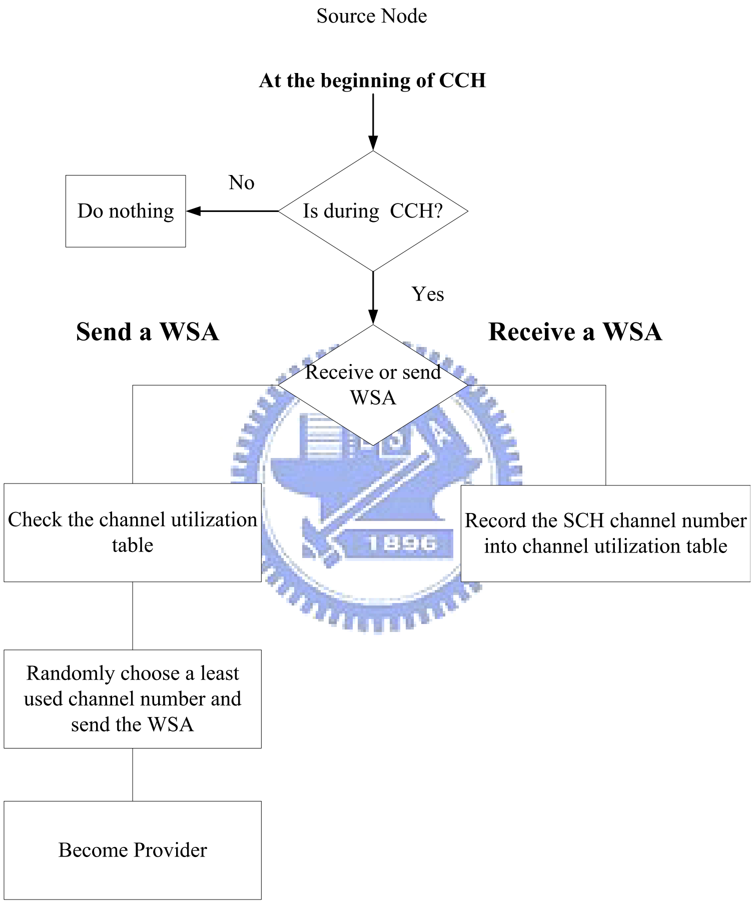

Figure 4.4: The flow chart of SMFS

a network is composed of three nodes, A, B, and C. Two transmitting nodes A and B simultaneously broadcast their WSA messages on the same control frame.

In such a condition, their common node C will listen to these two WSA messages at the same time. Consequently, node C can only attach itself to either node A's WBSS or node C's WBSS. Suppose that node C attaches itself to node A's WBSS. Then, it can only forward node A's data packets, and no nodes can forward the data packets broadcasted by node C. Because SMFS uses MAC-layer broadcasting to disseminate its packet, it cannot efficiently detect whether its transmitted packets are serviced by a neighboring node or not.

To address this issue, we propose a receiver-centric multi-hop forwarding scheme (RMFS) to efficiently carry out multi-hop forwarding in an 802.11(p) vehicular network. The operation of RMFS is explained below. As shown in Fig. 4.5, under RMFS, instead of creating a WBSS and announcing a WSA message, the transmitting node first uses a WSM to notify its neighboring nodes that it has packets that should be forwarded to a specific RSU node.

After receiving such a node $i$'s WSM, a neighboring node that is willing to forward node $i$'s data packets should create a WBSS and advertize the WSA message for this WBSS. If it has listened to a WSA message for acknowledging the same WSM message before its WSA message is transmitted out, it should cancel its WBSS and need not transmit the WSA message out. As such, ideally only one neighboring node will service node $i$'s forwarding need.

Using RMFS, every RSU should periodically flood its location information. Such location information should be flooded using a hop-count-based limited-flooding technique. In our simulations, we limit the flooding of this location information within four hops. RMFS employs geometric forwarding mechanism, i.e., each packet is forwarded geometrically towards the RSU node that is chosen by the source node.

