國立交通大學

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碩 士 論 文

具訊框調整及功率控制能力之可適性 RR-ALOHA 無線隨意網路存取協定

An Adaptive RR-ALOHA for Wireless Ad Hoc Networks with Frame Size Adjustment and Power Control

研 究 生：湯和家

指導教授：簡榮宏 教授

中 華 民 國 102 年 8 月

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研 究 生：湯和家　　Student：Ho-Chia Tang

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摘要

在無線通訊網路中，如何減少傳輸的延遲是一項很重要的議題。尤其對於智慧型運輸系統(Intelligent Transportation System, ITS)中的安全性應用更為重要，稍微差了些微的時間，可能都會造成重大的危害。

現有的無線網路媒體存取控制(Medium Access Control, MAC)主要可分為兩大類: (1)基於競爭模式的媒體存取控制(Contention-based MAC protocol) 以及 (2)基於排程模式的媒體存取控制(Schedule-based MAC protocol)。在高密度的網路之中，基於競爭模式的媒體存取控制會造成大量的競爭碰撞，因此無法保證訊息傳輸的可靠性。而基於排程模式的媒體存取控制透過將時間分割，讓節點在屬於自己的時間內傳輸資料，其他節點無法在他人的時間內傳輸資料因而達到無碰撞的資料傳輸。其中，屬於排程模式媒體存取控制類型的 RR-ALOHA 還能避免隱藏節點問題。然而，當節點的數量超出訊框長度時，會造成部分節點無法獲得時槽(time slot)傳遞資料。解決此問題的方法大致可分為兩種，一種是增加訊框長度，另一種是減少節點的傳輸功率。但這兩種方法都會造成較大的傳輸延遲。

在此論文中，我們提出一種可適性 RR-ALOHA，藉由將 RR-ALOHA 結合訊框調整技術以及功率控制技術以避免時槽壅塞(slot congestion)問題，並同時保持較低的傳輸延遲。

An Adaptive RR-ALOHA for Wireless Ad Hoc Networks with Frame Size Adjustment and Power Control

Student: Ho-Chia Tang   Advisors: Dr. Rong-Hong Jan

Institute of Network Engineering

National Chiao Tung University

Abstract

Reducing transmission delay is an important issue in wireless networks. For example, the delay is particular critical to safety applications of Intelligent Transportation System (ITS).

Existing MAC protocols for wireless ad hoc networks typically be classified into two categories: (1) Contention-based and (2) Schedule-based MAC protocols. In dense networks, the contention-based MAC cannot guarantee the reliability because of the collisions. The schedule-based MAC can achieve collision free by assigning unique time slot for each node to send data. Moreover, RR-ALOHA can avoid hidden terminal problem. However, if the number of nodes exceeds the frame size, some nodes cannot reserve time slot to transmit data. Two methods can solve the slot congestion problem, one is increasing the frame size, and the other is reducing the transmission power. But, these two methods may increase the end-to-end delay.

In this thesis, we present an adaptive RR-ALOHA for wireless ad hoc networks which combines RR-ALOHA with an adaptive mechanism with frame size adjustment and power control to solve slot congestion problem and retain a lower end-to-end delay.

Keywords**: Ad hoc networks, distributed TDMA, RR-ALOHA, power control, frame size adjustment.**

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Chapter 1

Introduction

An ad hoc network is a distributed wireless network. In the ad hoc network, the communication does not rely on any fixed infrastructure. Though the ad hoc network, any node can directly forward data to other nodes.

Reducing transmission delay is an important issue in wireless networks. For example, the safety applications of Intelligent Transportation System (ITS), such as Cooperative Collision Avoidance (CCA) [1]. CCA transmits a warming message hop-by-hop to avoid the chain-car accident. More specifically, a vehicle will send a message to alarm other vehicles though CCA when a car accident happens. From above aspect, it is essential to reduce transmission delay of ad hoc network.

In this thesis, we focus on the Medium Access Control (MAC) layer. Existing MAC protocol for wireless ad hoc networks typically are classified into two categories: Contention-based and Schedule-based MAC protocols [2].

In contention-based MAC protocol, the nodes are allocated to randomly access the radio channel. When collision occurs, the node generates a random binary back off time. The node maintains the binary back off time until next contention, e.g. CSMA/CA mechanism in IEEE 802.11p [3]. However, contention-based MAC protocol has some disadvantages because it cannot avoid collisions, especially in high density networks.

Schedule-based MAC protocol, such as Time Division Multiple Access (TDMA), it offers a collision-free scheme by assigning time slots for every node. For example, node can transmit data at its own time slot, and other nodes cannot transmit data at that time slot. By this way, the nodes can guarantee period of time to access the channel. Furthermore, if the slots were allocated according to two-hop-nodes information, the hidden terminal problem can be solved [4]. In order to improve the reliability, there have been many works on the TDMA based MAC protocols [4][6][10-17].

Schedule-based TDMA MAC protocol can be classified into two categories: Static frame size and Dynamic frame size. Static frame size TDMA MAC protocols are as mentioned above, time be divided into frames and the frame is composed by time slots for collision-free transmissions and each node can transmit data by reserving time slot.

However, in a dense network, the number of nodes may more than the number of time slots, in this case, node may not able to reserve free slot to transmit data, it is called *congestion problem* [5]. Moreover, if there are too many nodes cannot reserve time slot, the network may be disconnected. This problem is important in vehicular environment, if the messages loss due to shortage of free slot, it may cause traffic accident. Otherwise, if the frame size more than the number of nodes, in this case, the network resource is wasted, and the nodes have to wait more time to transmit data again.

In order to solve slot congestion problem, dynamic frame size TDMA MAC protocol be developed, which can adjust the frame size according to network density [6]. By adjusting the frame size, more nodes can reserve free slot to transmit data. Therefore, the larger frame size the more time before next frame coming. It means that each node has to wait longer time to transmit again. This phenomenon will more significant to the end-to-end delay. For example, if a packet has to be transmitted through multiple hops to destination, when the packet via every node in the path to destination, the delay at each hop will increase and the end-to-end delay will increase, too.

Another method to solve slot congestion problem is PC-ALOHA [7], this method combines schedule-based MAC protocol with an adaptive power control technique to avoid channel congestion. By reducing the transmission power range of nodes, number of nodes in transmission power range will decrease. Moreover, more nodes can reserve free slot without collision. But, it means the hop counts in the whole network will increase, and the end-to-end delay will increase, too.

In this thesis, we aim to combine dynamic frame size TDMA MAC protocol with an adaptive power control technique to avoid slot congestion problem and retain a lower end-to-end delay. More specifically, we adaptively decide the method from the two mechanisms to solve slot congestion problem that will bring about lower end-to-end delay at the time.

The remainder of the thesis is organized as follows: In Chapter 2, we introduce the previous studies of schedule-based MAC protocol and power control mechanisms for congestion problem. In Chapter 3, we introduce a well-known schedule-based MAC protocol and the methods to solve slot congestion problem of RR-ALOHA. In Chapter 4, we present our MAC protocol. Simulation results of our protocol are presented in Chapter 5. Conclusions are given in Chapter 6.

Chapter 2

Related Works

Reservation ALOHA (R-ALOHA) [8] is a distributed TDMA protocol. By dividing channel access time into time slots and each node can contend to reserve a free slot to transmit packet. But, R-ALOHA cannot avoid hidden terminal problem [9], because a node cannot know the slot information of two-hop members.

Reliable R-ALOHA (RR-ALOHA) [4] is an improved protocol, in order to increase reliability and overcome the hidden terminal problem. In RR-ALOHA, when a node enters the network, it listens a frame time and receives the information from other nodes. The information called Frame Information (FI), each node in the network will broadcast FI in its time slot. Moreover, the FI includes the slot status about the node and the one-hop members of the node. By exchanging this FI, a new node can know the time slot allocation of its two-hop members, and it reserve an available time slot without collision. In this way, it can overcome hidden terminal problem.

The authors of RR-ALOHA combined the protocol with an optimal multi-hop broadcast service, this new protocol called ADHOC-MAC [10]. In ADHOC-MAC, the broadcast service reduces retransmissions by using small number of relaying terminals to cover all nodes in the network.

In [6], the authors proposed an adaptive ADHOC MAC protocol (A-ADHOC) for wireless vehicular ad hoc network based on ADHOC MAC. The protocol can adjust frame size according to vehicular density. If the number of nodes is more than the upper threshold, every node can broadcast the message to double the frame size, in the other hand, if the number of nodes is less than the lower threshold, every node can broadcast the message to half the frame size. This mechanism can solve the congestion problem by adaptively changing the frame size at each node. However, the longer frame size will bring a larger end-to-end delay.

There are many theses with adjust frame size mechanism for wireless ad hoc network [11][12]. In [11], the authors proposed a dedicated multi-channel MAC (DMMAC). They divide the CCH into an Adaptive Broadcast Frame (ABF) and a Contention-based Reservation Period (CRP). In the duration of ABF, each node tries to content the free slot for sending the FI which based on RR-ALOHA. If CCH is congested, DMMAC can adjust the frame size in ABF. In [12], this thesis proposes a TDMA-based reservation MAC protocol with changes the frame size slot by slot when there is no free slot can be reserved.

A number of studies have been proposed to adapt the VANET with RR-ALOHA [13][14][15][16][17]. In these research, the goal is to increase the reliability in VANET.

In [13], authors proposed a protocol similar to RR-ALOHA called Distributed Reliable Multi-channel MAC (DR-MMAC). They showed the delivery ratio of WAVE MAC will decrease when the network density increases, because of the collision in control channel and hidden terminal problem. Their protocol can guarantee 100% delivery ratio. However, the number of time slot in DR-MMAC is fixed, which means that if the number of vehicle is larger than the number of time slot, the delivery ratio will decrease.

The VeMAC [14] divides the CCH into time slots and classifies the time slots into three sets, according to the moving direction of vehicles (Left or Right) and Road Side Units (RSUs). By this way, the slot collision problem called *merging collision* can be avoided. The *merging collision* problem happens when two opposite vehicles are using the same time slot without collision since they are not in the same sub-network. But, when the two vehicles are approaching to each other, the collision will happen.

