Delft University of Technology

Wireless and Mobile Communication (WMC) Group
Faculty of Electrical Engineering, Mathematics and Computer Science
Delft University of Technology

Gateway Selection Mechanisms for Beyond 3G Multi-hop Cellular Networks

ASSIGNMENT	: Master of Science Thesis
INSTRUCTORS	: Jinglong Zhou, MSc, Dr. Anthony Lo
SUPERVISOR	: Prof. Dr. Ir. Ignas Niemegeers
DATE	: Sep. 27th, 2009
STUDENT	: Jiazhen Hao
STUDENT NUM	: 1385127

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This thesis being finished stands for my significant step achievement of my life. It has given me the greatest confidence study and research on the wireless telecommunications field. It also will make a big influence on the rest of my life.

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Abstract

Nowadays, there are a host of demands on the Internet applications (IP based multimedia applications) coming into people's life. How to access the Internet and get these application services more quickly and better becomes gradually critical for people to meet their demands. However, the existed two technologies: the third generation (3G) cellular mobile networks and the wireless ad-hoc networks technology have big distinctions, which can meet different parts of people's demands. For the 3G cellular networks technology, the familiar one is Universal Mobile Telecommunications System (UMTS) and its enhanced version High Speed Downlink Packet Access (HSDPA) offering up to 14.4Mbit/s peak data rate. However, the two communication techniques mentioned above have their own characters. The former can only provide a relative lower data rate though can support a broad coverage range, whereas the latter can only support a limited communication distance but own a relative higher bit rate. In order to explore their own advantages of these two networks techniques, the HSDPA cellular and the wireless ad-hoc integrated networks model has been developed in the Network Simulator (ns-2).

But the old integrated networks model is just the one with single one gateway node (GW) that connects the two distinguished networks subfields. In this thesis, the model of the integrated networks with multiple gateways is implemented; and a vast number of simulations on the integrated networks with multiple gateways are carried out. Through the work above, we attain some valuable results one of which is that there is more obvious unfairness occurring in the integrated networks due to the two networks subfields using. For instance, assuming that the Node B of the integrated networks communicates with two GWs and the distances between these two GWs and the Node B are configured equal, if in the wireless ad-hoc networks subfield there are different hop count Mobile Nodes (MN), the TCP throughput of each terminal node in their own GW coverage will come out the more unfairness though each GW spaces the same distances from the Node B, namely due to adding the wireless ad-hoc networks subfield and different ad-hoc setting (e. g. different hop count, etc.), the TCP throughput of each terminal node will be distinguished. But we want to these TCP throughputs as equal as possible if the conditions in the HSDPA subfield are the same, because we only want to extend the HSDPA services into the wireless ad-hoc networks field in the small cost.

A completely new scheduling algorithm is proposed to resolve the unfairness problem above. It is named Fair Two-Subfields-Dependent Scheduling (FTSDS) that the scheduler in the Node B considers not only the HSDPA information but also the ad-hoc knowledge to reschedule each GW in our integrated networks.

Finally, since the novel scheduling algorithm has been designed, we test whether it can reach our goal or not, namely if it can solve the unfairness problem. Through a great deal of investigation simulation work again, the new scheduling mechanism has been proven to reach the eventual design goal that it can deal with the unfairness in the integrated networks better.

1 Introduction

In this chapter, the special integrated networks of the HSDPA cellular networks and the IEEE 802.11b ad-hoc networks and its relevant applications will be introduced. Firstly, the description of the subject of this thesis will be given in section 1.1. Secondly, the purpose of this thesis will be stated in section 1.2. In the end, we will outline the thesis in section 1.3 to give a picture of the whole thesis to make reading easier.

1.1 Background

In modern society, there are a vast number of the Internet (IP based) application demands appearing in people's life. Meanwhile, there are various ways of accessing the Internet which can be chosen by people, especially wireless access methods that become gradually a trend, such as the Third Generation (3G) cellular networks [13], the Wireless Local Area Networks (WLAN) [26] and the Wireless Personal Area networks (WPAN) [26]. However, there are some distinguished accessing characteristics among another. For instance, the 3G cellular networks are able to support a large covering range but a low speed access, whereas the WLAN can offer a high speed access in limited range of covering and the WPAN can enable Personal Electronic Devices (PED) to connect between each other more quickly and conveniently to achieve the cable displacement.

The 3G cellular networks include lots of solutions such as Universal Mobile Telecommunication System (UMTS) [1] in Europe, Code Division Multiple Access 2000 (CDMA 2000) in the USA and the Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) in China, etc. Here we will focus on the UMTS and its advancement: High Speed Downlink Packet Access (HSDPA) so called 3.5G cellular mobile networks. They are all based on the Wideband Code Division Multiple Access (WCDMA). The UMTS supports for high user data rates up to 2 Mbit/s, which is the reason that it can support advanced multimedia services compared with the 2G GSM and 2.5G GPRS mobile networks. Figure 1-1 [2] shows the overview of UMTS architecture.

However, as the enhancement of the UMTS, the HSDPA [17] achieves the high speed downlink data link, providing up to 14.4 Mbit/s bit rate. But the HSDPA only offer the high speed downlink data link through the High Speed-Downlink Shared Channel (HS-DSCH). Because the HS-DSCH is a 'common' channel that is shared by all the User Equipments (UE), it is necessary that there is a UE selective metric to realize the share of the channel, namely the share of the radio resources. In the HSDPA, the UE choice method is known as the Fast Scheduling which is achieved by the Node B. There are various Fast Scheduling mechanisms in terms of different scheduling standards such as the Round Robin and the channel quality dependent scheduling, etc.

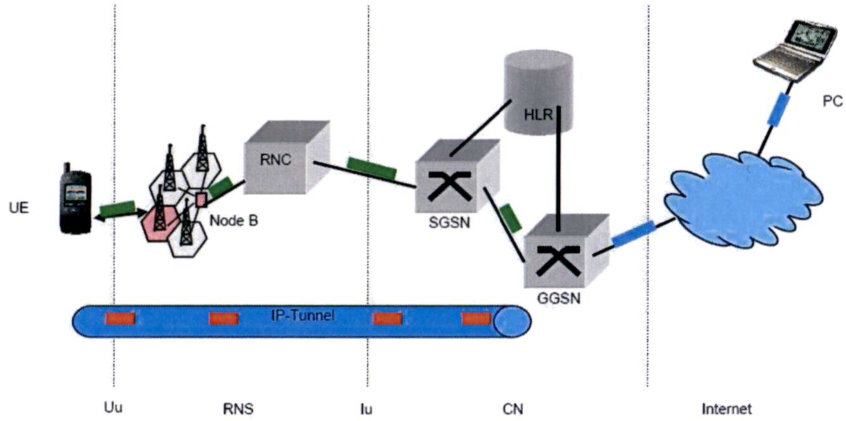

Figure 1-1 UMTS Architecture [2]

As another popular accessing the Internet method, the WLAN [37] provides higher data rate but in less coverage range compared with the UMTS cellular networks. The standard WLAN adopts the 802.11b protocol which is established by the Institute of Electronic and Electrical Engineers (IEEE). WLAN is classified two Infrastructure and ad-hoc completely distinguished types.

The former has fixed 'basic element' like the UMTS cellular networks called the Access Point (AP) in the center of the whole networks. It uses star topology and explores CSMA/CA protocol in MAC layer. And its minimum unit is Basic Service Set (BSS), which includes one AP and several Mobile Nodes (MN). All the MNs are able to communicate between each other directly in the one BSS, but they have to be interconnected through the AP if two MNs belong to two different BSS. If two BSS connect with one Distribution System (DS), the whole networks make up of one Extended Service Set (ESS). The infrastructure WLAN system architecture can be seen in Figure 1-2 [37].

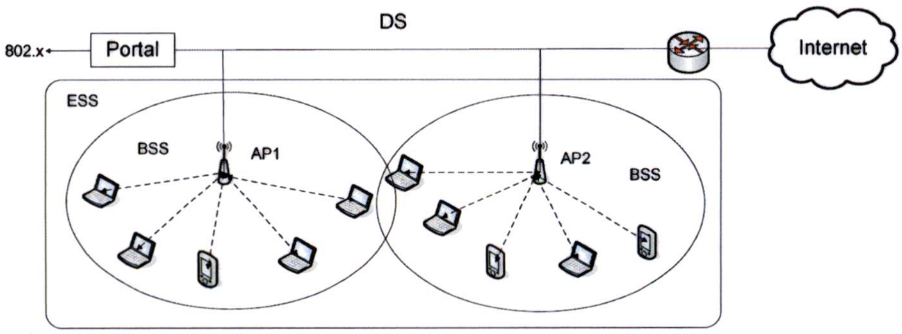

Figure 1-2 Infrastructure WLAN system architecture [37]

The latter is the special WLAN that does not own the fixed AP like the former, which is also named as the self-organizing networks. Each MN is in the fair state in the ad-hoc networks [27] [37] to communicate between each other, namely, there is no central node as a 'server' like the server-client mode in wired networks. It seems to be more similar with the Peer-to-Peer (P2P) mode in the wired networks. The Figure 1-3 [37] will show the special communication progress. When the MN A (source) communicate with the MN E (destination), the packets will go through

A-B, B-C, C-D and D-E eventually to reach the destination node E, which is a relay progress. The MN B, C and D are all the relay nodes which have routing functionality.

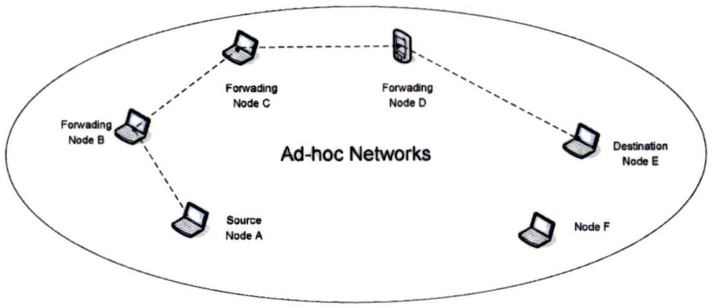

Figure 1-3 Ad-hoc networks [37]

In order to utilize the benefits of all kinds of wireless access the Internet methods completely, a type of special gateway which can integrate the two networks: the cellular networks and the WLAN will be needed to be created. The gateway has the two network interfaces that can connect the two different UMTS cellular networks and the wireless ad-hoc networks. These works have been done much in the thesis [4] and [5]. The integrated networks topology is given in the Figure 1-4 [5]. The work of the thesis [5] achieve the UMTS and wireless ad-hoc integrated networks and do lots of simulation to test its performance, and eventually gain a host of very useful results. The thesis [4] implement the enhanced UMTS (i.e. HSDPA) and wireless ad-hoc integrated networks and also do a lot of simulation in terms of different scheduler type of the BS. However, the two theses above realize and simulate the integrated networks with the only one gateway. We need to implement more than two gateways integrated networks and do some simulations.