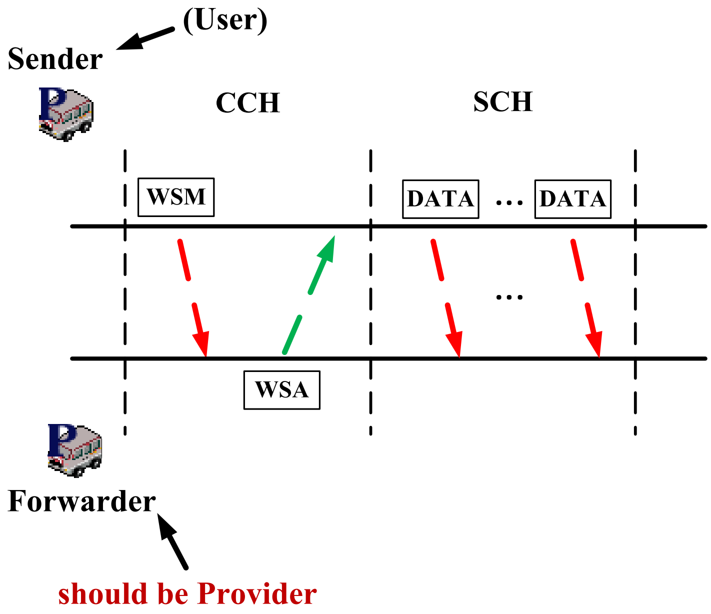

Figure 4.5: The procedure of RMFS

### 4.2.1 The Operation of a Transmitting Node (Acting as a WBSS User)

For RMFS, We also design a channel-load-balancing algorithm in order to efficiently utilize SCHs and to avoid traffic congestion on a specific SCH. Fig. 4.6 depicts the operation of a transmitting node, which should act as a WBSS user under our proposed RMFS.

A transmitting node should broadcast a WSM to notify neighboring nodes (its potential providers) of the channel number of the SCH that it chooses. The selection of the used SCH should be based on the utilization of each SCH, which is maintained in the channel utilization table. For a transmitting node, the selection of its used SCH is on the least-used basis.

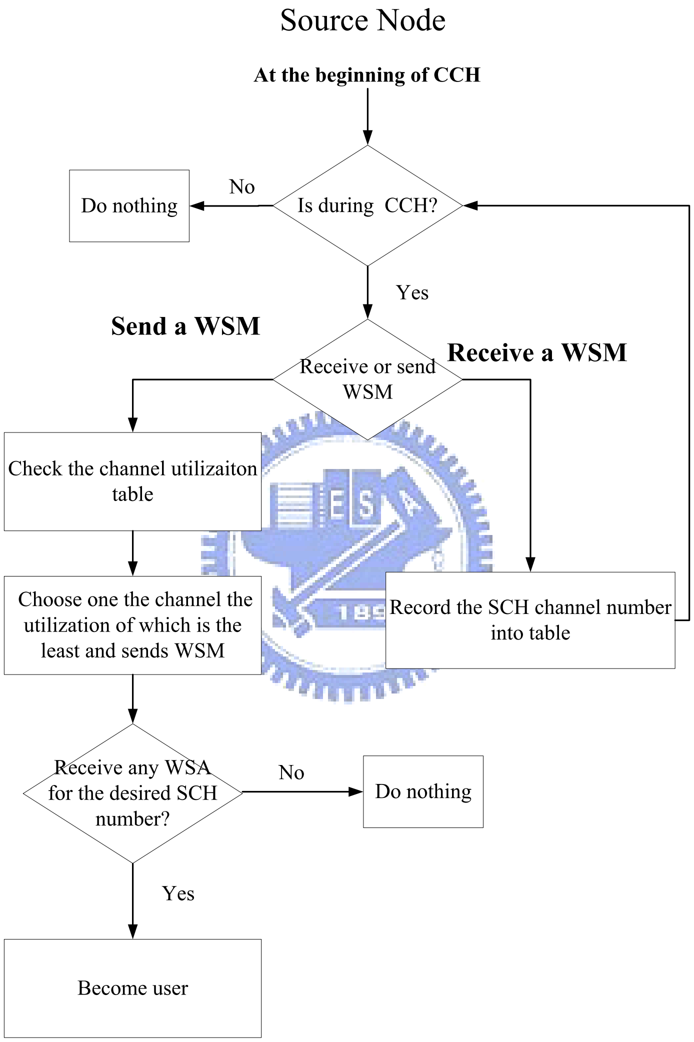

Figure 4.6: The processing flow of a transmitting node using RMFS

### 4.2.2 The Operation of a Receiving Node (Acting as a WBSS Provider)

Fig. 4.7 depicts the operation of a receiving node using RMFS. Under RMFS, each receiving node should actively create a WBSS and wait for the intended transmitting node's attaching. Upon receiving a WSM broadcasted by a transmitting node, it should update its own channel utilization table using the SCH channel number information indicated by the received WSM.

As shown in Fig. 4.8, when a WBSS provider, node A, receives the WSA message sent by another WBSS provider (node B), node A check whether this WSA message is used to service the same WSM that it intends to service. If it is, node A should cancel its own WSA broadcasting procedure immediately to prevent itself from servicing the same node. Using such a design, node A can have a chance to service another transmitting node for more efficiently utilizing its link bandwidth.