In RR-ALOHA+ [15], MS-ALOHA [16] and MARR-ALOHA [17] are proposed the mobility problem with RR-ALOHA in VANET. The mobility problem is a critical issue in RR-ALOHA with VANET. For example, the new node brings the old FI in the origin sub-network to other sub-network, the collision will happen.

In MARR-ALOHA, each node calculates a *count-3hop* and a *count-2hop*, which separately record count of two-hop neighbors and three-hop neighbors that transmit in a certain slot. Moreover, each node can choose the time slot with smallest *count-3hop* to reserve. By this method, the collision in three-hop range can be reduced.

The collision problem in contention-based MAC protocol is a critical problem. There many researches were designed to avoid congestion. For example, if the traffic density is high on channel, they can adjust the transmission power. In [18], they proposed a Fair Power Adjustment for VANET (FPAV) algorithm. This algorithm is to reserve a chunk of bandwidth for event driven message. By this way, the communication of safety application is not obstructed by channel saturation. But it is a centralized algorithm. In [19], the authors further propose a distributed algorithm, called Distributed Fair Power Adjustment for Vehicular networks (D-FPAV). This method collects status information and exchanges the power level in distributed way, but it will bring the huge overhead. The [20] proposed a method to improve the overhead in D-FPAV by exchanging the number of vehicles in each road segment and estimate the load of channel.

The PC-ALOHA [7] combines the power control and RR-ALOHA to solve slot congestion problem and hidden terminal problem. This protocol adds additional GPS information in FI, and each node can know the distance between other nodes. When the new node enters to the network, the node collects FIs form other nodes to realize the slot status, if no free slot can be reserved, it adjusts its transmission power range according to the slots which be reserved by two-hop members, and re-use the time slot.

However, the above researches can alleviate the channel congestion by power control or frame size adjustment, but these studies cannot guarantee the lower end-to-end delay. In this thesis, we propose a schedule-based MAC protocol with RR-ALOHA, and we combine RR-ALOHA with the method of power control and the method of frame size adjustment to solve slot congestion problem. In order to achieve lower end-to-end delay, our protocol adaptively selects the lower delay method to solve the slot congestion problem at that time.

Chapter 3

Background Knowledge and Problem Description

In this chapter, first, we introduce the Reliable R-ALOHA. Second, we illustrate the slot congestion problem. Third, we introduce the methods to solve the slot congestion problem. Finally, we discuss the main idea of our protocol.

3.1 Preliminaries on RR-ALOHA

RR-ALOHA (Reliable R-ALOHA) is a MAC protocol based on Time Division Multiple Access. Under the construct of RR-ALOHA, the node will achieve collision free and avoid hidden terminal problem by transmitting additional Frame Information (FI), FI includes the node ID and the status of which slot be used by one-hop member. By these FIs, every node in the network can get the slot status of two hop members.

When a new node V_i enters the network, it needs to do following steps. First, node V_i listens a frame to collect Frame Information (FI), and the node V_i checks if there is available slot or not, which called FREE slot. If there exists any FREE slot *n*, it broadcasts a FI on FREE slot *n* to reserve the time slot; otherwise, node V_i cannot contend time slot, because all slots are used by other nodes. Second, if all one hop members received reserve message by node V_i , and then join this information to their FI and broadcast it in their time slot. Finally, if node V_i receives all FIs from its one hop members in this frame end and the FI includes node V_i using time slot *n* which means this reservation is successful; otherwise, there are some one hop members did not receive the FI of node V_i, node V_i needs to contend time slot in next frame.

As shown in Figure 1, the number of time slot is 6. Node F connects to node A and node D, and node E connects to node C. If a node V_i wants to join the network, it needs listening to a frame and collects FIs from its one hop members. After this step, node V_i can know which one hop node use which time slot directly, the one hop node A, B and C use time slot 3, 2 and 1, respectively, and time slot status which comprises one hop members and two hop members by the FIs that one hop members send (i.e. slot status of FI:A is time slot 2, 3, 4 and 5 are used by node B, A, F and D, respectively.)

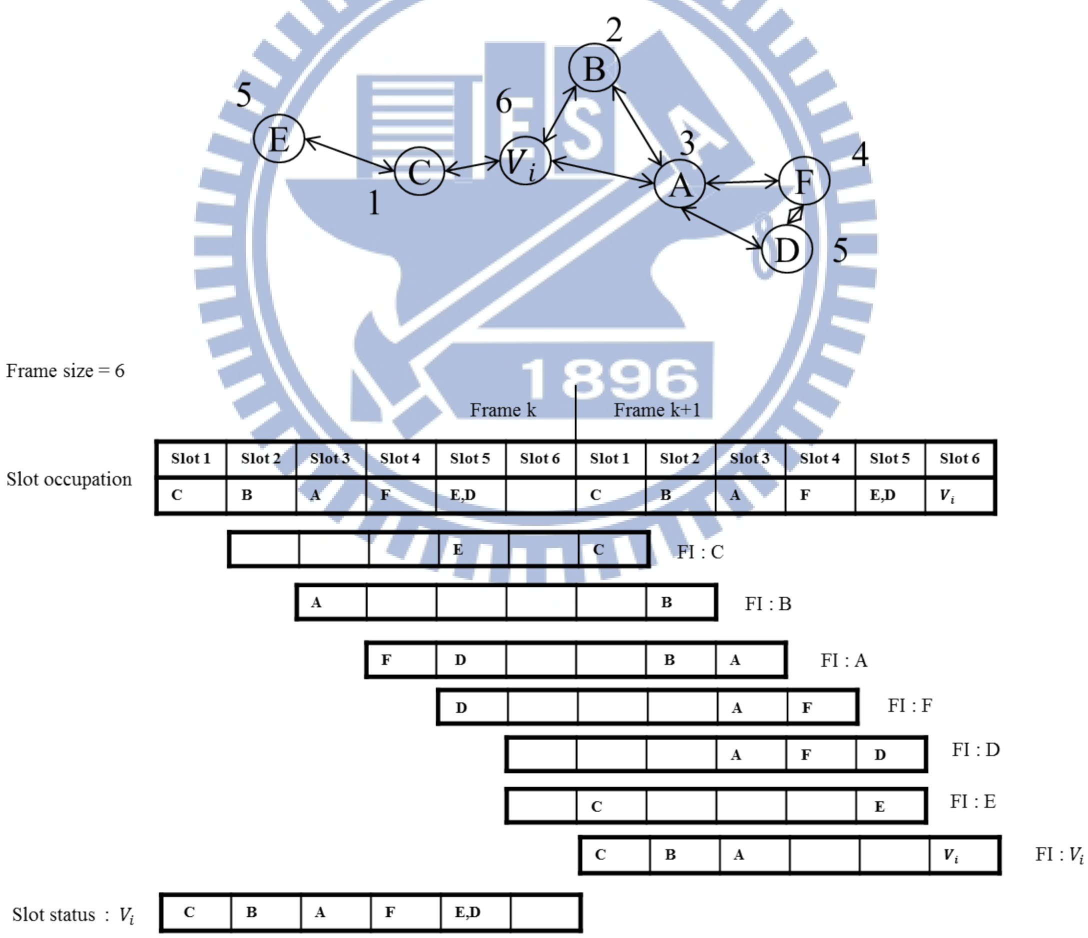


Figure 1. An example of slot reservation of frame size 6.

Therefore, node V_i can get the slot status of one hop members and two hop members, and will find slot 6 is free. Node V_i transmits its FI at slot 6 and waits for a frame time (frame time = 6 slots in Figure 1). If all one hop members of V_i receive the FI, they mark slot 6 used by node V_i in their FI and transmit in their time slot, and node V_i reserve slot 6 successfully.

3.2 Slot Congestion Problem

If all nodes can reserve time slot to transmit data, the process goes well, but there are some problem with RR-ALOHA. Suppose there are M slots in one frame, and there are N nodes trying to contend for time slot to transmit data. First, if frame size is too large that the number of time slots more than the number of nodes (i.e. M > N), it may incur a larger delay since node has to wait for a long time to transmit data again before next frame coming. In the other hand, if in a dense network (i.e. M < N), the channel congestion problem may occur. As shown in Figure 2, in the network, there are 7 nodes and 5 time slots. Assume that time slots 1, 2, 3, 4 and 5 already be reserved by node A, B, C, D, E and F. Therefore, node V_i cannot find any FREE slot to reserve and node V_i cannot transmit data in the network. What is more serious is that cannot guarantee the network connectivity.