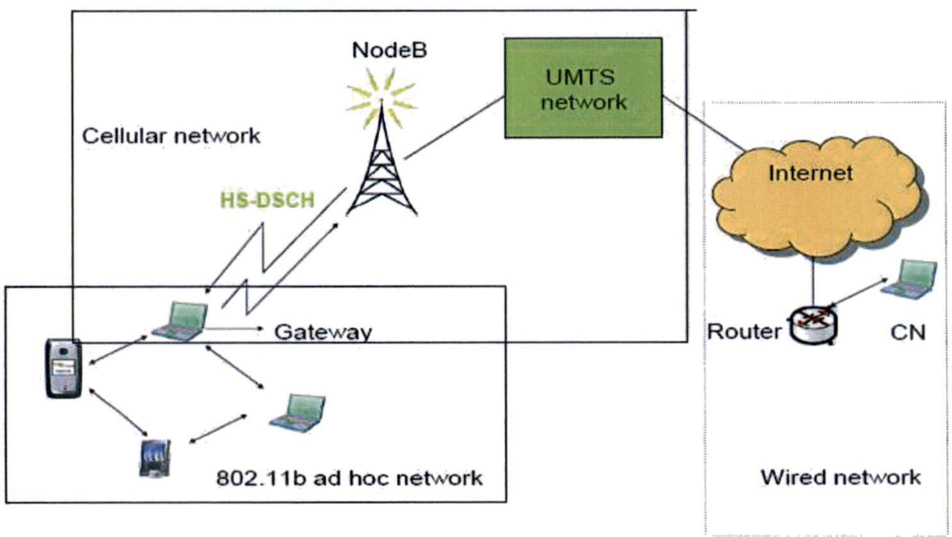

Figure 1-4 Integrated networks topology [5]

1.2 Goal of Thesis

The purpose of this thesis is to realize the integrated networks with multiple gateways and propose a new scheduling mechanism of the BS to achieve the selection of these gateways which can enable the TCP throughput of terminal nodes in the coverage of each gateway fairer in HSDPA and wireless ad-hoc integrated networks. Besides, some simulation needs to be designed to validate the performance of the new scheduling mechanism in the integrated networks.

1.3 Outline

In order to make reading more easily, the rest chapters of the thesis are arranged as follows. Some related works about the integrated networks with original single one gateway, its network simulator (ns-2) [7] model [4] [5] [6] and existed scheduling metric in wired and HSDPA networks are given in Chapter 2. Chapter 3 implements the integrated networks with multiple gateway nodes and carries out a great deal of simulation work to find a way of designing a new scheduler type. Based on the research of the simulation work above, Chapter 3 eventually proposes a new scheduling mechanism to select the gateway in terms of not only the HSDPA subfield but also the wireless ad-hoc networks subfield. Chapter 4 dose a host of simulations of the integrated networks with the new designed scheduler type to test its performance. In the end, the main conclusions and future works are given in Chapter 5.

2 Related work

Due to our aim of implement the integrated networks with multiple gateways and designing a new scheduler type in terms of two subfields in our integrated networks, some related work about the HSDPA and ad-hoc integrated networks will be presented firstly. Then we will discuss existed scheduling schemes in wired networks and in HSDPA cellular networks, respectively.

2.1 Integrated networks of the HSDPA cellular mobile networks and the wireless ad-hoc networks

In this chapter, initially, the integrated networks with one gateways will be described simply again. Then the integrated networks with multiple gateways will be given. Finally, three known typical scheduling methods in the HSDPA will be stated in details.

2.1.1 Integrated networks with original one gateway

In thesis [4] and [5] the ad-hoc gateway in the integrated networks has been implemented to connect the wireless ad-hoc networks field with the HSDPA and UMTS cellular mobile networks field, respectively. However, only one hybrid UE (i. e. GW) is realized and simulated to gain a host of useful results on the integrated networks. Meanwhile it is all general UE that the other UEs in the HSDPA or UMTS subfield are. The integrated networks system architecture is brought out in Figure 2-1 [4]. The gateway is a special UE – hybrid UE that owns two interfaces to communicate with one side HSDPA cellular mobile networks and the other side wireless ad-hoc networks. In the Figure 3-1 the distinctness between the general UE and the hybrid UE (GW) is apparently illustrated. The general UE cannot forward any packets, while the GW can forward the packets from the wired core networks Internet through the UMTS Core Network to the terminal nodes in the wireless ad-hoc networks.

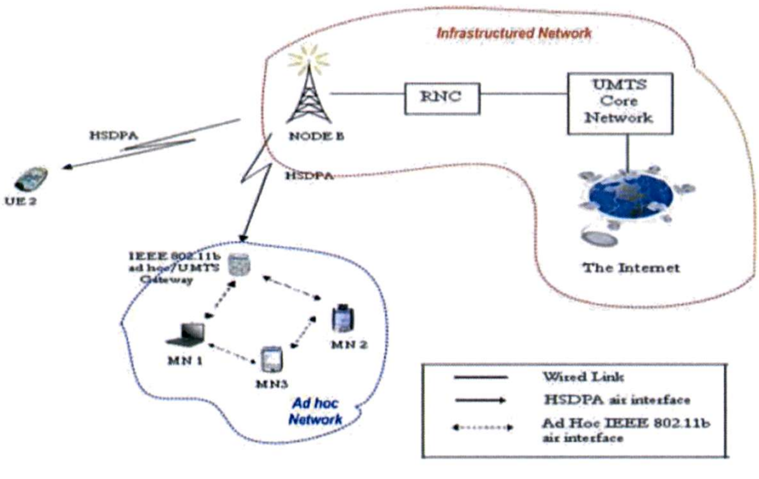

Figure 2-1 System architecture of integrated networks with one gateway [4]

It is manifest that the HSDPA-IEEE 802.11 ad-hoc gateway plays an important role in the protocol stack architecture of the integrated networks. As can be seen from the Figure 3-2, the protocol stack of the GW achieves the interconnection between the two different networks in the network layer (layer 3) through the ad-hoc routing and the gateway discovery. At the same time, the special UE (GW) owns two interfaces that can communicate the two completely distinguished networks.

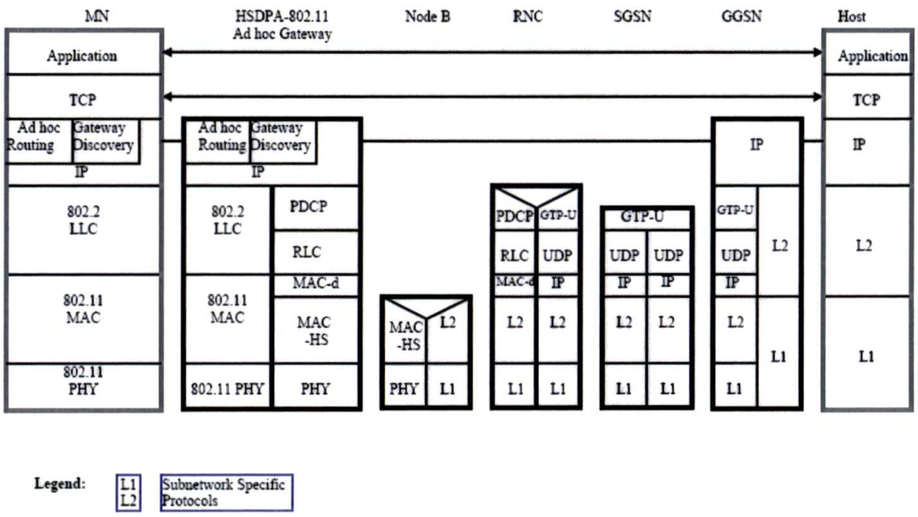

Figure 2-2 Integrated HSDPA and IEEE 802.11 ad-hoc network protocol architecture [6]

According to the protocol stack of the GW shown in the Figure 3-2 above, the ns-2 model of the GW is designed as the following Figure 3-3. From the Figure 3-3, the ad-hoc routing agent is added into the ns-2 model of the general UE in HSDPA cellular mobile networks as well as a Network Interface Stack (NIF) of the IEEE 802.11 including IEEE 802.11 LL, MAC and PHY layer, which can make a general UE forward packets from HSDPA cellular networks field to wireless ad-hoc networks field, or vice versa.

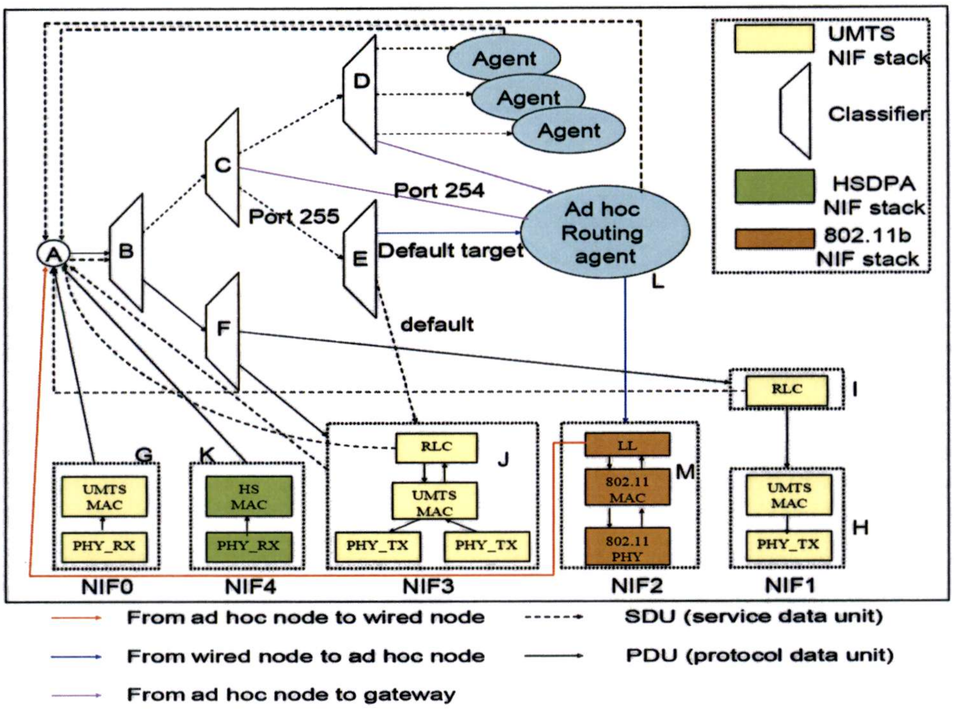

Figure 2-3 Hybrid UE (Gateway) implementation [5]

2.2 Scheduling mechanism

Although there are some distinctions in scheduling schemes between the wired networks (i. e. Internet) and HSDPA cellular networks, the scheduling methods are referring to the packets queuing regulation or data flows selection mechanism. In the Internet this functionality is carried out by routers, while the Node Bs execute the scheduling function in the HSDPA cellular networks. Actually, the scheduling methods which are explored in the two completely different networks are similar between each other in the real essence. Thus, we can refer to several scheduling schemes of the routers in the Internet to implement our new scheduling mechanism in our integrated networks of the HSDPA cellular networks and the wireless ad-hoc networks.