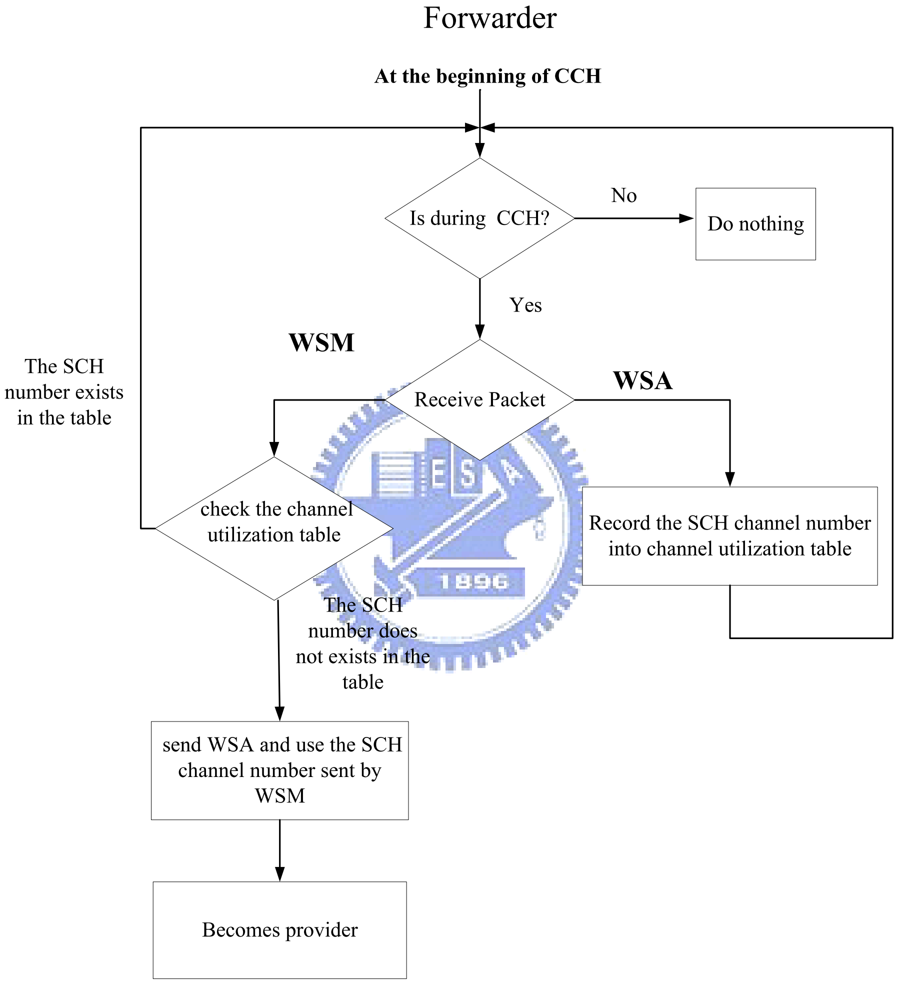

Figure 4.7: The processing flow of a receiving node using RMFS

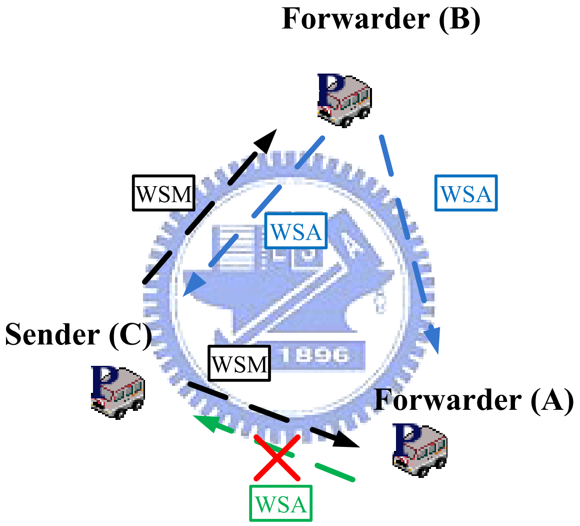

Figure 4.8: An example scenerio in RMFS

# Chapter 5

# Performance Evaluation

In this chapter, we first introduce the simulation software that are used for our simulation experiment and then explain the simulation scenerios. Finally, we present the simulation results of SMFS and RMFS.

## 5.1 Simulation Settings

### 5.1.1 Simulation tool

We adopt the NCTUns 5.0 [14] [1] network simulator to conduct our simulation experiements. The NCTUns 5.0 provides an open-architeture development environment, which allows protocol modules to be easily added to the simulation engine. Over this network simulator, we first developed the 802.11p protocol modules and then built our SMFS and RMFS on top of these protocol modeuls.

### 5.1.2 Simulation Topology

Fig. 5.1 shows the first simulation topology used for the performance evaluation. In this topology, one RSU is installed at the center of the map while twenty OBUs are randomly distributed on the roads.

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[1] NCTUns stands for National CHiao Tung University network simulator.