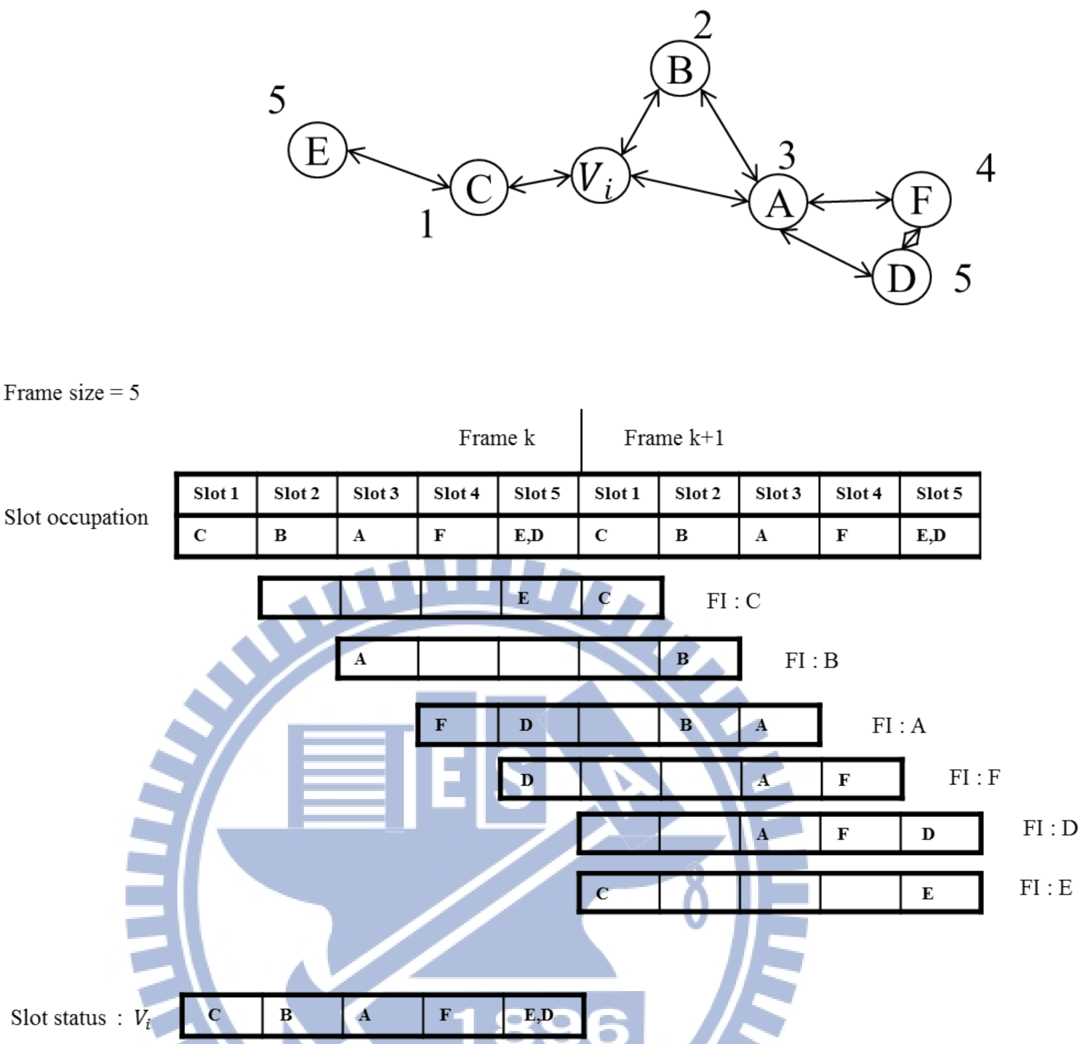


Figure 2. An example of slot congestion of frame size 5.

As shown in Figure 3, if some critical node (i.e. node V_i) cannot reserve time slot to transmit data, the message from network N1 cannot transmit to network N2. Similarly, any node in N2 (i.e. node F) cannot forward the packet to N1 via node V_i, either.

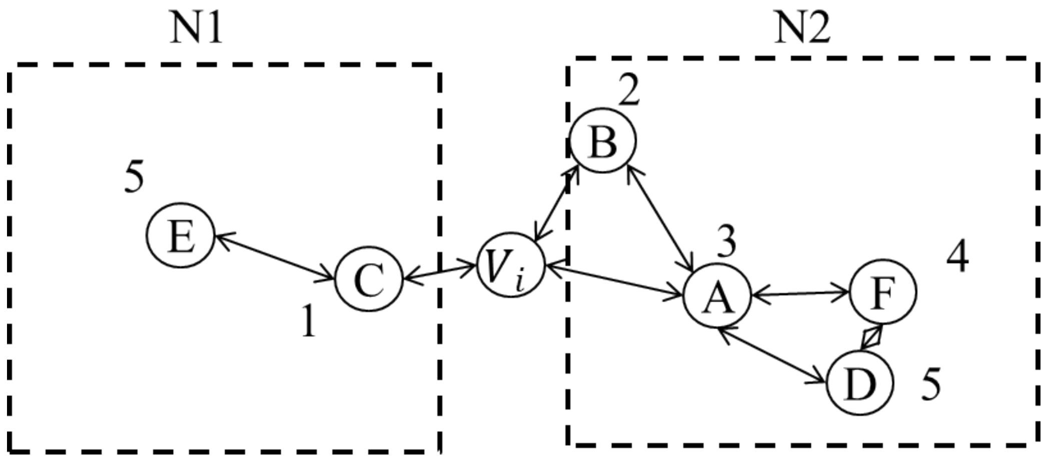


Figure 3. The network be separated by a node that cannot reserve time slot.

3.3 How to Solve Slot Congestion Problem

There are two basic ideas to solve the slot congestion problem, one is increasing the frame size, and another is reducing transmission power.

By increasing the frame size, more FREE slot can be reserved (i.e. new node V_i enters the network, if its frame size increase, there are more FREE slot, and node V_i can reserve time slot to transmit data.), but there is a frame synchronization problem between two nodes with different frame size. In A-ADHOC, solve this problem by restricting frame size adjustment only with multiple of frame size. As shown in Figure 4, the frame size of node E is 4 and other nodes are 8, but, this case will not collision since the frame size is multiple of the others frame size.

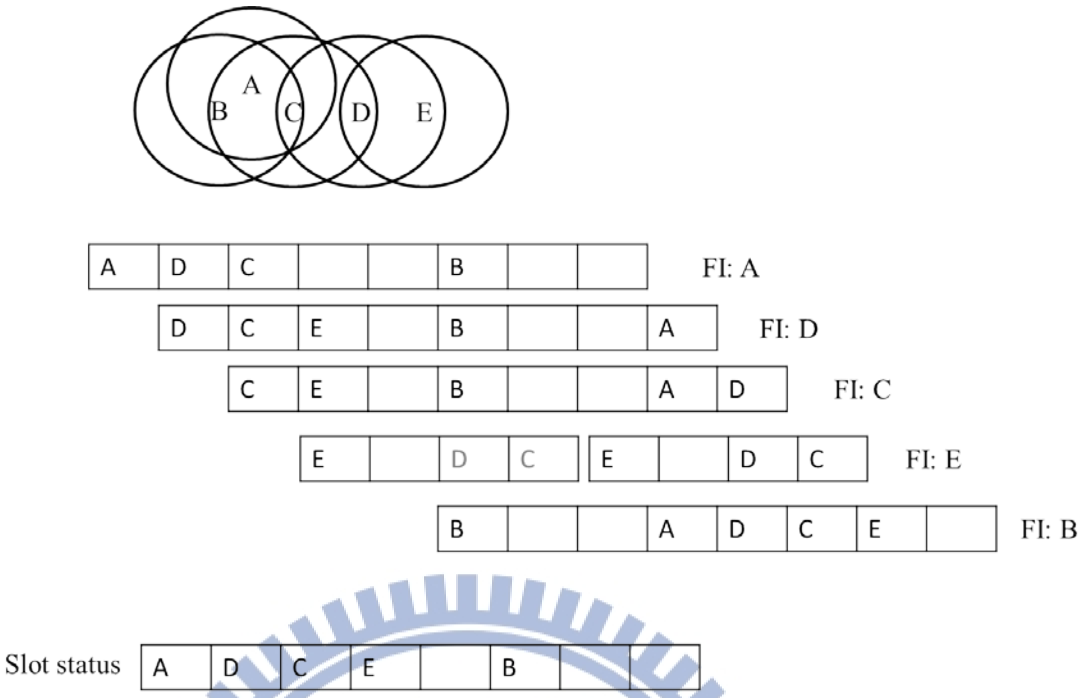


Figure 4. A simple example of frame synchronization in A-ADHOC

By reducing the transmission power, the number of one hop members and two hop members will reduce, and more slots can be re-use by the node which did not have time slot. As shown in Figure 5, the new node V_i enters the network, if it reduces its transmission power, the number of nodes in its two-hop-range decrease, too. Node V_i can re-use the time slot which be used by ex-two-hop-members, but how to maintain network connectivity is a question.

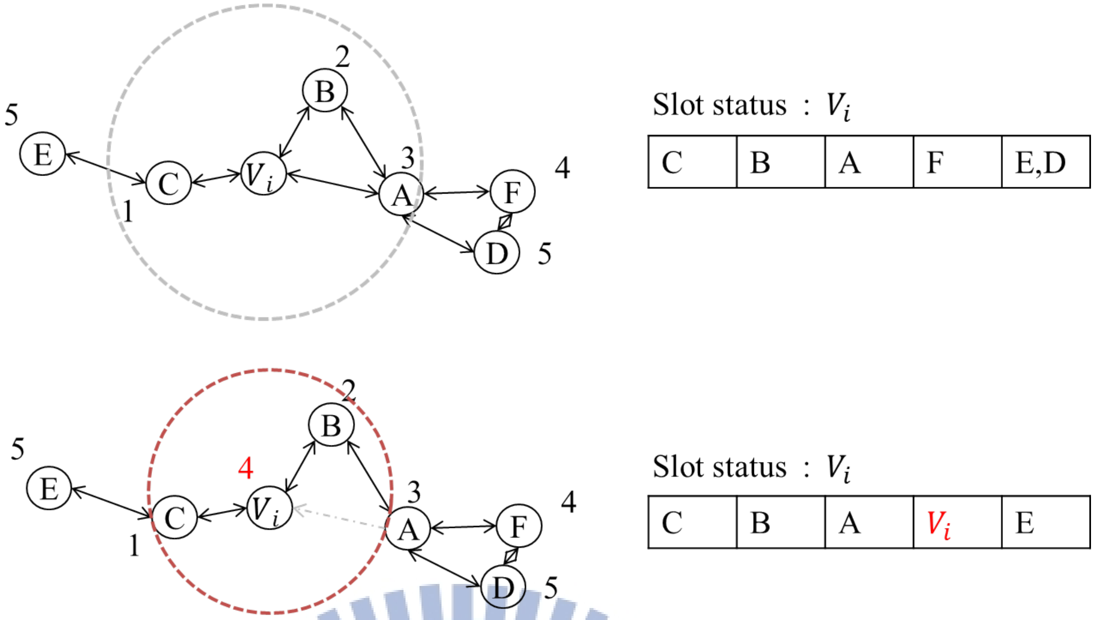


Figure 5. To solve congestion problem by reducing the transmission power.

In PC-ALOHA, it uses the Gabriel Graph (GG) to check the network connectivity after adjust transmission power. GG is a connection scheme proposed by Gabriel and Sokal (1969), if there is a circle with the diameter of two endpoint, and does not have any point within the circle, it means the two endpoints are Gabriel neighbors. Mathematically, the GG is defined as follows: there are three vertices x, y and z, if the circle with edge (x, y) as diameter, and no vertex z within the circle, vertex x and vertex y are Gabriel neighbors. Otherwise, if the vertex z within the circle with edge (x, y) as diameter, vertex x and vertex y are not Gabriel neighbors, as shown in Figure 6 and Figure 7.