2.2.1 Some scheduling methods in wired networks

In the wired networks (i. e. Internet), in order to enable the Internet to provide the quality of service (QoS), the scheduling scheme is added into routers to rearrange packets queuing. There are some classic scheduling methods as follows.

2.2.1.1 First In First Out (FIFO)

In fact, the FIFO [32] is not a real scheduling method because it do not do anything in the packets queuing. No matter which packet will be served firstly as long as it arrives at the router in first. When the queue has been full, the packets that reach the router will be dropped.

There are lots of disadvantages in the FIFO method. The worst one is that it cannot distinguish between the time sensitive packets and the general packets. Furthermore, it is not fair as this way would make the small packets after the large packets wait for a long time to be served.

Based on the FIFO we add into the queuing the priority dependent, which enables the highest priority packets to be served firstly. While adding the priority into the queues, a classifier also needs to be added into the router so as to differentiate the received packets according to the different priority to make them go into the corresponding queues.

2.2.1.2 Fair Queuing (FQ)

In spite of the benefit of the priority dependent queuing in the previous section, it also brings about a problem that if there are always some packets in the high priority queue, the packets in the low priority queue would not be served for a long period. This is not fair, thereby, here the Fair Queuing [33] scheduling is proposed to resolve this problem.

The FQ produces a queue for each data flow and get each queue send a packet a time in turn. If a certain queue is empty, the queue will be ignored and the next queue will be served.

Although this scheduling scheme is called the Fair Queuing, it can also produce the unfairness that the service time which the large packets can get is more than that of the small packets. Besides, the FQ do not make a distinction in the priority of each packet.

2.2.1.3 Weighted Fair Queuing (WFQ)

In order to solve the disadvantage that the FQ cannot distinguish the packet priority, the weight concept has to be adding into each queue to reschedule in terms of the different weight of each queue, which is named Weighted Fair Queuing (WFQ) [35].

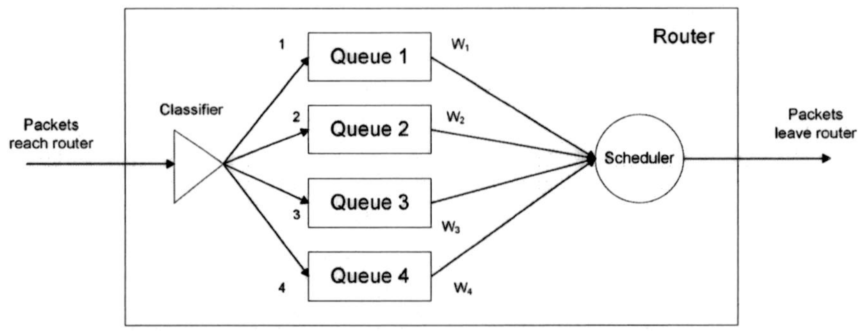

Figure 2-4 WFQ operational principle

As can be seen from the Figure 2-4, the principle of operation of the WFQ is: When the packets arrive at the router, these packets are firstly classified and then passed to the corresponding queues. It is assumed that there are 4 classes of queues. The packets at the beginning of these 4 queues are sent out in the circle turn. Similarly, while some queue is empty, the next queue will be scheduled by the router. If the router only provides these functionalities mentioned above, it only implements the FQ scheduling. If at this time the served time is distributed to each queue differently in terms of their own priority, this new scheduling method is just so called WFQ. The priority of the queue i is referring to its weight w_i. Thus, the normalized served time the queue i can get is $Wi/\left(\sum Wi\right)$. If the bandwidth of the router is R, the data rate for the queue i is $Ri = \frac{R \times Wi}{\sum Wi}$.

2.2.2 Several typical scheduling schemes in HSDPA cellular mobile networks

Since the radio resources and frequency bandwidth are limited and all UEs in HSDPA using the hs-dsch share these limited resources, how to allocate them in terms of the provity and the fairness becomes critical. It is well-known that this functionality is by the scheduler located in the Node B in HSDPA. The scheduler is moved from RNC in UMTS release 99' to Node B in HSDPA, which can offer a faster way allocating radio resources than that located in the RNC. That is one of reasons that it is called fast scheduling. Another reason is each TTI (2ms) the Node B reschedules all the UEs to reallocate the radio resources and frequency bandwidth according to different instantaneous CQI value indicating instantaneous channel quality between the UE and the Node B. This per 2ms frequency scheduling is very fast and illustrates instant scheduling functionality considering the real instant various channel condition.

2.2.2.1 Round Robin Scheduling

This term of Round Robin [10] is from other situation in the real world, where each element takes a queue to share something in turn in the same probability. In HSDPA, Round Robin allocates TTI to each UE in equal percentage in turn. It is also named Fair Time Scheduling in terms of equal TTI assignment for all the UEs irrespective of their own channel qualities. Round Robin scheduling guarantees all the UEs in the cell share the radio resources according to a certain order.

There are lots of advancement of Round Robin. One of them is that not only does Round Robin ensure the fairness of all the UEs in the long run, but it also make sure the short time fairness of all the UEs. Besides, as the Round Robin scheduling is simple to implement in reality, it is adopted by a lot of real systems. However, the simple design of the Round Robin is not to consider different channel conditions of each UE, as a result it also leads to a big disadvantage that the throughput of the whole system becomes lower in order to gain the throughput fairness of all the UEs.

2.2.2.2 Minimum Power Scheduling

The minimum power [10] scheduling is also called the maximum C/I scheduling. The former is referring to that the UEs which have least power demands are firstly scheduled by the Node B, while the latter is defining that the UEs that own the largest C/I are scheduled in priority. In fact, these two terms indicate the same meaning. In other words, the farer the UE spaces from the Node B, the less probability it can be served by the Node B. However, the maximum C/I scheduling is to gain the larger the whole system capacity at the cost of the fairness among all the UEs. The TCP throughput that the whole system can derive while adopting the minimum power scheduling is the upper bound.

Although the maximum C/I scheduling can increase the system capacity as large as possible and also implemented simply, it cannot be utilized by the real system because it completely ignores the fairness among different UEs. For a real system the fairness is more significant than the largest throughput. Thus, it is well-known that the minimum power scheduling is the most unfair of all the scheduling mechanisms.

The Figure 2-5 shows the difference between the Round Robin and the MAX C/I scheduling methods.

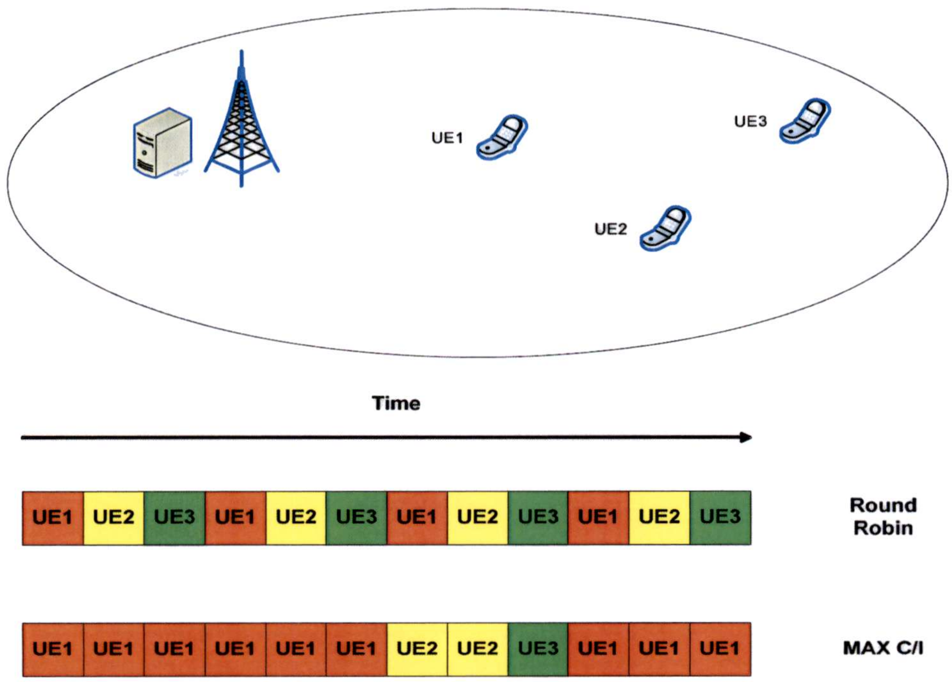

Figure 2-5 Round Robin V. S. MAX C/I []

2.2.2.3 Fair Channel-Dependent Scheduling

The first scheduling method Round Robin is fair and uses power inefficiently, whereas the second one minimum power is unfair and efficient in power usage. They go the two limits, respectively. In order to balance them, the third one fair channel-dependent scheduling [10] is proposed, which is more fair than the second one and more efficient power use than the first one.

3 Integrated networks with multiple gateways and new scheduling mechanism

In this chapter, due to the implementation of multiple ad-hoc gateways between the HSDPA subfield and the ad-hoc networks subfield in our new integrated networks, how to improve the performance of the special integrated networks with the multiple gateways will be focused on.