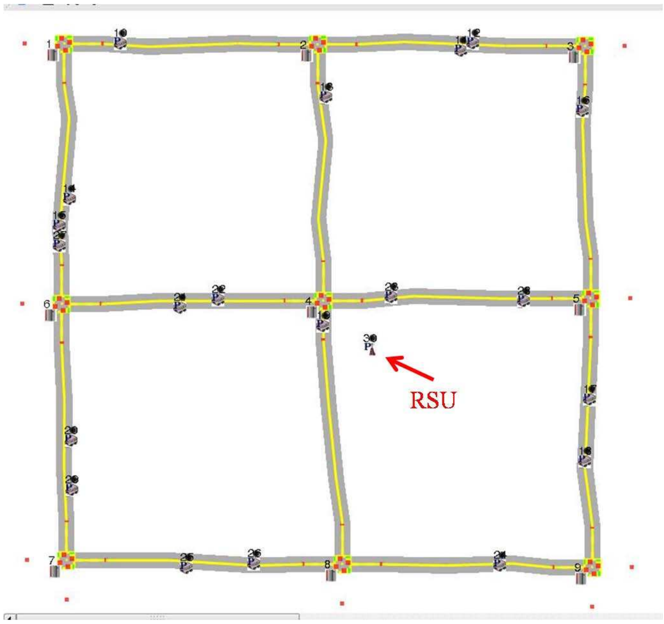

Figure 5.1: The topology of one-RSU

Fig. 5.2 shows the second simulation topology in which four RSUs are installed in the four corners of the map and twenty OBUs are randomly distributed on the roads.

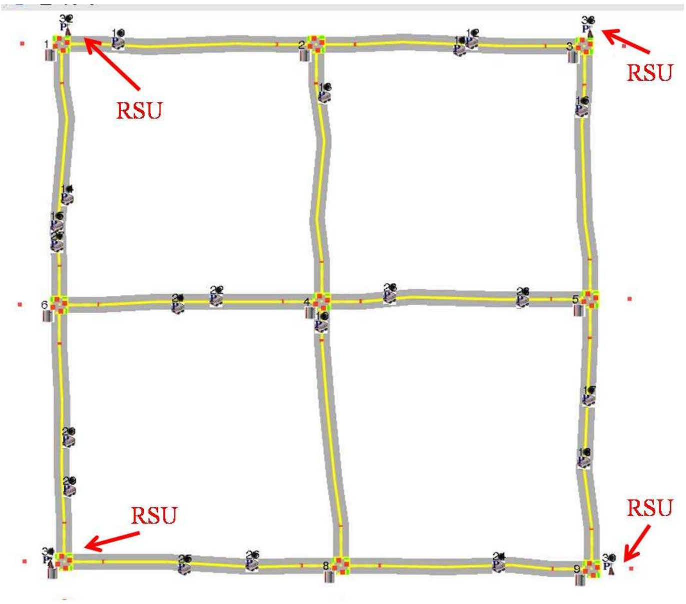

Figure 5.2: The topology of four-RSU

### 5.1.3 Simulation Metrics

In this section, we explain the simulation setting and the performance metrics used in our simulation. Table 5.1 shows the main parameters used in our simulations.

The used performance metrics are explained in details as follows.

- Aggreate UDP-flow Goodput (AUG)

Table 5.1: Simulation metrics used in our simulation

| **Metrics** | **Details** |
|---|---|
| Traffic Pattern | UDP with constant bit rate (CBR) |
| Transmitting Frequency(1) | one 1400 byte packet per 0.1 second |
| Transmitting Frequency(2) | one 1400 byte packet per 1 second |
| Number of Flows | 5, 10, 15, 20 |

The Aggregate UDP-flow Goodput is defined as follows:

$$AUG = \sum_{i=1}^{N} g_i(Kbytes/s) \tag{5.1}$$

where $t_i$ is the average goodput of the $i$th traffic flow and N denotes the total number of traffic flows in the simulation.

- Average End-to-end Packet Delay (AETEPD)

  The Average End-to-end Packet Delay is defined as follows:

  $$AETEPD = \frac{\sum_{i=1}^{N} AD_i}{N}(sec) \tag{5.2}$$

  where $AD_i$ denotes the average delay of the $i$th traffic flow and N denotes the total number of traffic flows in the simulation.

## 5.2 Simulation Results

### 5.2.1 The Simulation Results under 1-RSU topology

Fig. 5.3 and Fig. 5.4 shows the average end-to-end packet delay time and the aggregate UDP-flow goodput when packet transmitting frequency is set to one 1400 bytes packet per second. As can be seen, SMFS's goodput and delay time are both better than RMFS. That's because there is only one RSU so that most of the packets will remains in the mac queue. In addition, SMFS use the broadcast mechanism. Therefore, the transmission range of SMFS is larger than RMFS's. As a result, there may have the possibility that SMFS forwards a packet in fewer hops than RMFS. Another minor reason is that broadcast packet do not need to wait the reply of an ACK packet. However, RMFS use unicast scheme to forward packet that may consume a little more time.

By the way, when the flows increase, the delay time of RMFS fell near the SMFS. That is becasue some OBUs near the only one RSU are the source nodes. Then those sources can transmit packets to the RSU directly. That may reduce the average delay time.