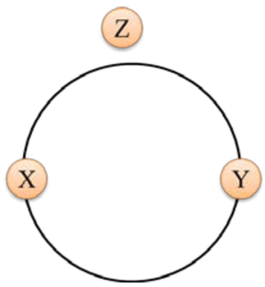


Figure 6. Node x and y are Gabriel neighbors.

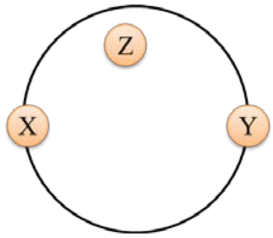


Figure 7. Node x and y are not Gabriel neighbors.

By the definition of GG, PC-ALOHA adjusts the transmission power of the node which cannot reserve time slot. If it can find any point as vertex z as shown in Figure 7 from one hop members, the node can adjust its transmission power and maintain network connectivity at the same time.

But, these methods make more delay increase, for instance, the node V_i increases the frame size, the frame time increases, too. It will make more delay time in the network. By the other hand, if the node V_i reduces the transmission power, the packets be transmit via node V_i will increase the hop counts, and make more delay time in the network.

In this thesis, we propose a protocol which can adjust the frame size and the transmission power at the same time, and we aim to solve slot reserve congestion problem and minimize the end-to-end delay.

Chapter 4

Protocol Design

In this chapter, we present the Adaptive Frame size and Power control ALOHA (AFP-ALOHA). We describe the main idea of our protocol in 4.1. Then, we discuss how to calculate the end-to-end delay. In last part, we summarize the algorithm of AFP-ALOHA.

4.1 Main Idea

AFP-ALOHA is a medium access protocol with RR-ALOHA for ad hoc network. It is a schedule-based MAC protocol and it can adjust frame size and transmit power for solve slot congestion problem of RR-ALOHA with lower end-to-end delay.

In order to solve congestion problem with lower end-to-end delay, we combine RR-ALOHA with the frame size adjustment mechanism of A-ADHOC and the power control mechanism of PC-ALOHA in our protocol. Then, we choose the lower delay method at the time to solve slot congestion problem. By this determination, it can maintain the communication of the nodes which had reserved time slot, and make lower delay increase with whole network. However, new node cannot know the delay to other nodes in the network, in order to solve this question, we transform the topology to directed weighted graph G.

4.2 Directed Weighted Graph

As shown in Figure 8. , node A in the transmit range of node B, and node B in the transmit range of node A, too. It shown these two nodes can direct transmit packet to each other without any retransmission. Therefore, we can transform this case to directed graph.

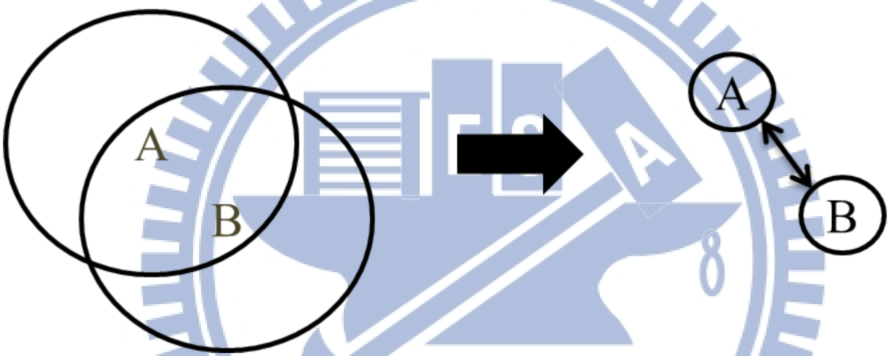


Figure 8. A simple directed graph.

In schedule-based TDMA MAC protocol, the node retransmits packet have to queue the packet upon the slot of this node coming. As shown in Figure 9. , node A use slot 1 and node B use slot 4, if a packet transmit from node A to other node via node B in slot 1, the packet has queue in node B until slot 4 coming, when slot 4 coming the node B can retransmit the packet. In this case, packet be queued in node B three slot times, we can understand the packet transmit from node A via node B to other node has to wait three slot time, in the other hand, node B transmit a packet to other node via node A has to wait two slot times. Therefore, we define the waiting time is the weight in the directed weighted graph G.

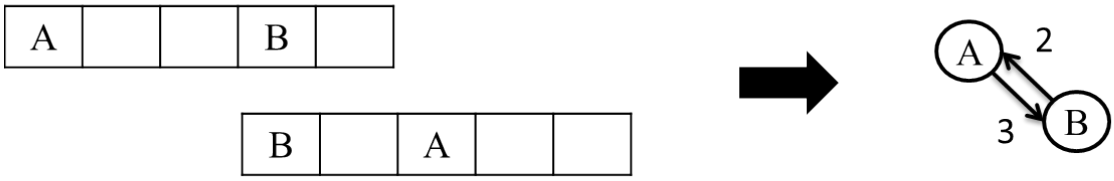


Figure 9. A simple directed weighted graph

By above transform, the nodes can know the weight and direct to every node in the network, in order to know the total delay in the network, the node calculates the all pairs shortest path of graph G. Finally, we get the average all pairs shortest path in the graph G, and transform to the network, we get the average end-to-end delay in the network.

4.3 How to Reduce End-to-End Delay

Our protocol is a distributed contention-free system. If the node wants to calculate the all pairs shortest path, it needs to construct the network topology by itself. First, the new node V_i enters to the network, and the FREE slots are less than or equal to the threshold (in this thesis we set threshold is 1). As shown in Figure 10, the node V_i sends a Node Information request REQ to each node in the network at the remaining FREE slot.

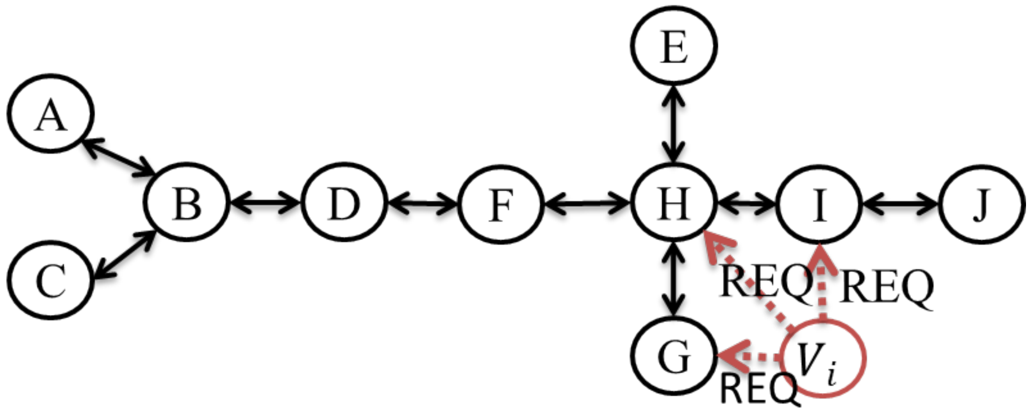
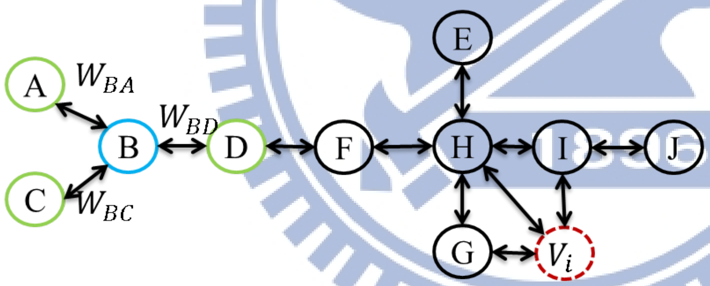


Figure 10. New node V_i sends REQ to all nodes for Node Information.

Second, upon node receives the REQ, it sends Node Information (NI) to node V_i, NI includes the node ID, one hop member IDs and the weight to each one hop member, there is a simple case as shown in Figure 11. Node B receive the REQ from node V_i, and send NI back to V_i.



Node Information B :

ID	One hop member ID	Weight
B	A, C, D	W_{BA}, W_{BC}, W_{BD}

Figure 11. The NI of node B.

Third, after all nodes send NI back to node V_i, it constructs the network topology according to these NI, and transforms the topology to graph G. Node V_i can calculate the average all pairs shortest path by G, as shown in Figure 12.

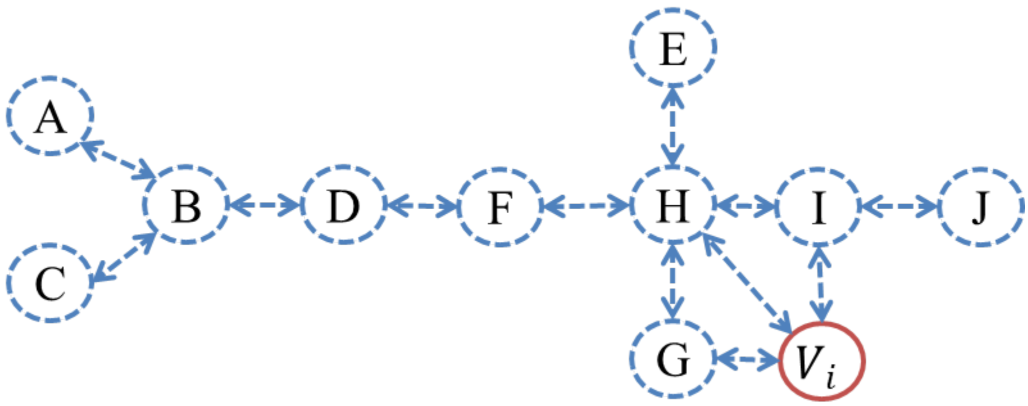


Figure 12. Node V_i constructs the directed weighted graph by NI.

While we calculate the average all pairs shortest path, we can get the average end-to-end delay of the network. Finally, we can calculate the delay of node V_i use frame size adjustment and power control, respectively. And choose the lower end-to-end delay method to solve slot congestion problem. As shown in Figure 13 and Figure 14. If the power control method cannot adjust the power range because of the connectivity reason which describe in Chapter3-3, we will choose the frame size adjustment method to solve the slot congestion problem.