As the radio and bandwidth resources are limited, the usage of multiple gateways will definitely lead to decrease the available resources per gateway, which will eventually cause the performance degradation of terminal nodes in corresponding ad-hoc networks subfield. The pre-analysis of improving the performance is essential.

In addition, because the special networks integrate the two different networks, it is possible that the one has good performance, while the other is in bad performance condition for the same gateway. This is the critical reason why not only to consider the HSDPA field, but also to think about the ad-hoc networks field while enhancing the performance of our integrated networks.

In order to gain the better performance of the integrated networks, the performance of the networks with the original single one gateway node need to be checked up again. These performance simulation and analysis have been done in [5] in details. Here the performance of TCP throughput is only considered. Besides, the new simulation of the integrated networks with multiple ad-hoc gateways will be done here and then the performance will be analyzed when there is no any performance improvement to do for the integrated networks. These two works are very significant before finding out the way of enhancing the performance.

In the first, some simulation parameters are given in the following Table 3-1.

HSDPA subfield	
RLC mode	Acknowledged Mode (AM-HS)
RLC payload (Byte)	40
ACK mode	Bitmap acknowledgement
RLC Window Size (Byte)	4096
HS-DSCH rate (kbps)	64
HS-DSCH TTI (ms)	2
IEEE 802.11 ad-hoc networks subfield	
Routing Protocol	AODV
MAC Protocol	CSMA/CA, RTS/CTS
Propagation Model	Two Ray Ground
Data Rate (Mbps)	1, 2, 5.5, 11
Topology Instance (m*m)	1000*1000, 1500*1500, 2000*2000
TCP Configuration	
TCP Version	TCP Reno
TCP Window Size	128, 256
TCP Packet Size (Byte)	512, 1460

The FCDS scheme defines a new variety: the relative power that is referring to the instant power in terms of its own previous history values. The variety gets the local mean power value of the recent history and adapts it up or down according to the power value in the current period. The mechanism is simple but it requires additional data storage space and processing time overhead. In spite of existing these disadvantages, the FCDS improves the unfairness of the minimum power scheme in terms of different link quality of each UE. Meanwhile, it also considers the different power requirements of per UE compared with the Round Robin completely fair channel-independent scheduling method to enhance.

Simulator Configuration	
Simulation Time (s)	200

Table 3-1 Simulation Parameters

After that, using these parameters, two types of simulations based on the part discussed above are carried out.

3.1 Measurement and evaluation of the integrated networks with original single one gateway node

In this part, the performance of TCP throughput in the integrated networks with only one ad-hoc gateway node is mainly measured and assessed. Firstly, the simulation topology is given in Figure 3-1.

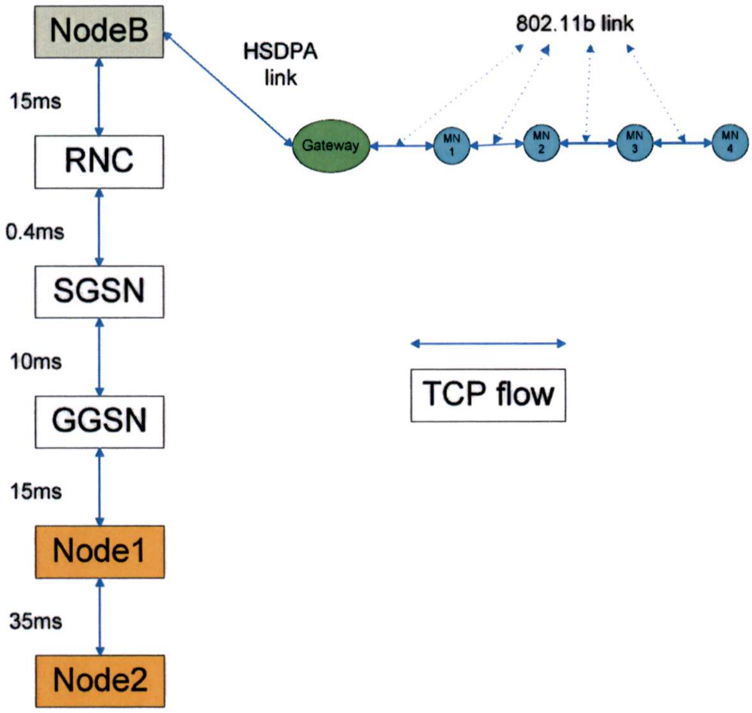

Figure 3-1 Simulation topology

The fixed hosts, RNC, Node B (i.e. Base Station), ad-hoc gateway and Mobile Nodes (MN) are modeled as the protocol stack depicted in Figure 3-. The setting of each link is also seen in Figure 3-1 (e.g. the delay of 0.4ms between SGSN and RNC, etc.). Furthermore, here the IEEE 802.11 ad-hoc networks subfield needs to be specialized. The ad-hoc networks subfield chain topology is set for our special integrated networks simulation from 0 hop to at most 4 hops and every Mobile Node has the same distance between each other, i.e. the interval distance of 130m. N.B., the available propagation distance of the IEEE 802.11 ad-hoc networks in NS2 is configured to 250m.

Since the aim of this part is to check up the performance of our integrated networks with only one gateway again and find out the special parameters for the future simulation of the networks with multiple gateways. Meanwhile, we also get the maximum TCP throughputs of two situations and compare them. In theorem, the first TCP throughput limits the second one.

According to the thesis [5], the end-to-end TCP throughput of the integrated networks has something with these parameters as follows: TCP window size, TCP packet size, Status prohibit timer and Ad-hoc MAC protocol mode.

Based on the analysis of the thesis [5], we get the possible optimal parameters in the test simulation. In order to make the result more clear, TCP throughput needs to be maximum. Then CSMA/CA should be chosen as the ad-hoc MAC mode and the TCP window size and the TCP packet size should be selected as large as possible. But if the larger TCP window size and segment size are chosen, the whole time of the simulation will increase much more. So the tradeoff of the result clearness and time of the simulation needs considering. Due to the test and checkup aim of this part, the TCP window size and packet size are selected 128 and 512, respectively. Here we only test 0 hop and 1 hops scenarios to check the maximum TCP throughputs whether they are right or not. The results are given in following Figure 4-2.

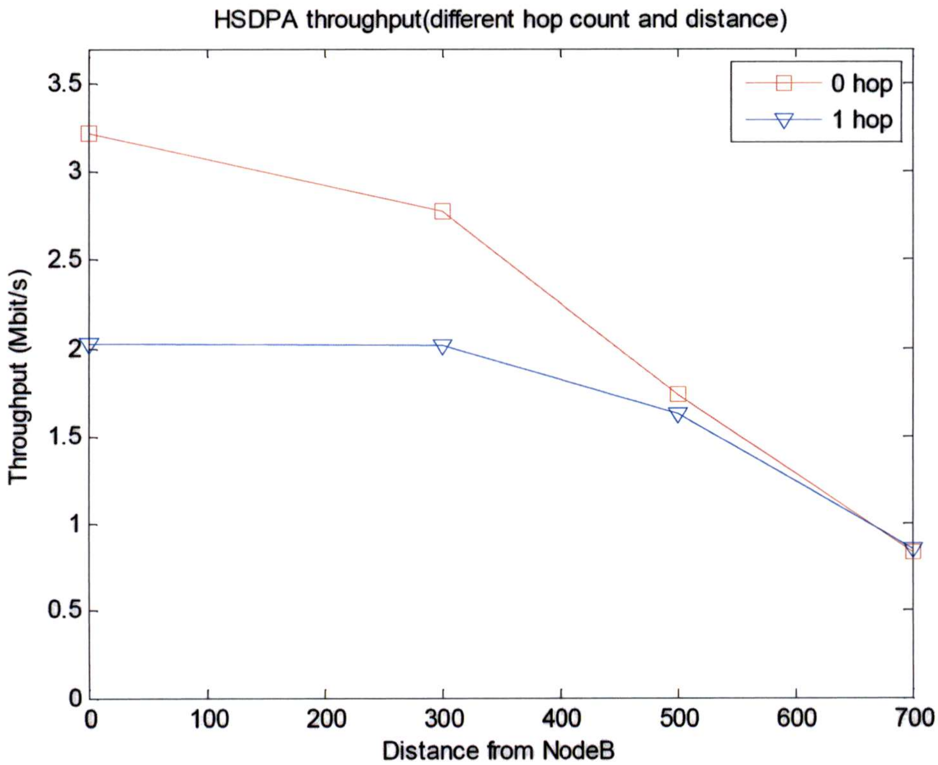

Figure 3-2 HSDPA throughput (CSMA/CA)

From the Figure 3-2, we can see that it is similar with the Figure 4-20 in the thesis [5]. Through our simulation, the TCP throughput for 0 hop of 3.22Mbits/s, 2.77Mbits/s, 1.74Mbits/s, 0.84Mbits/s at 0m, 300m, 500m, 700m is similar with those of the thesis [5]. Because a modified HSDPA link model (see the thesis [6]) is adopted, there are some small differences in the TCP throughput. So far, the checkup process has been finished and all the optimal parameters have been gained, which in turn, we will design some new simulation scenarios and do some research on the new integrated networks with multiple ad-hoc gateways.

3.2 New simulation scenarios and results of the integrated networks with two ad-hoc gateway nodes

In this section, the topology of our new simulation of the integrated networks with two ad-hoc gateway nodes is seen as the figure 3-3. The parameter configuration is the same as that of the simulation of the integrated networks with only one ad-hoc gateway except for the extension of two ad-hoc gateways. There are three factors in total in our new simulation, i.e. the scheduler-type of the Base Station (BS), the Channel Quality Indicator (CQI) value which is fed back by the gateway nodes to the BS and the Hop Count of the ad-hoc networks subfield, which impact on the end-to-end performance of the integrated networks with two ad-hoc gateway nodes. In general, if there are three interrelated factors, two of them need to be fixed, whereas the last one can be changed to search its effects on TCP throughput.