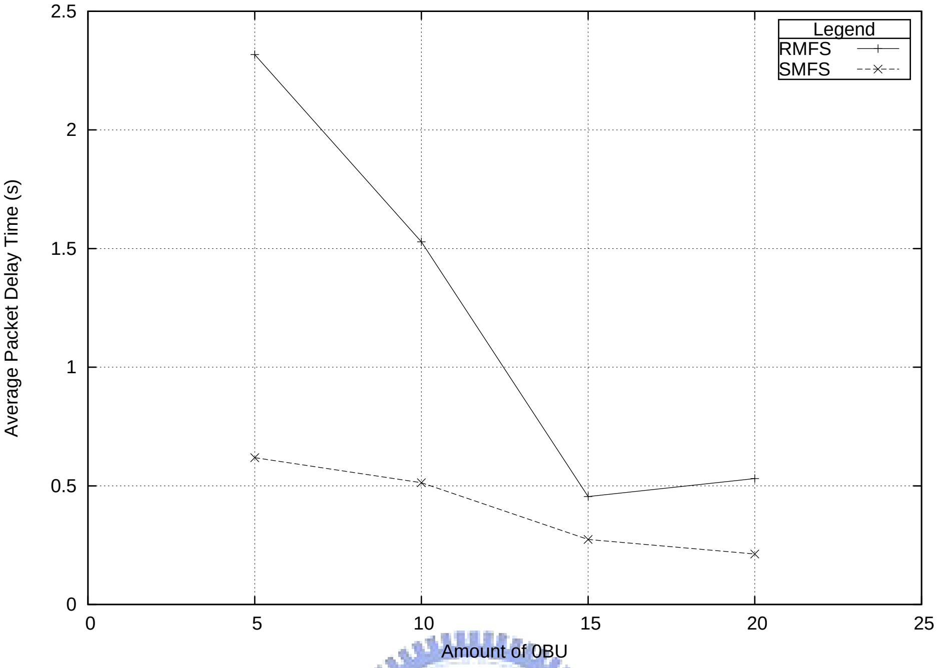

Figure 5.3: 1-RSU delay with UDP packets per 1 (s)

Fig. 5.5 and Fig. 5.6 shows the average end-to-end packet delay time and the aggregate UDP-flow goodput when packet transmitting frequency is set to one 1400 bytes packet per 0.1 second. Compare to the above section, The average delay time of RMFS is almost close to SMFS's. And the goodput of RMFS gains a 64% improvement when the flows set to 20. Due to the increasing of loading, the repeated receipt of broadcasting packets in the SMFS cause the lower goodput. Instead, as metioned in the Chap.3, RMFS take advantage of the channel-load-balancing algorithm. Furthermore, Geometric forwarding mechanism also reduces the redundency of packet trasmitting.

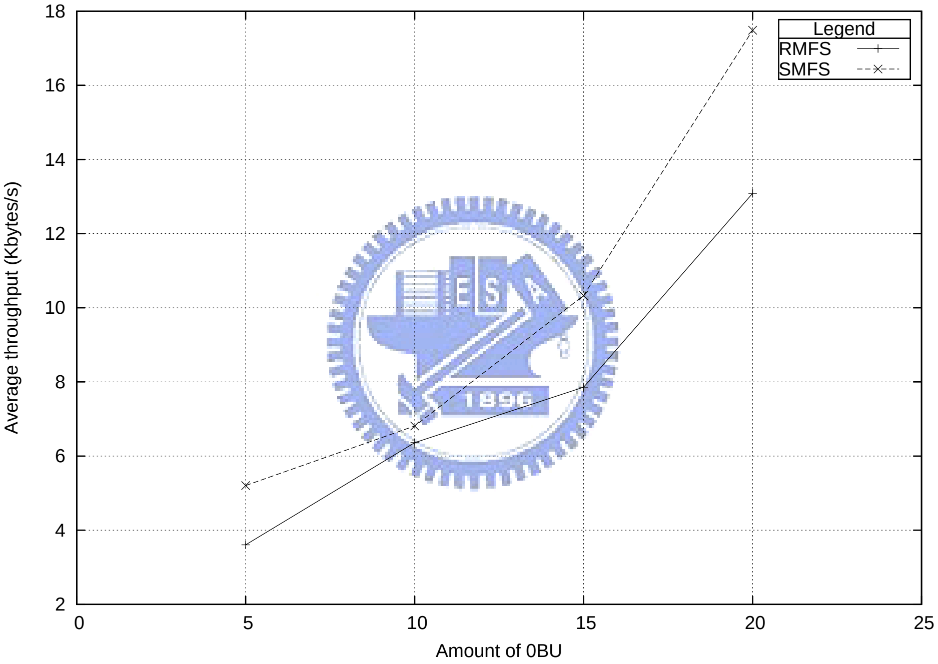

Figure 5.4: 1-RSU goodput with UDP packets per 1 (s)