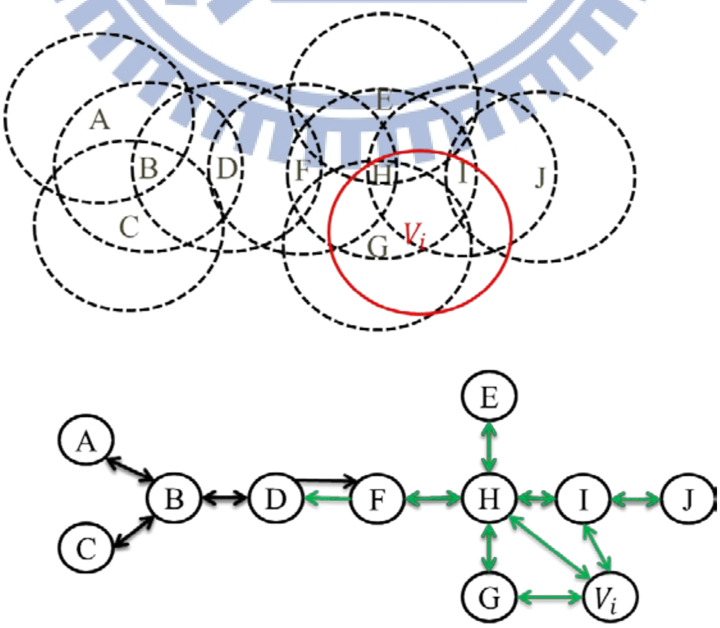


Figure 13. The topology of node V_i use adjusts frame size method to get time slot.

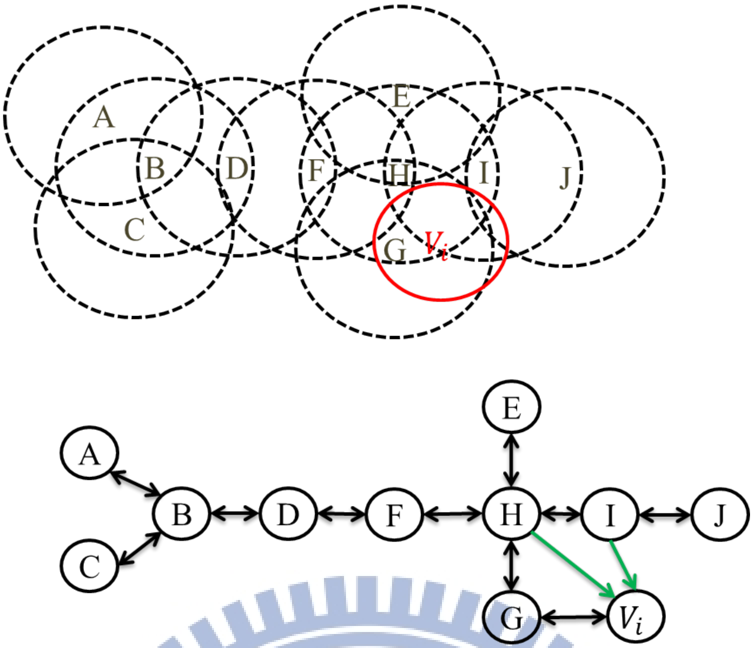


Figure 14. The topology of node V_i use adjusts transmission power range method to get time slot.

4.4 AFP-ALOHA Protocol

In this section, we summarize the above descriptions of AFP-ALOHA into the procedures. We show the procedures of AFP-ALOHA in the Figures 15~20. And the flow charts of AFP-ALOHA are given in Figures 21~25. Table 1 lists the parameters used in AFP-ALOHA protocol.

```
// RESERVE_SLOT
Node V_i enters the Network;
Listen a Frame and collect FI from one hop members;
if (there is FREE slot) then
```

P = Random Probability (0<=P<=1);

if (P < K reserve threshold) **then**

send reserve message R_msg to all one hop members;

Listen a Frame, if all one hop members received the R_msg it means that

reserve has succeed, Otherwise, reserve has failed;

run CHECK_RESERVE;

if (all one hop members send R_success_msg back) **then**

reserve has succeed;

Node V_i can use the time slot;

FI add Node V_i's slot status;

else

reserve has failed;

else

reserve has failed;

else

Node V_i send REQ_NI message to all nodes in the network and require them

send Node Information (ID_j, $One\_Hop\_Member_j$,$Weight_{jk}$) back to node V_i;

run SEND_ NODE_INFORMATION

create directed weighted graph G;

run SELECT_POWER_RANGE (G);

use graph G_{power} to calculate the average all pairs shortest path;

AVG_$Delay_{power}$ = G_{power}'s average all pairs shortest path;

run ADJUST _FRAME_SIZE (G);

use graph $G_{frame\ size}$ to calculate the average all pairs shortest path;

AVG_$Delay_{frame\ size}$ =$G_{frame\ size}$'s average all pairs shortest path;

29 **if** (AVG_Delay$_{power}$ $\leq$ AVG_Delay$_{frame\ size}$) **then**

30 Node V_i chooses select power range way to get time slot;

31 **else**

32 Node V_i chooses double frame size way to get time slot;

Figure 15. Operation of AFP-ALOHA

The details of procedure RESERVE_SLOT are described as follows:

- line 1: New node V_i enters the network
- line 2: Node V_i listen a frame and collect FI from one hop members.
- line 3~4: If there is any FREE slot, random generate a probability P
- line 5~9: If probability P small than reserve threshold K, node V_i sends reserve message R_msg to each one hop member, and listens a frame upon receives all acknowledgement messages from each one hop member.
- line 10~13: If in a frame time, node V_i receives all acknowledgement messages from each one hop member, time slot reservation has succeed. Therefore, node V_i can use the time slot to transmit packet when the slot come in the frame. Update the FI with node V_i use new time slot.
- line 14~15: If in a frame time, node V_i cannot receive all acknowledgement messages from each one hop member, the reservation has failed. Node V_i has to listen a frame and reserve again.
- line 16~17: If probability P lager than reserve threshold K, node V_i cannot send reserve message, the reservation has failed. Node V_i has to listen a frame and reserve again.
- line 18~21: If there is no FREE slot, it means that all time slots are BUSY, node

V_i has to send REQ_NI message to each node in the network and require them send Node Information (NI) back to node V_i, NI include node ID, one hop member IDs and the weight to each one hop member.

- line 22: Upon receive NI, node V_i use the NI to create the network topology, and creates directed weighted graph G.
- line 23~25: Node V_i use the method of adjust transition power to get time slot in graph G, and get the new graph G_{power}. Calculate the average all pairs shortest path in graph G_{power} , we can get the average end to end delay in the network.
- line 26~28: Node V_i use the method of adjust frame size to get time slot in graph G, and get the new graph $G_{frame\ size}$. Calculate the average all pairs shortest path in graph $G_{frame\ size}$, we can get the average end to end delay in the network.
- line 29~30: If the average end to end delay of method adjust transition power is lower than the average end to end delay of method adjust frame size, node V_i chooses the method of adjust transition power as the method to get time slot.
- line 31~32: If the average end to end delay of method adjust frame size is lower than the average end to end delay of method adjust transition power, node V_i chooses the method of adjust frame size as the method to get time slot.

// CHECK_RESERVE

if (received R_msg from Node V_i) **then**

    send acknowledge message : R_success_msg;

Figure 16. Operation of check reserve message.

The details of procedure CHECK_RESERVE are described as follows:

- line 1~2: Upon receive R_msg from node V_i, send acknowledge message R_success_msg back to node V_i .

// SEND_NODE_INFORMATION

1 **if** (received REQ_NI from Node V_i) **then**

2 send Node Information (ID_j, $One\_Hop\_Member_j$,$Weight_{jk}$) to V_i;

Figure 17. Operation of send node information.

The details of procedure SEND_NODE_INFORMATION are described as follows:

- line 1~2: Upon receive REQ_NI from node V_i, send Node Information (NI) back to node V_i. The NI include node ID, one hop member IDs and the weight to each one hop member.

// SELECT_POWER_RANGE (G)

Find out the slot only used by two hop member from our FI table which called

Candidate_slot;

if (Find Candidate_slot) **then**

Find out a one hop node which in the circle use distance between V_i and V_{cand}

as diameter. Then, we can guarantee the network connectivity;

```
6      if (any node in circle C) then
7          adjust V_i's power range (Range), Range is overline(V_i V_cand) - D_adj ;
8          V_i can reuse Candidate_slot as time slot;
9      else
10         cannot reuse Candidate_slot;
11   else
12       cannot adjust power range to get time slot;
```

Figure 18. Operation of adjust transmission power range.

The details of procedure SELECT_POWER_RANGE are described as follows:

- line 1~2: Find out the slot only used by two hop member which called Candidate_slot.
- line 3: If node V_i can find Candidate_slot from FI table.
- line 4~5: Find out a one hop node which in the circle C, the circle use the distance between V_i and V_{cand} as diameter. Then, we can guarantee the network connectivity after reducing transmission power range.
- line 6~8: If any node in circle C, adjust node V_i's transmission power range as V_{cand} - D_{adj}. Then, node V_i can reuse Candidate_slot as time slot.
- line 9~10: If there is no node in circle C, node V_i cannot reuse Candidate_slot as time slot.
- line 11~12: If cannot find Candidate_slot, node V_i cannot adjust transmission power range to get time slot.

```
// ADJUST_FRAME_SIZE(G)
1  V_i send adjust (double) frame size message ADJUST_Frame_msg;
2  New frame size = twice of old frame size;
```

Figure 19. Operation of adjust frame size

The details of procedure ADJUST_FRAME_SIZE are described as follows:

- line 1~2: Node V_i adjusts its frame size and sends ADJUST_Frame_msg to one hop members.

```
// RECEIVE ADJUST _Frame_msg
if (first time reserve ADJUST _Frame_msg) then
    if (direct receive message) then
        use new frame size;
        rebroadcast ADJUST _Frame_msg;
    else
        use new frame size;
else
    drop the message;
```

Figure 20. Operation of receive adjust frame size message.