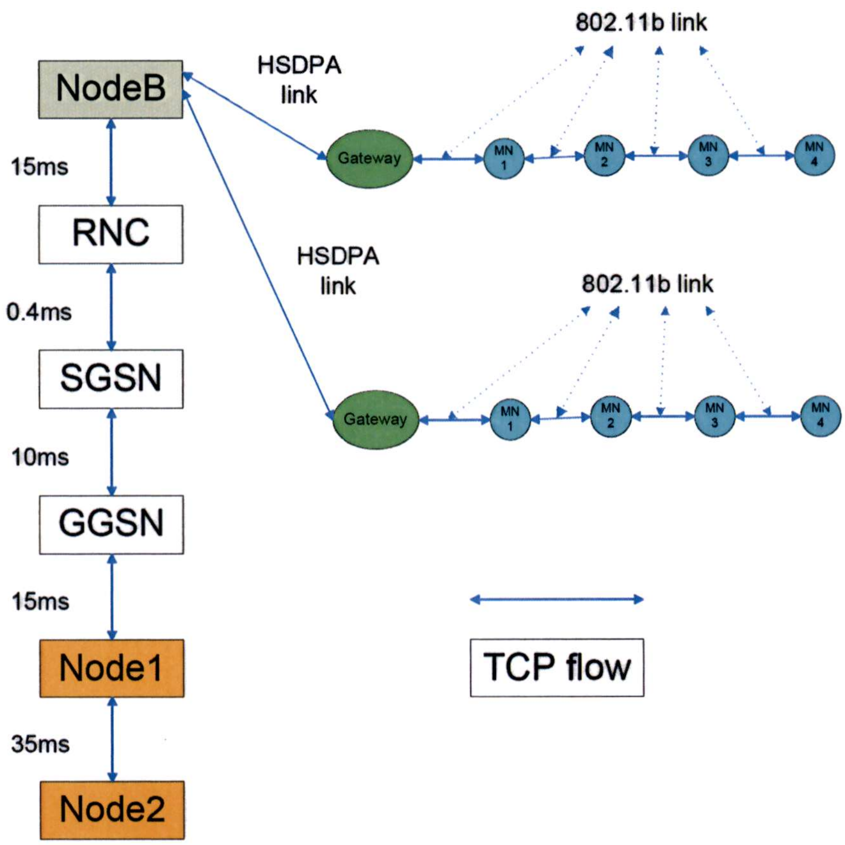

Figure 3-3 Simulation topology

3.2.1 Same scheduling scheme adopted by the Base Station

Because the target of this part is to investigate what extent of performance degradation of the integrated networks with two ad-hoc gateways compared to that with only one gateway, the scheduler type of MAC-hs is set a value of 1, i.e. Round Robin Scheduling algorithm, which is the completely fair scheduling for two ad-hoc gateways irrespective of their link condition in HSDPA subfield and hop count in the IEEE 802.11 ad-hoc subfield. The classification of simulation scenarios is in terms of the difference in the link condition and the number of hop of each gateway node. Based on the analysis above, there are the simulation scenarios as follows:

3.2.1.1 Same link condition between single one Base Station and two ad-hoc gateways

Since there are two changeable parameters in our new simulation here, one of two parameters needs to be kept stable to investigate what effect the other has on our simulation of the integrated networks with two ad-hoc gateways. In the first, we keep up the same link condition between one Base Station and two gateways. In the same words, in the high speed downlink shared channel (hs-dsch) two hybrid UEs (ad-hoc gateway) experience the same packet error trace, i.e. these two gateways has the same link conditions. Here the packet error trace of a value of 100m are chosen. Because of random property, there are ten packet error traces produced. In order to gain more exact simulation results, we need run every packet error traces, i.e. ten times of simulation.

Scenario 1 – First gateway: 1hop; Second gateway: 1, 2, 3, 4hop

In this part, the first ad-hoc gateway node has always 1-hop mobile node, while the second gateway node has 1-, 2-, 3- and 4-hop mobile nodes in each simulation of the integrated networks, respectively. According to their TCP throughput, the figure 3-4 can be given as follow:

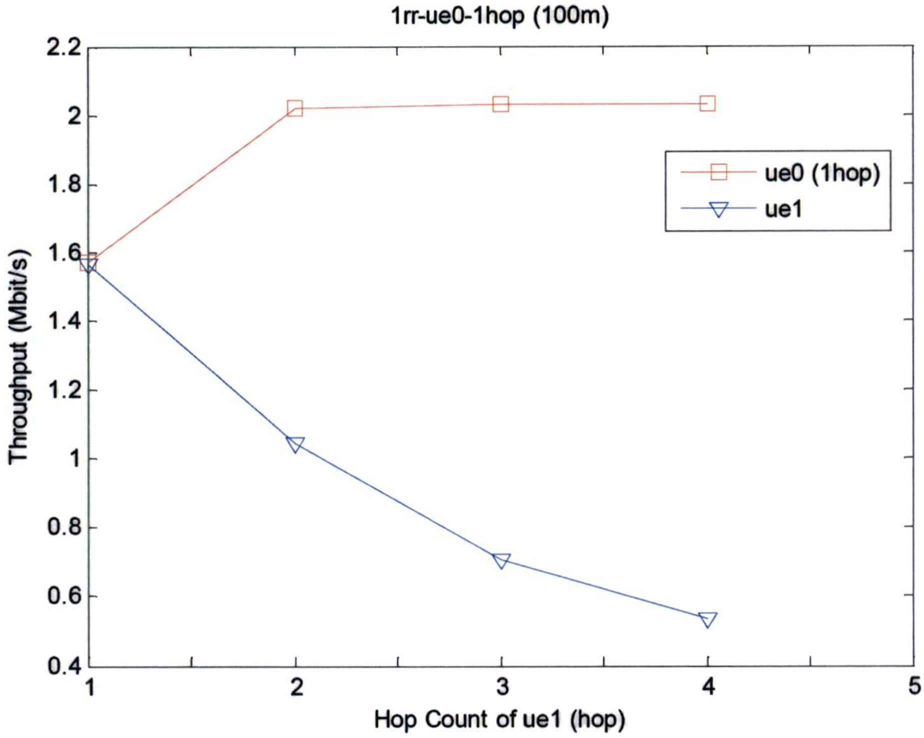

Figure 3-4 TCP throughput of First gateway: 1hop; Second gateway: 1, 2, 3, 4hop

Scenario 2 – First gateway: 2hop; Second gateway: 2, 3, 4hop

The scenario 2 is similar with the scenario 1. The difference is that the first gateway node has 2-hop mobile nodes in the ad-hoc networks subfield, whereas the other one has 2-, 3- and 4-hop mobile nodes. The figure 3-5 can be plotted.

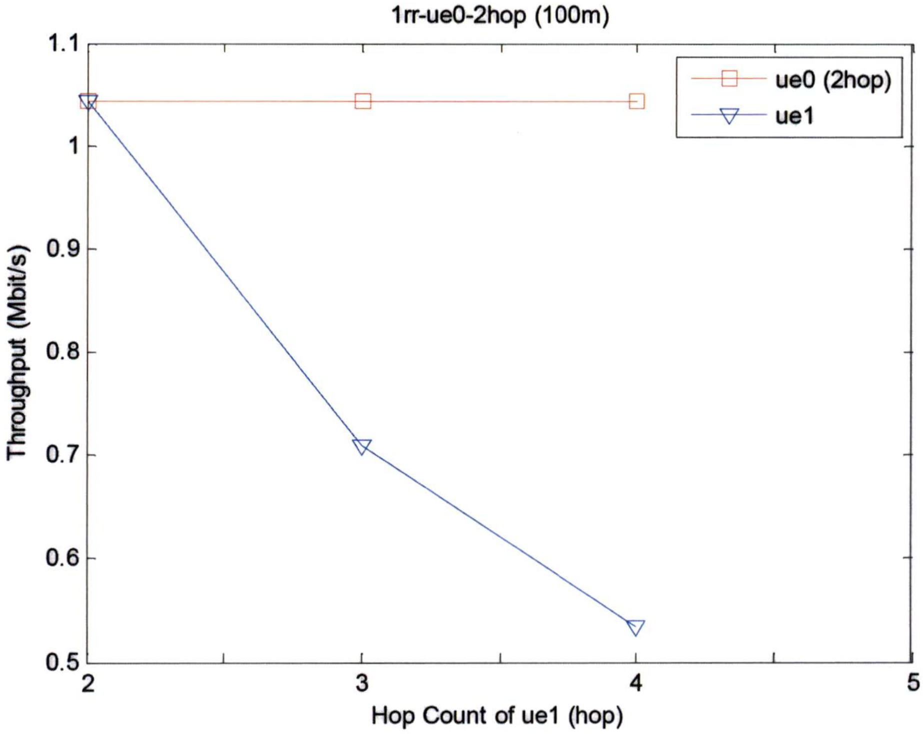

Figure 3-5 TCP throughput of First gateway: 2hop; Second gateway: 2, 3, 4hop

Scenario 3 – First gateway: 3hop; Second gateway: 3, 4hop

In the scenario 3, the first ad-hoc gateway node has 3-hop mobile node. However, the second one has 3- and 4-hop mobile node in the ad-hoc networks subfield. Similarly, the figure 3-6 is drawn.