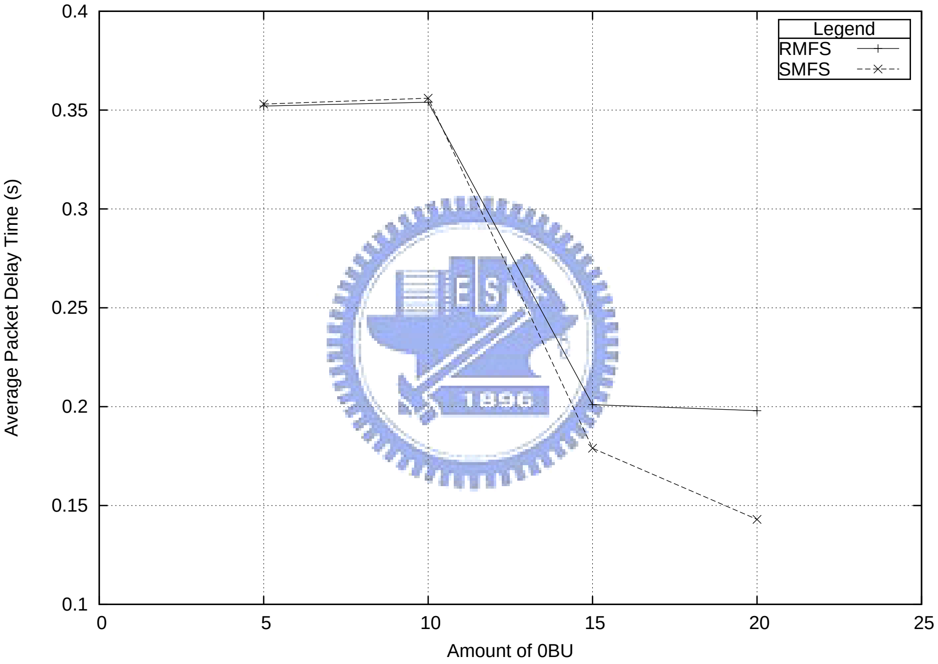

Figure 5.5: 1-RSU delay with UDP packets per 0.1 (s)

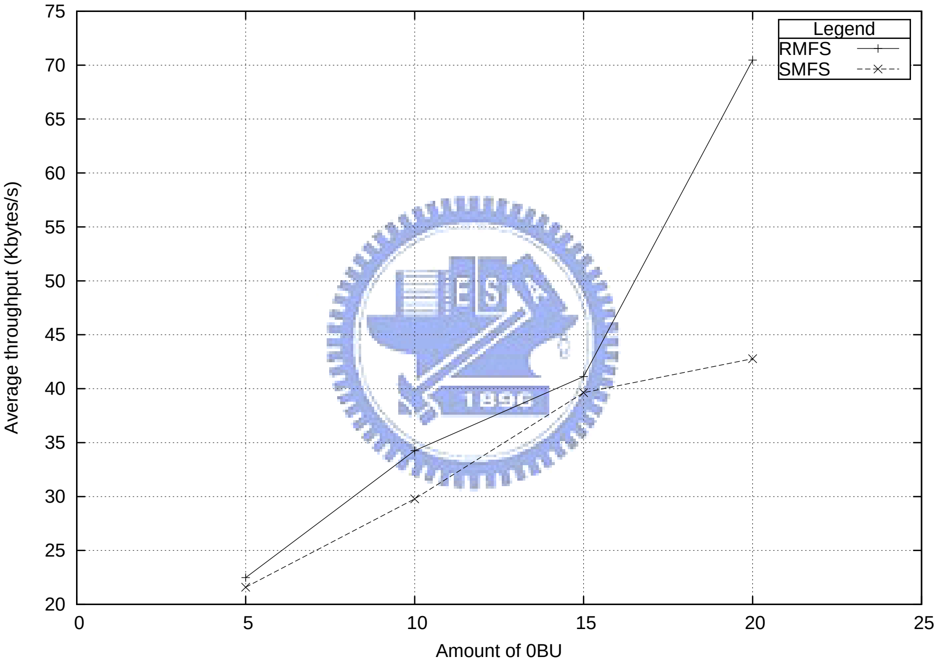

Figure 5.6: 1-RSU goodput with UDP packets per 0.1 (s)

### 5.2.2 The Simulation Results under 4-RSU topology

Fig. 5.7 and Fig. 5.8 shows the average end-to-end packet delay time and the aggregate UDP-flow goodput when packet transmitting frequency is set to one 1400 bytes packet per second. The delay time of RMFS has a 5% decline compared to SMFS's. And the goodput of RMFS gains a highly improvment instead of SMFS's. The drawback of SMFS have been fully exposed because every RSU maybe get the same broadcast packets. Also, the increased amount of the RSUs also benefits the performance of RMFS, i.e., the forwarding count maybe decreases. The queueing delay in the MAC layer may decrease because OBUs can easily find a RSU to forward packets.

Fig. 5.9 and Fig. 5.10 shows the average end-to-end packet delay time and the aggregate UDP-flow goodput when packet transmitting frequency is set to one 1400 bytes packet per 0.1 second. Compared to above two figures, the goodput get evidently better because the loading is extremely full. So the performance of RMFS reaches the highest peak. By the way, The average delay time has a little decline.