The details of procedure RECEIVE ADJUST _Frame_msg are described as follows:

- line 1: If the node receives the ADJUST_FRAME_msg message at the first time.
- line 2~4: If the node receives the message from the node V_i. The node adjusts the frame size to new frame size, and rebroadcasts the ADJUST_FRAME_msg message.
- line 5~6: If the message did not from the node V_i, it means the message was from the one hop members of V_i. The node adjusts its frame size, but does not rebroadcast the message.
- line 7~8: If the node does not receive the message at first time, the node does not do anything and drops the message.

Table 1: List of parameters

Parameters	**Descriptions**
Initial	Every node has to execute four processes: Reserve_slot, Upon receive R_msg, Upon receive REQ_NI and Upon Receive ADJ_Frame_msg.
Reserve_slot	Node needs reserve time slot to transmit data.
Upon receive R_msg	Check the reserve message and send acknowledgement.
Upon receive REQ_NI	Check request of Node Information and send node ID, one hop member IDs and the weight to every one hop member back.
Upon receive ADJ_Frame_msg	Check ADJ_Frame_msg and adjust frame size, if direct receive ADJ_Frame_msg, rebroadcast it.
V_i	New node needs to reserve time slot in the network.
FI	Frame information, every node broadcast this message periodically in their time slot, the information include slot status of one hop, node ID and GPS information.
FREE	Slot status, the slot is available to reserve.
NI	Node information, the message with node ID, one hop member IDs and weight to every one hop node

REQ_NI	Request every node send node information back.
K	Reserve threshold, in order to decrease the probability of reserve collision.
R_msg	Reserve message.
R_success_msg	Acknowledgement message in FI from one hop members.
Candidate_slot	The time slot only used by two hop member and one hop node did not use.
V_{cand}	The node which use Candidate_slot as time slot.
D_{adj}	Constant.
G	Nodes form a directed weighted graph G.
G_{power}	The graph after adjust transmit power range.
$G_{frame\ size}$	The graph after adjust frame size.
AVG_Delay_{power}	Calculate average all pairs shortest path in G_{power}.
$AVG\_Delay_{frame\ size}$	Calculate average all pairs shortest path in $G_{frame\ size}$.

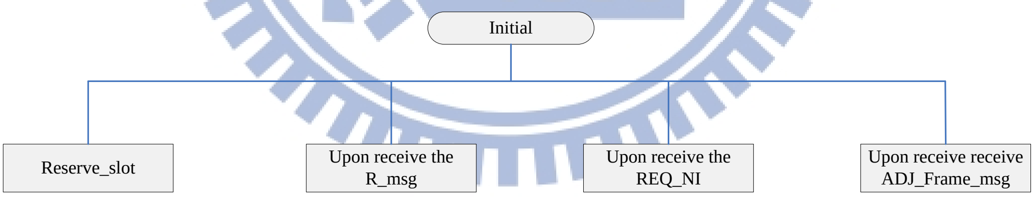


Figure 21. Flow chart: Initial states of AFP-ALOHA.

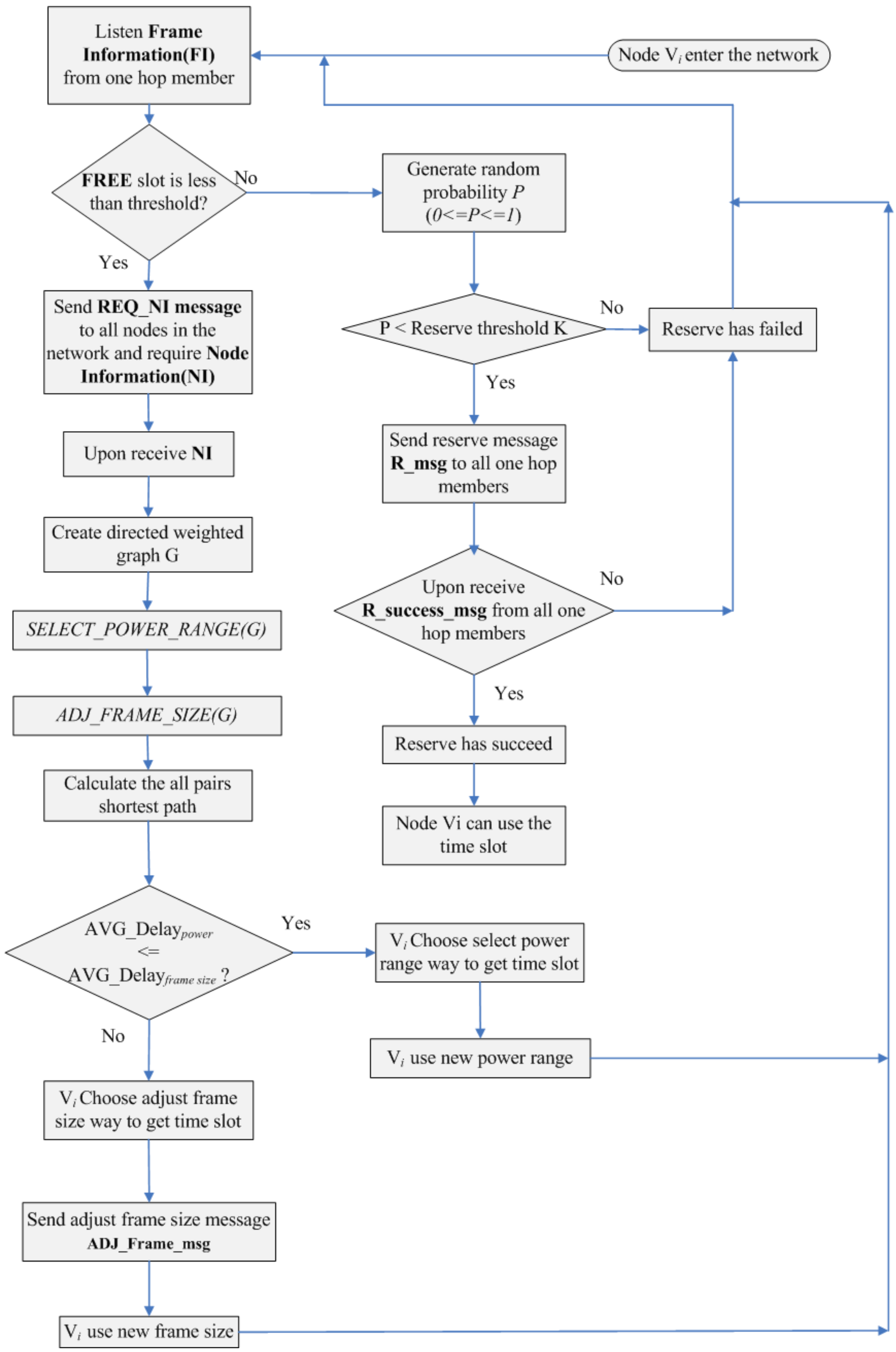


Figure 22. Flow chart: How to reserve time slot in AFP-ALOHA

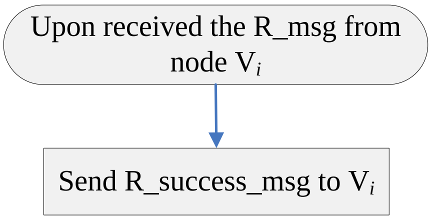


Figure 23. Flow chart: Upon receive reserve message

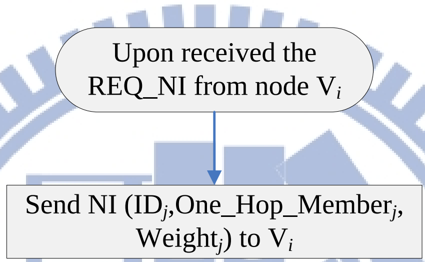


Figure 24. Flow chart: Upon receive request

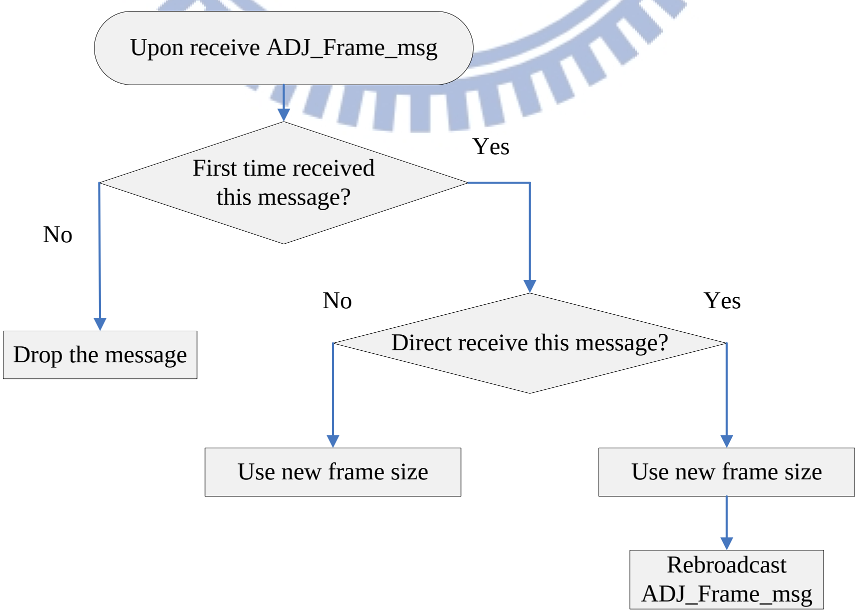


Figure 25. Flow chart: Upon receive the message of adjust frame size

Chapter 5

Simulation Results

5.1 Simulation Environment

In this section, we compare the performance of our protocol AFP-ALOHA with RR-ALOHA, PC-ALOHA and A-ADHOC MAC protocol in ns-2 [21]. We simulated two scenarios, which are fixed node environment and the environment of node mobility. In first scenario, the number of nodes is 50, 75 and 100. The simulation topologies are in 1000*1000 meters square. We simulate 10 topologies for each density. The data rate is 2 Mbps (802.11b). The slot time is fixed at 2ms. We simulate two default and maximum transmission range (Range), which are 250 and 150 meters. In A-ADHOC MAC and AFP-ALOHA, we restrict the range of the frame size value to 8, 16, 32, 64, and 128. The simulation time of each simulation is 10 seconds. And the all results are under 100% reserve ratio (e.g., the RR-ALOHA requires 21 slots upon all nodes can reserve time slot to transmission data at the number of nodes is 50). It means that the values of fixed frame size protocol (e.g. RR-ALOHA and PC-ALOHA) are optimal.