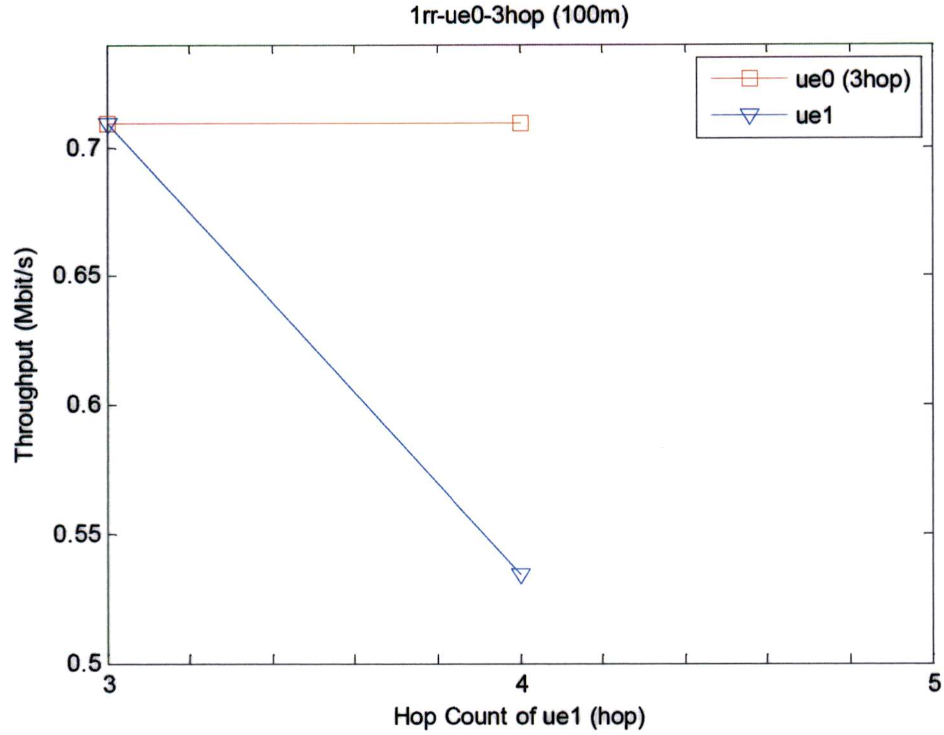

Figure 3-6 TCP throughput of First gateway: 3hop; Second gateway: 3, 4hop

Compared with the three figures above, there is the similar phenomenon that due to the same link quality between the Node B and ad-hoc gateways in the HSDPA subfield and I hop count between the two gateways in the IEEE 802.11b ad-hoc networks subfield, there is no doubt that the hop count in the ad-hoc networks subfield can influence on the end-to-end TCP throughput to some extent. Besides, from these figures, we can also see that the more differences between the hop counts of the two gateways are, the more distinguish TCP throughput of the terminal nodes is.

3.2.1.2 Different link quality between single one Node B and two ad-hoc gateways

In this section, Round Robin scheme is always selected as the scheduler type of the base station. The effects on the integrated networks performance of the hop count in the ad-hoc networks subfield has been investigated above when two link conditions between base station and two ad-hoc gateways are set to equal (i.e. the same distance value of 100m). However, here, the influence of link quality in the HSDPA subfield on the whole integrated networks need to be studied, so the hop count schemes are adopted the same as that of the section above. The scenarios 1, 2 and 3 here are designed similarly with the section 3.2.1.1 except for different link condition between the single one BS and the two ad-hoc gateway nodes. We can get the figures of the scenario 1, 2 and 3, respectively.

Scenario 1 – First gateway: 1hop; Second gateway: 1, 2, 3, 4hop

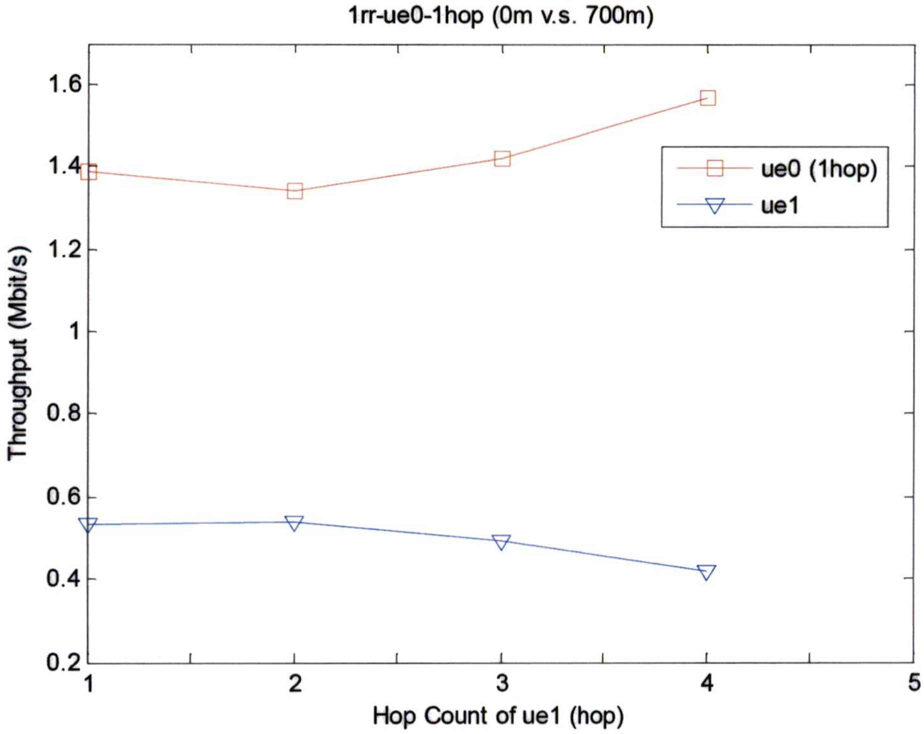

Figure 3-7 TCP throughput of First gateway: 1hop; Second gateway: 1, 2, 3, 4hop

Scenario 2 – First gateway: 2hop; Second gateway: 2, 3, 4hop

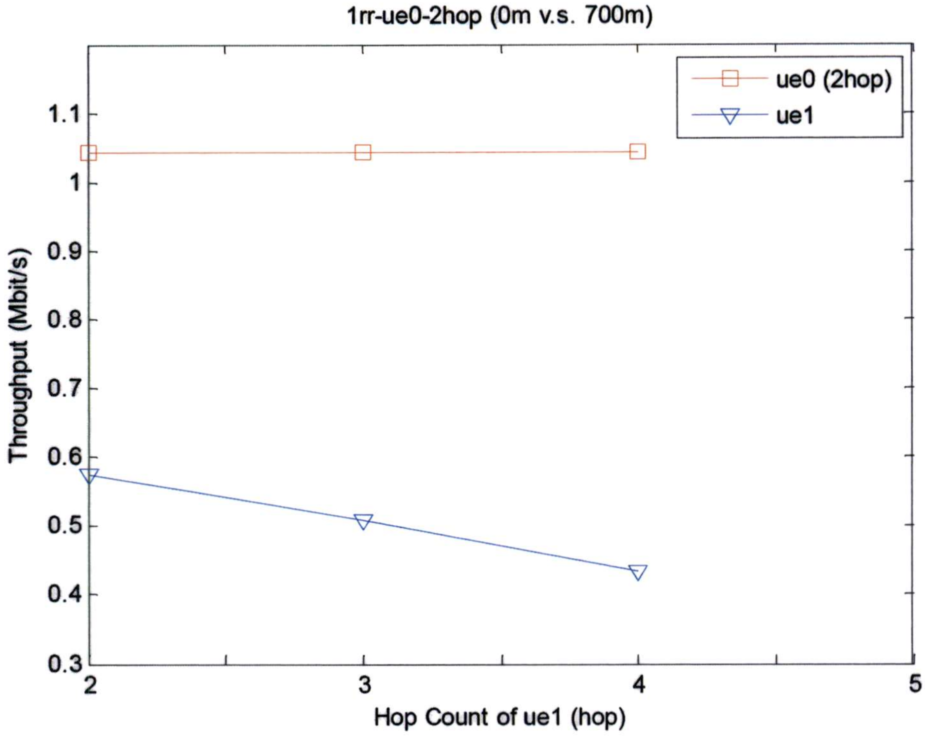

Figure 3-8 TCP throughput of First gateway: 2hop; Second gateway: 2, 3, 4hop

Scenario 3 – First gateway: 3hop; Second gateway: 3, 4hop

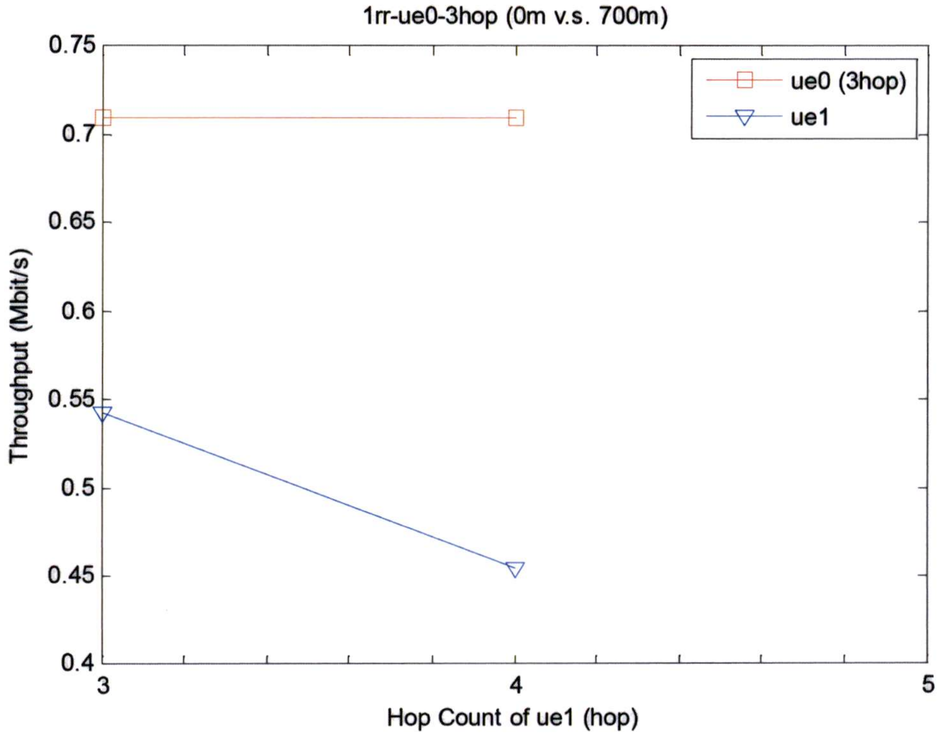

Figure 3-9 TCP throughput of First gateway: 3hop; Second gateway: 3, 4hop

As been seen from the three figures above, there is the same phenomenon in the TCP throughputs through the two ad-hoc gateways as those of the previous section 3.2.1.1. Here, the two factors of the hop count in the ad-hoc networks subpart and the link condition in the HSDPA subpart are all changeable. So not only dose the hop counts impact on the TCP throughput, but the link conditions also make an influence on it, which is proved in further.