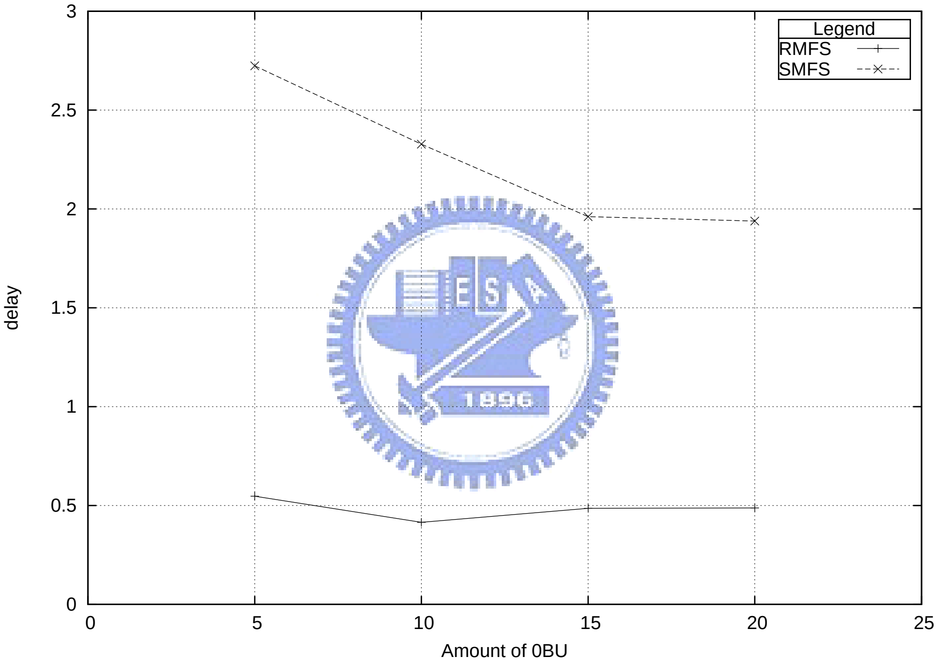

Figure 5.7: 4-RSU delay with UDP packets per 1 (s)

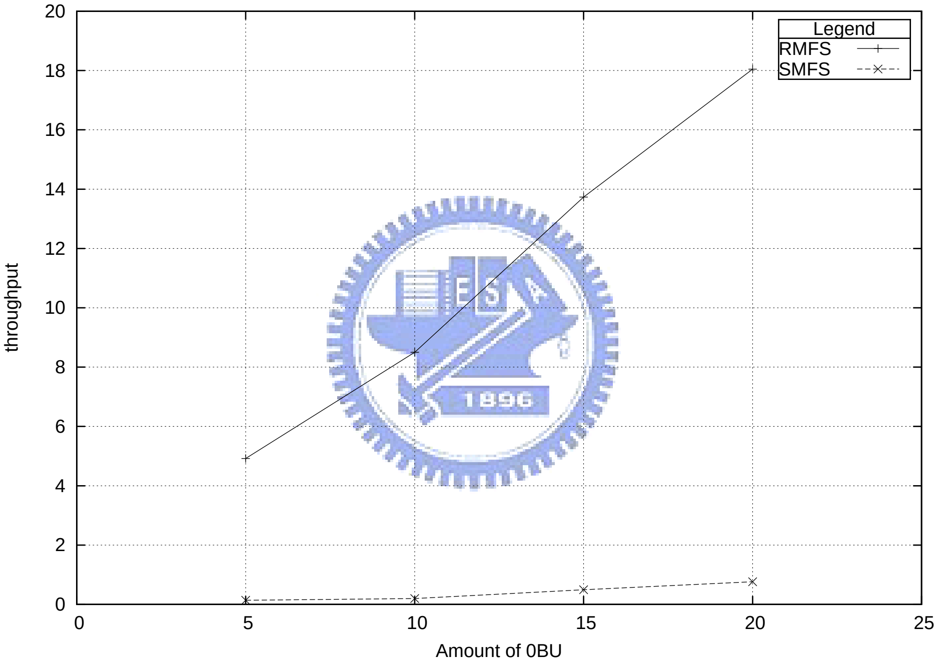

Figure 5.8: 4-RSU goodput with UDP packets per 1 (s)