Second, our scenario of node mobility is on the highway model that is 1000 meters two-way straight road. The vehicle flow rate of each direction is 2500 vehicles/hour . And the speed of every vehicle is 100 km/hour . The transmission range is 250 meters. The simulation time is 30 seconds.

5.2 Result Analysis

A. Average frame size under 100% reserve ratio.

As shown in figure 26, the relationship between average frame size and different network density under 100% reserve ratio. Each protocol in higher density requires the larger frame size. As the result of the simulation: the frame size under 100% reserve ratio is based on the nodes density. The result shown that PC-ALOHA and AFP-ALOHA require smaller frame size than RR-ALOHA and A-ADHOC, since PC-ALOHA and AFP-ALOHA can find free slot by reducing the node's transmission range.

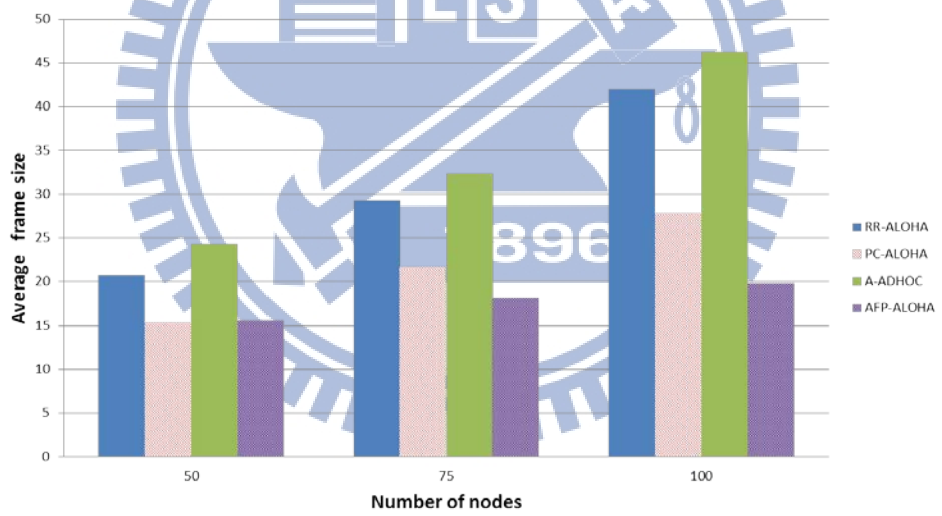


Figure 26. Average frame size under 100% reserve ratio in different network density. (Range = 250 m)

And the average frame size in 250 meters range is larger than 150 meters range, because in 250 meters range, the number of one-hop members and two-hop members is more than the number of one-hop members and two-hop members in 150 meters range.

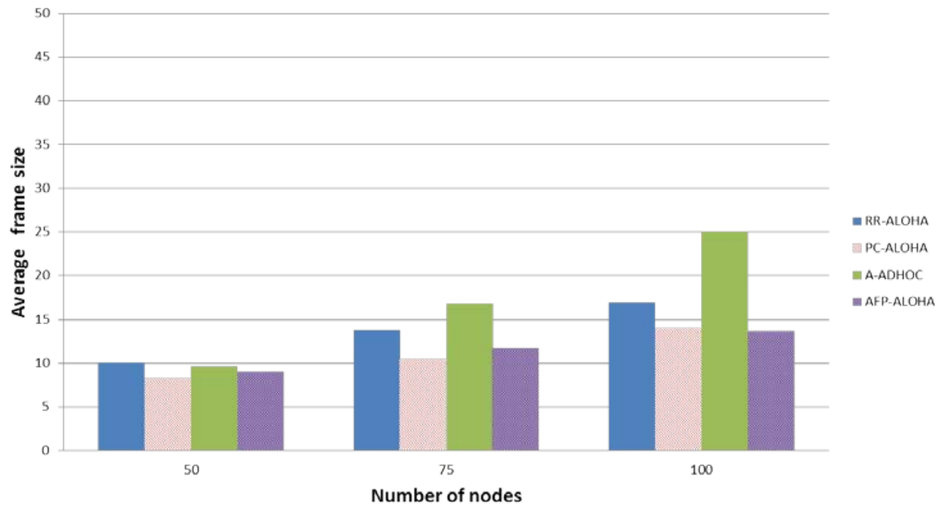


Figure 27. Average frame size under 100% reserve ratio in different network density.

(Range = 150 m)

B. Average hop counts under 100% reserve ratio

As shown in figure 28 and 29, the average hop counts under 100% reserve ratio in different network density. Because of the RR-ALOHA and A-ADHOC do not reduce the node's transmission range, the average hop counts lower than PC-ALOHA and AFP-ALOHA.

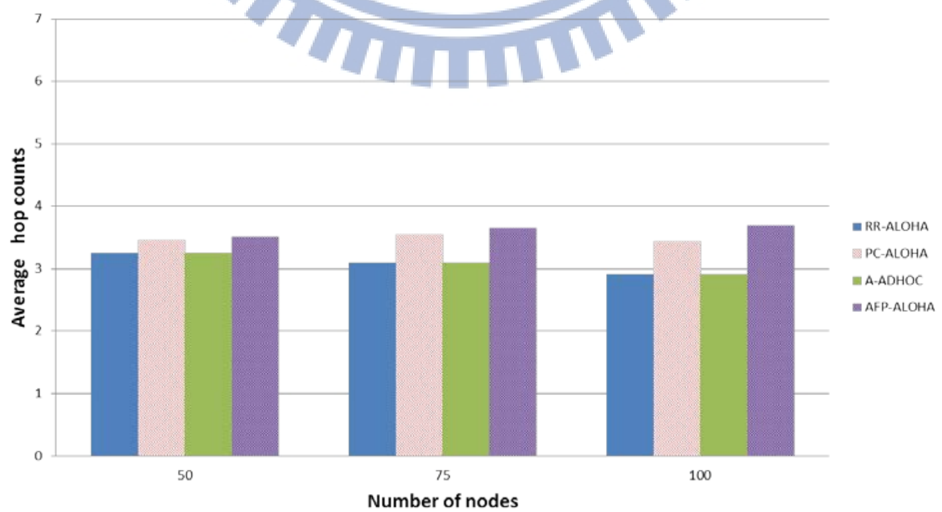


Figure 28. Average hop counts under 100% reserve ratio in different network density.

(Range = 250 m)

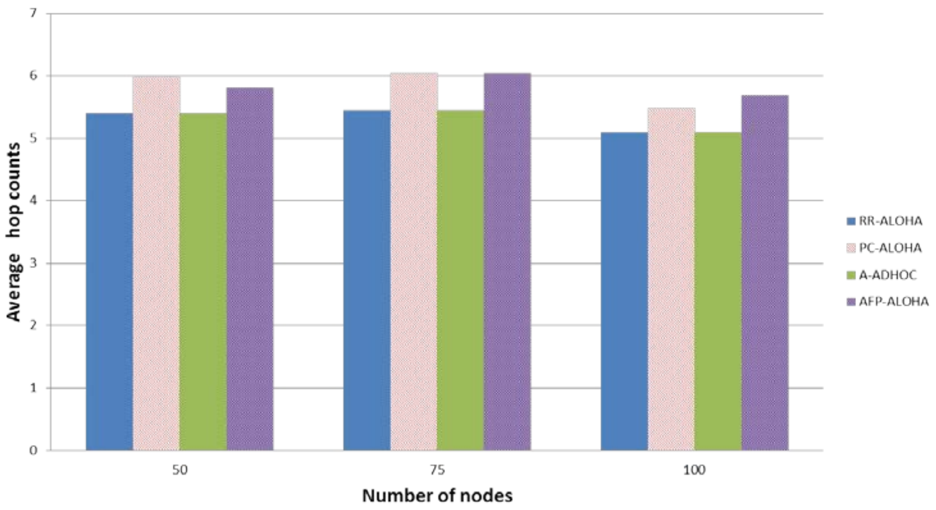


Figure 29. Average hop counts under 100% reserve ratio in different network density. (Range = 150 m)

C. Average relaying delay under 100% reserve ratio

Figure 30 is shown the relaying delay under 100% reserve ratio. The relaying delay is the value of average frame size * average hop counts * slot time. We can know the trend of delay by figure 30.

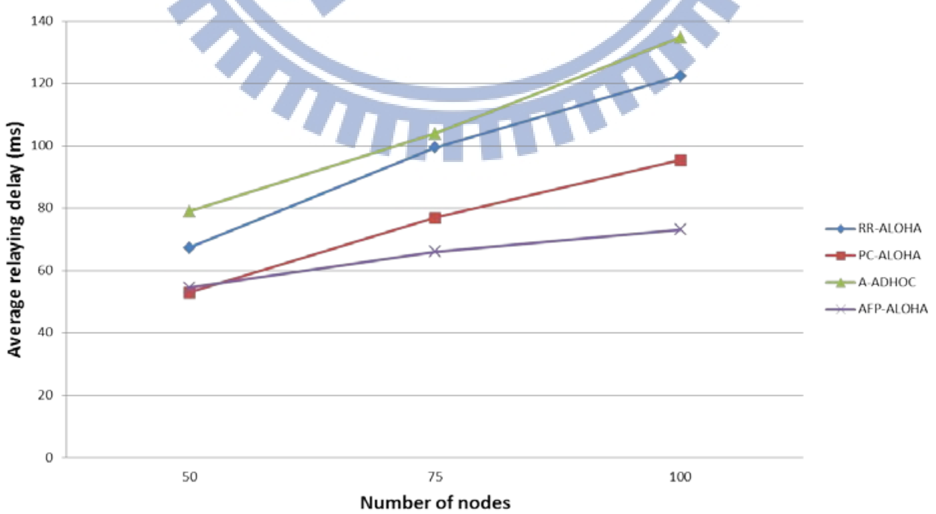


Figure 30. The average relaying delay under 100% reserve ratio in different network density. (Range = 250 m)