3.2.2 Different scheduling method explored by the Base Station (Node B)

In our new integrated networks simulation, there are three typical BS scheduler schemes which can be utilized. They are the Round Robin mechanism (RR), the Minimum Power method (MP) and the Fair Channel-Dependent Scheduling scheme (FCDS), respectively. The first one is a completely fair scheduling technique, while the second one is an unfair scheduling mechanism based on channel quality between the Base Station (BS) and ad-hoc gateway node (GW). In other words, the former is that the BS fairly distributes resources to all the GWs in terms of the same time interval (TTI). The latter is that the GWs which own good channel condition will be served firstly, i.e., these GWs need less power to communicate with the BS. In contrast, the GWs that have bad channel quality will hardly be served. However, the last scheduling scheme is a tradeoff between the first RR and the second MP. The last FCDS technique is to consider a relative power that is a local mean in terms of the history power. So, the GWs of maximum relative power will be given first priority to. In the section above, we have investigated the first RR scheduling mechanism, but the aim is to focus on comparing the influence on performance based on different channel quality and different hop count, which in turn, the impact on performance based on distinguished scheduler type will be researched.

3.2.2.1 Round Robin Scheduling

The simulations in this part are the completely same as those of Scenario 1 in the subpart 4.2.1.1 and the subpart 4.2.1.2 of the section 4.2.1. In order to compare with the two other scheduling schemes easily, we directly put the figure 3-4 and the figure 3-7 in here:

Scenario 1 – Same channel condition and distance of 100m between the single BS and the two ad-hoc gateway nodes.

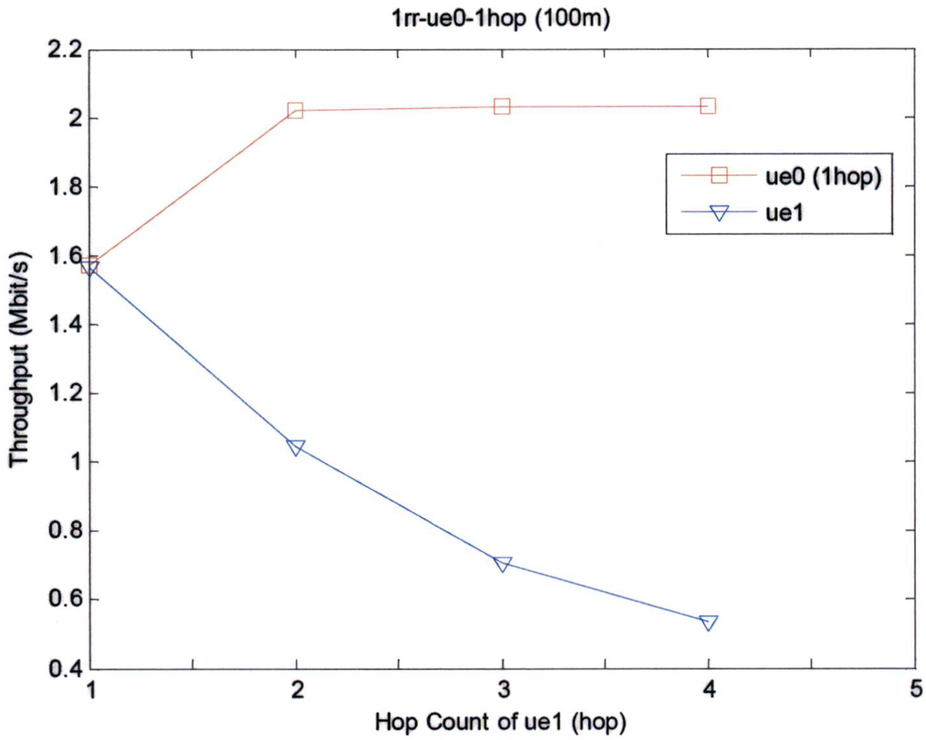

Figure 3-4 TCP throughput of round robin scheduling for the same channel

Scenario 2 – Different channel condition and distance of 0m v.s. 700m between the single BS and the two ad-hoc gateway nodes, respectively.

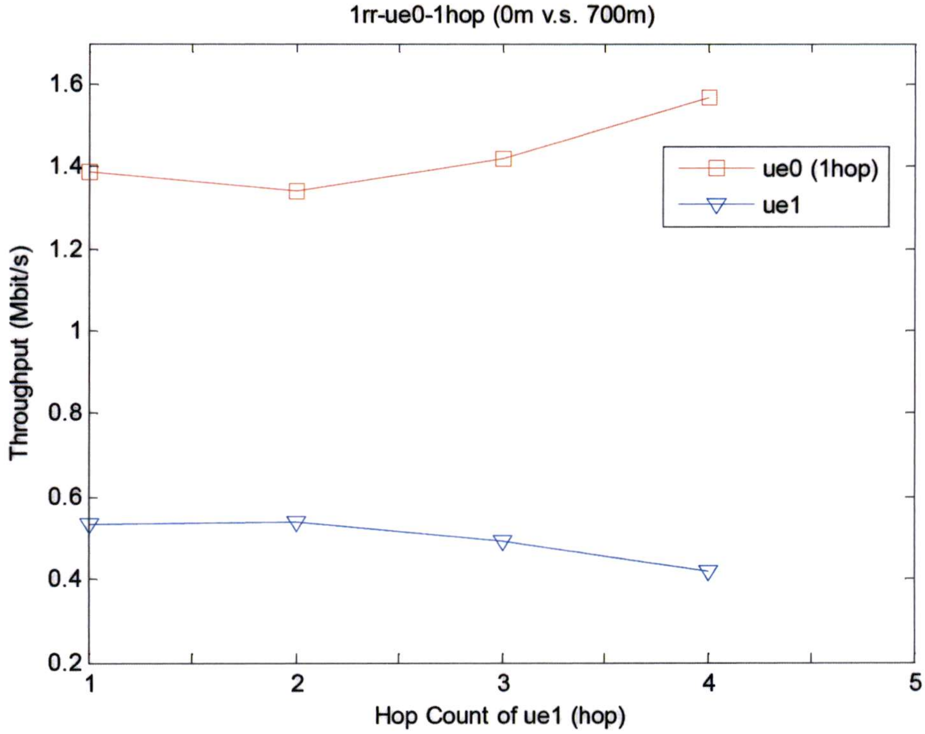

Figure 3-7 TCP throughput of round robin scheduling for two channels

3.2.2.2 Minimum Power Scheduling

In this part, the second MP scheduling mechanism will be used in our new integrated networks with two ad-hoc gateway nodes. The topology is not distinguished with the section 3.2.1, and the other parameters configuration is also the same as the previous simulation except for the MP scheduler type of the BS. Similarly, through running 10 packet error traces, we will gain the simulation results of two scenarios in terms of whether the channel qualities are different or not:

Scenario 1 – Same channel condition and distance of 100m between the single BS and the two ad-hoc gateway nodes.

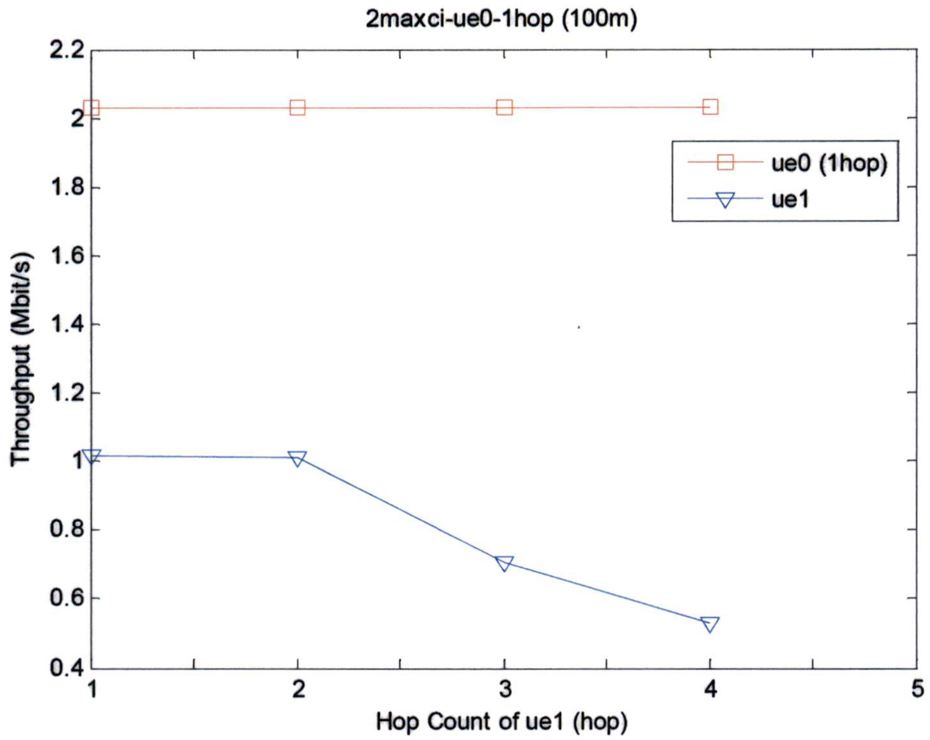

Figure 3-10 TCP throughput of MP scheduling for the same channel

Scenario 2 – Different channel condition and distance of 0m v.s. 700m between the single BS and the two ad-hoc gateway nodes, respectively.

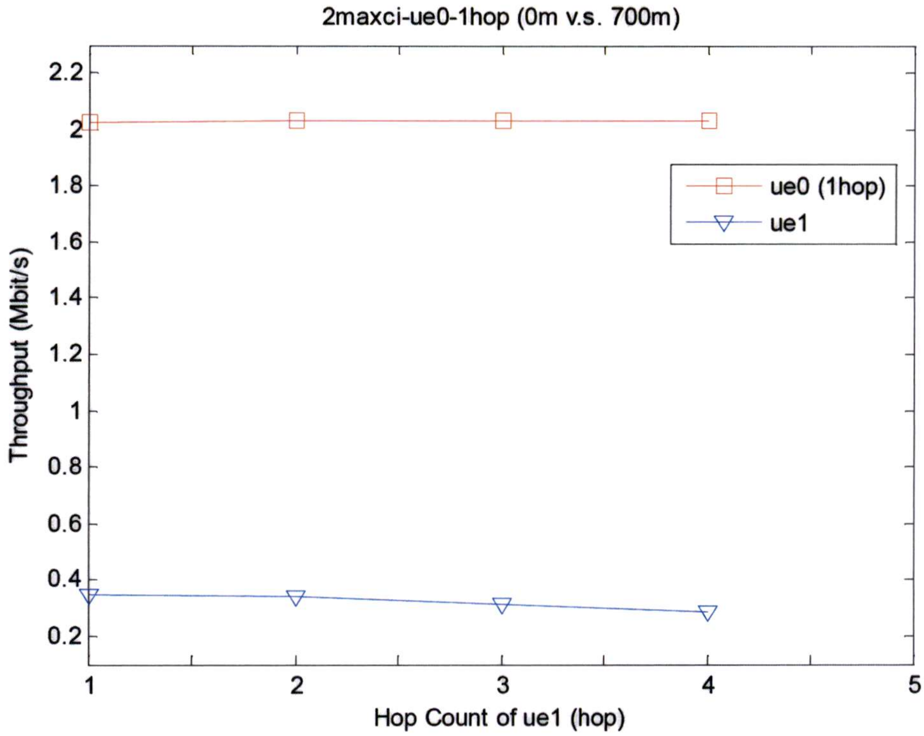

Figure 3-11 TCP throughput of MP scheduling for two channels

3.2.2.3 Fair Channel-Dependent Scheduling

The simulation in this part is similar with that in the part 3.2.2.2. However, the third FCDS scheduling mechanism is selected as the scheduler type of the Node B. According to different link quality between the BS and the two ad-hoc gateway nodes, the two similar scenarios will be got as follows:

Scenario 1 – Same channel condition and distance of 100m between the single BS and the two ad-hoc gateway nodes.