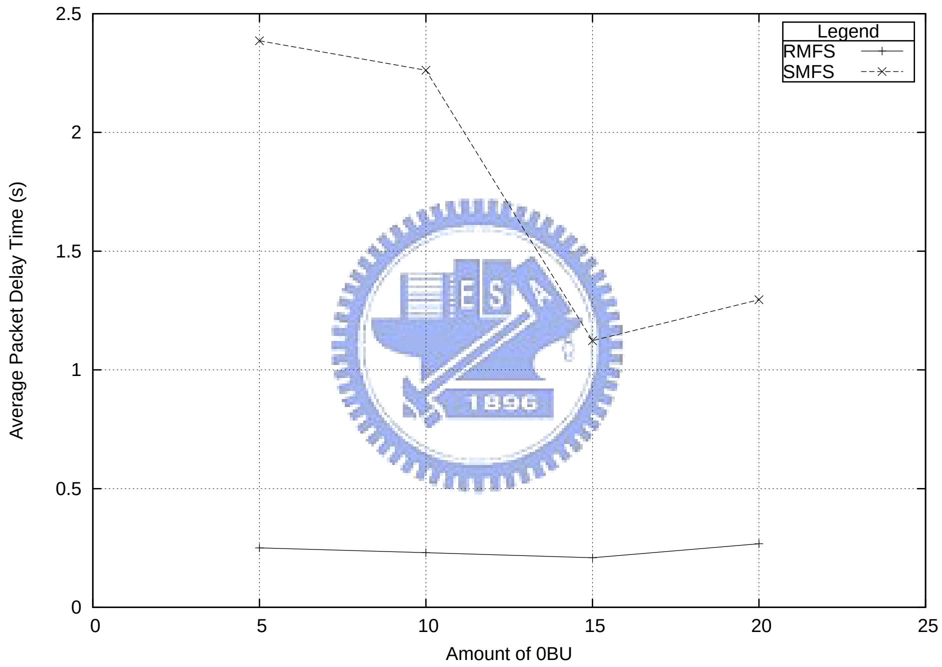

Figure 5.9: 4-RSU delay with UDP packets per 0.1 (s)

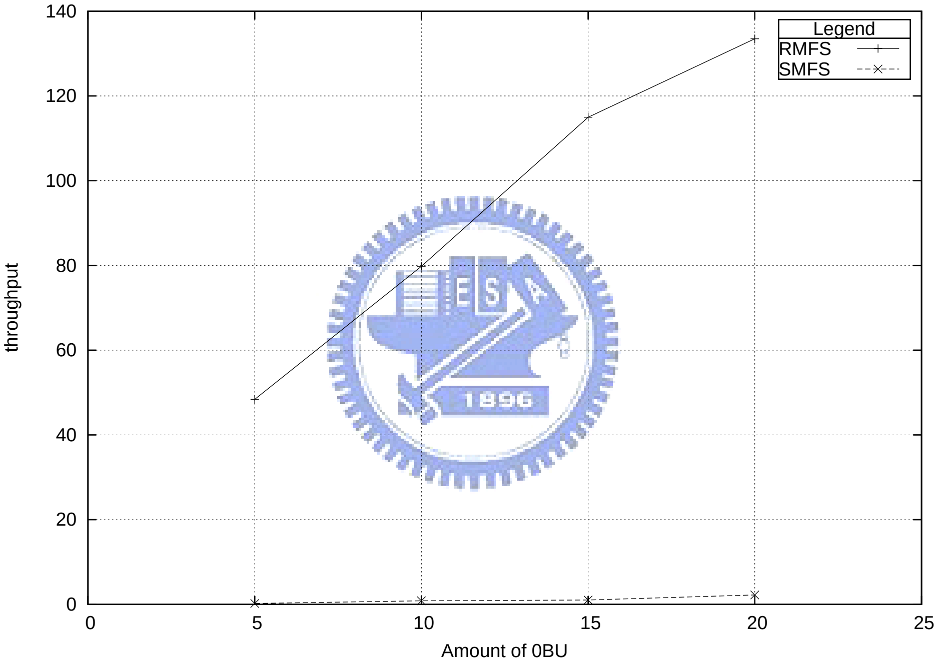

Figure 5.10: 4-RSU goodput with UDP packets per 0.1 (s)

# Chapter 6

# Future Work

We have already measured two types of the topologies. however, more dynamical topologies should be examined. For instance, we can adjust the amount of OBUs and RSUs or increase the map size. Moreover, the amount of cars can be increased. Some new parameters may be added such as the car velocity or packet-error rate. Therefore, we will study the performance of our proposed RMFS using more other system parameters.

To compare with our RMFS scheme, we will also evaluate unicast routing protocols, e.g. AODV, DSR, over 802.11(p) networks. To assure the improvement of our survey.

# Chapter 7

# Conclusion

The multi-hop packet forwarding mechanism in an IEEE 802.11(p) network remains un-standardized. There may have some of the applications need the multi-hop forwarding mechanism. Thus, we proposed RMFS to support multi-hop packet forwarding in an 802.11(p) network. Moreover, to compare with our RMFS, we also designed SMFS to show the basic operations of a original multi-hop mechanism in an IEEE 802.11(p) network.

Our simulation results show that our proposed RMFS can increase the application goodputs and reduce end-to-end packet delay time for an 802.11(p) network, as compared with SMFS. Though when there is only one RSU, the advantages of RMFS cannot be stand out. This result imply that RMFS maybe more suitable in the city-like environment. Instead of the environment that do not have much RSUs. By the way, the throughput of the two multi-hop mechanism seems not as good as one-hop transmission. The formation of WBSS cost most of the works.

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