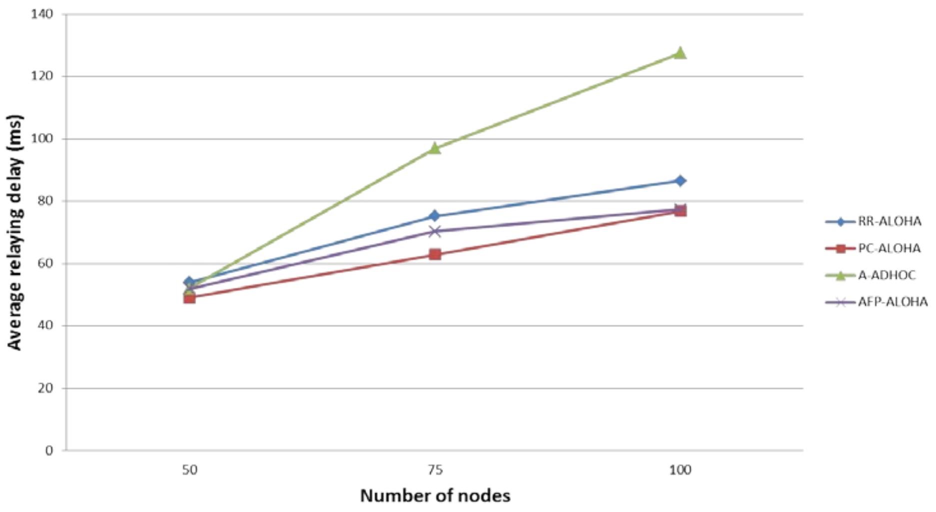


Figure 31. The average relaying delay under 100% reserve ratio in different network density. (Range = 150 m)

D. Average end-to-end delay under 100% reserve ratio

We analyzed the average end-to-end delay under 100% reserve ratio. As shown in figure 32, the average end-to-end delay of AFP-ALOHA is lower than RR-ALOHA, PC-ALOHA and A-ADHOC in dense network.

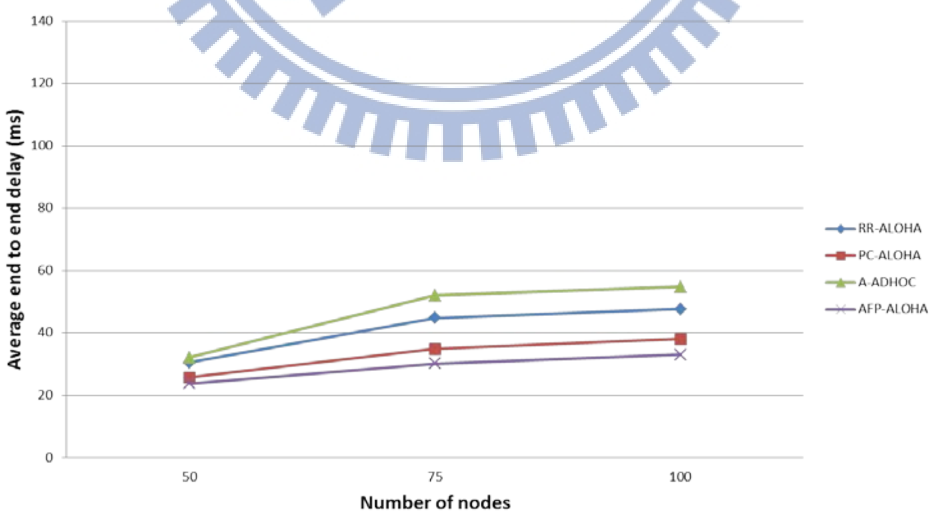


Figure 32. The average end-to-end delay under 100% reserve ratio in different network density. (Range = 250 m)

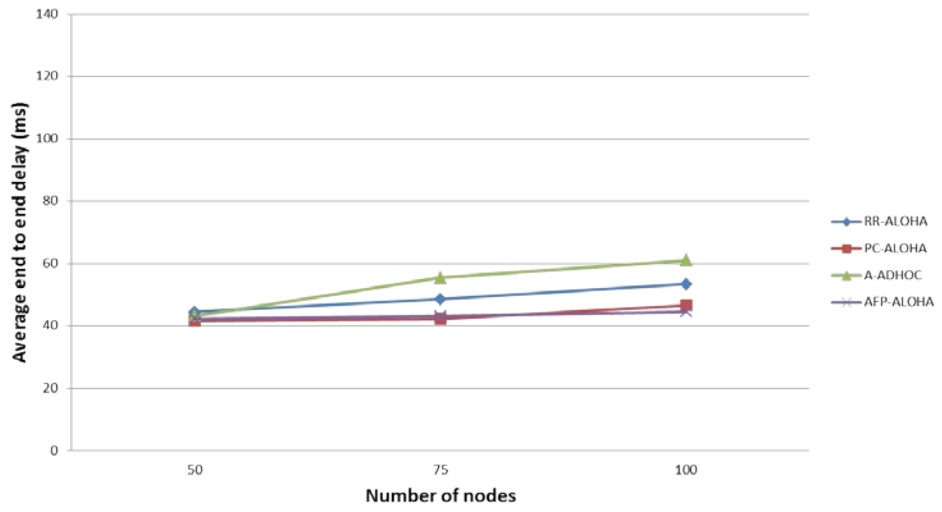


Figure 33. The average end-to-end delay under 100% reserve ratio in different network density. (Range = 150 m)

E. The results in mobility environment

We analyzed the reserve ratio and average end-to-end delay in mobility environment at 30 seconds. As shown in figure 34, the reserve ratio at 30 seconds. All protocols cannot achieve 100% reserve ratio, because of the *merging collision* [14]. The merging collision is the opposite vehicles used the same time slot without collision, but when they approached to each other, the collision happened.

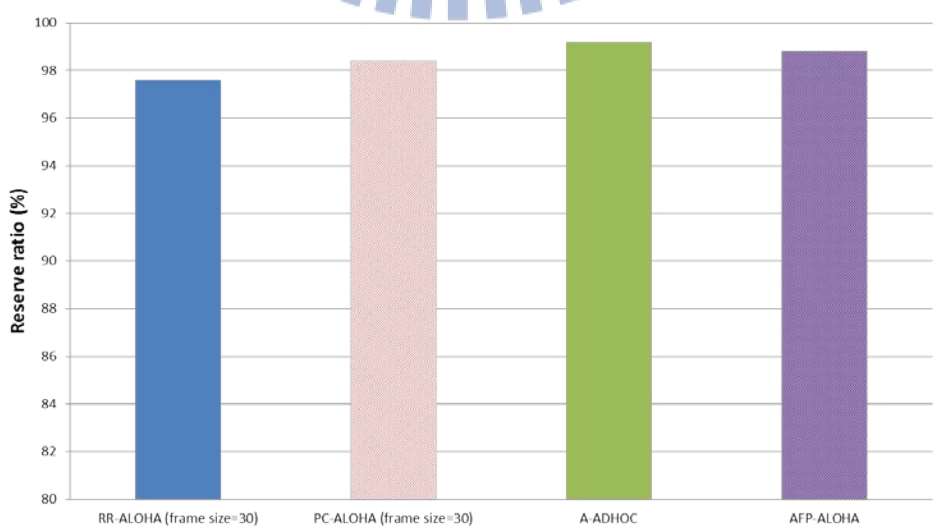


Figure 34. The reserve ratio of node mobility.

The average end-to-end delay at 30 seconds as shown in figure 35. We gave the frame size of RR-ALOHA and PC-ALOHA as 30, because the reserve ratio cannot fix at 100% in mobility environment. The result shown the end-to-end delay of AFP-ALOHA is lower than RR-ALOHA, PC-ALOHA and A-ADHOC.

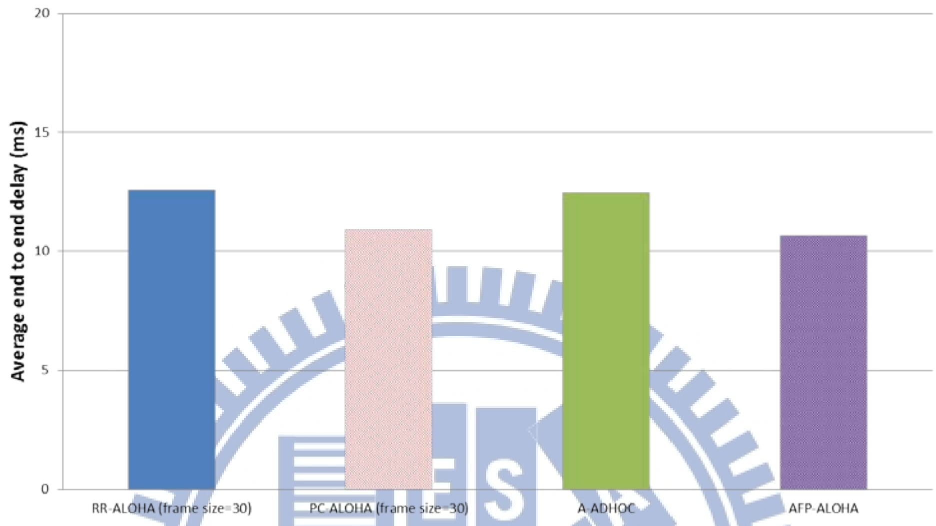


Figure 35. The end-to-end delay of node mobility.

Chapter 6

Conclusion

In this thesis, we have proposed an adaptive low-delay schedule-based MAC protocol with RR-ALOHA called Adaptive Frame size adjustment and Power control ALOHA (AFP-ALOHA). We combine RR-ALOHA with frame size adjustment mechanism and power control mechanism to solve the slot congestion problem in RR-ALOHA.

There are two important features of our protocol: (1) AFP-ALOHA can adaptively adjust the frame size and transmission power range at the time to solve slot congestion problem, and (2) achieve the lower end-to-end delay at the same time.

As the simulation results, the end-to-end delay of our AFP-ALOHA is lower than RR-ALOHA, PC-ALOHA and A-ADHOC in the dense network. It means that our AFP-ALOHA can provide the lower delay of safety applications. In the future, we will consider the problems at node mobility environment (e.g. *merging collision* [14]).

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