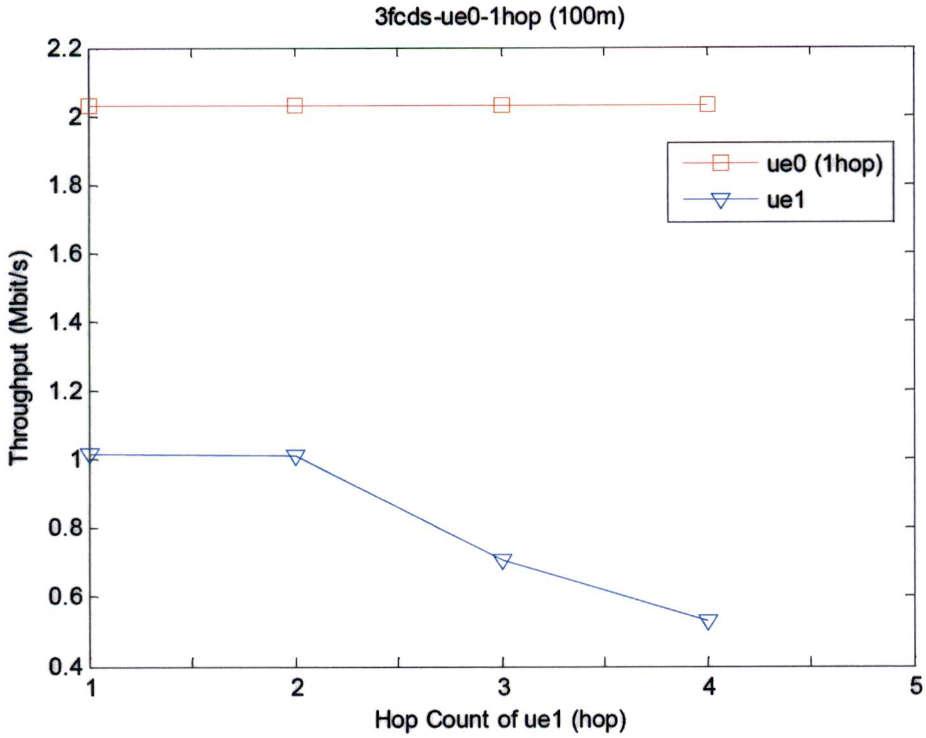

Figure 3-12 TCP throughput of FCDS scheduling for the same channel

Scenario 2 – Different channel condition and distance of 0m v.s. 700m between the single BS and the two ad-hoc gateway nodes, respectively.

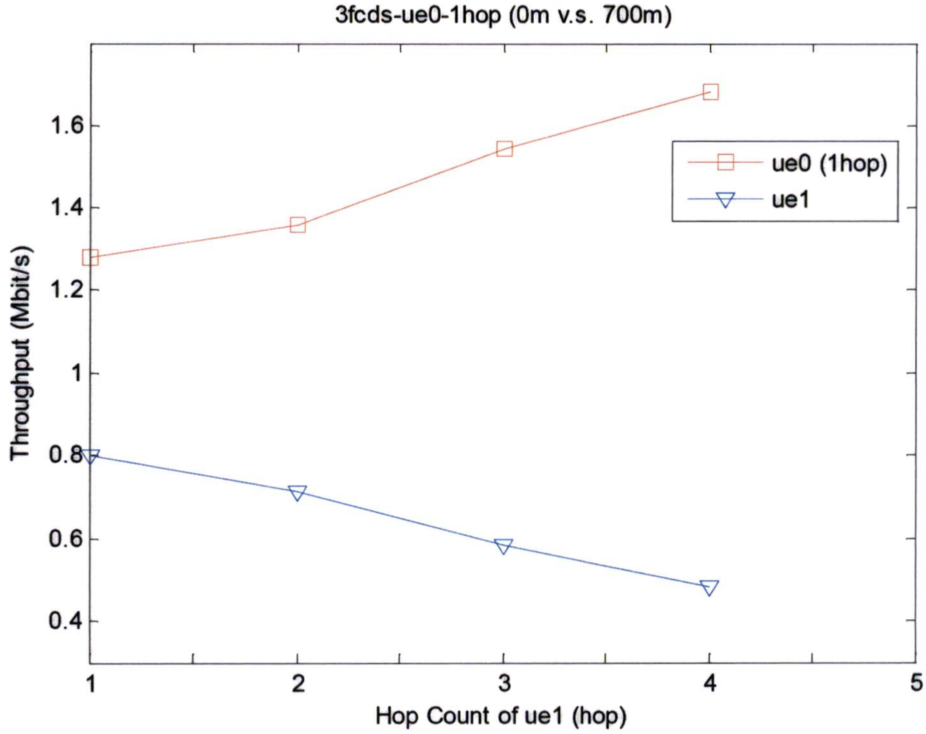

Figure 3-13 TCP throughput of FCDS scheduling for two channels

3.2.2.3 Conclusion

As been seen from all the pictures of the new simulation of the integrated networks with two gateways using different scheduling schemes above, not only be the TCP throughput influenced by the link quality between the BS and the gateway node in the HSDPA subfield, but the hop count in the ad-hoc network subfield also makes an effect on it. However, the original scheduling metrics consider only the channel condition in the HSDPA subpart. Based on the result which we gain from the new simulation above, a new scheduling method two variables of channel quality and hop count dependence needs to be designed.

3.3 Research on the scheduling unfairness

Based on the simulation result of the section 3.2, we have concluded that the performance of the integrated networks is impacted by two subfields at the same time, i.e. the HSDPA subfield and the ad-hoc networks subfield. We can design a new scheduler type considering two subparts. But how to create a new scheduling method is not clear, so some new analysis and simulation scenarios that investigate how the two subfields influence on the integrated networks performance in details need to be done. Actually, the previous section 3.2 has shown some regulations. One of them is significant that if there are two gateways sharing the hs-dsch in the HSDPA subfield, an unfairness phenomenon between the TCP throughputs of the terminal nodes through the two gateway nodes occurs. The larger the difference of hop count in the ad-hoc networks subfield is, the more the unfairness between two end-to-end nodes in the two ad-hoc networks subfield respectively is, i.e. the larger the difference of the TCP throughput between two end-to-end nodes. Since there exists the unfairness in the new integrated networks, the new scheduling metric can be designed based on improving the unfairness. In order to investigate the unfairness further, we need design some new simulation scenarios to get the detail information about the extent of the impact of the two subfields on the unfairness. Firstly, the influence of the HSDPA subpart will be investigated. Secondly, we will do some research on the impact of the ad-hoc networks subpart.

3.3.1 Different link condition in the HSDPA subfield

In this part, the impact of channel quality of the HSDPA subfield on the TCP throughput will be researched in details. Here we will simulate all the distance parameters so as to find in which distances the unfairness becomes obvious. Meanwhile, to compare the unfairness much more easily, the simulation of the integrated networks with a gateway owning different hop count in ad-hoc networks subfield is also done. Besides, in order to tradeoff the clearness of results and the overhead of simulation time, here we run only one packet error trace, because the result has been clear enough.

3.3.1.1 Scenario 1 – Two gateways

In this scenario 1, the simulation topology is the same as that of the previous section, seeing Figure 3-3. The parameter setting is also the same as that of the previous simulation. Eventually, we can gain the available results as the following table 3-2.

	1 GW 2 hop	2 GWs 1-2hop	1 GW 3 hop	2 GWs 1-3hop	1 GW 4 hop	2 GWs 1-4hop
0m	1.042956	2.030445 1.043048	0.709396	2.031772 0.709355	0.534576	2.030505 0.534302
100m	1.043523	2.023128 1.042047	0.709163	2.030691 0.709437	0.534935	2.032280 0.534600
200m	1.042024	1.929973 1.043504	0.709035	2.033957 0.709282	0.534582	2.030999 0.534421
300m	1.041944	1.356200 1.025181	0.708742	1.615807 0.708784	0.534576	1.749730 0.534800
400m	1.042002	1.278724 0.995891	0.709116	1.507711 0.708075	0.534343	1.662170 0.534205
500m	1.035602	1.181716 0.962682	0.708247	1.390408 0.701192	0.534600	1.530866 0.533476
600m	0.945623	0.675638 0.683104	0.682656	0.722426 0.605552	0.527398	0.820497 0.491501
700m	0.950696	0.708827 0.707112	0.694310	0.773223 0.607986	0.529811	0.856529 0.504619

Table 3-2 TCP throughput of the integrated networks with 1 gateway and 2 gateways in case of different hop count in the ad-hoc networks subfield

3.3.1.2 Scenario 2 – Three gateways

As we need design a new scheduling scheme which can reply on two factors, i.e., the channel condition in the HSDPA subfield and the hop count in the ad-hoc networks subfield, it is significant to investigate the performance of the integrated networks not only with two gateways but also more gateway nodes such as three gateways, four gateways, etc. The simulation of the integrated networks with two gateways has been done above, so, which in turn, we need do some research in the integrated networks with more than two gateway nodes. The simulation topology here is similar with that of the previous section except for the extension of multiple IEEE 802.11b ad-hoc gateways, seeing Figure 4-14. And there is also the same parameter configuration with that of the previous part.

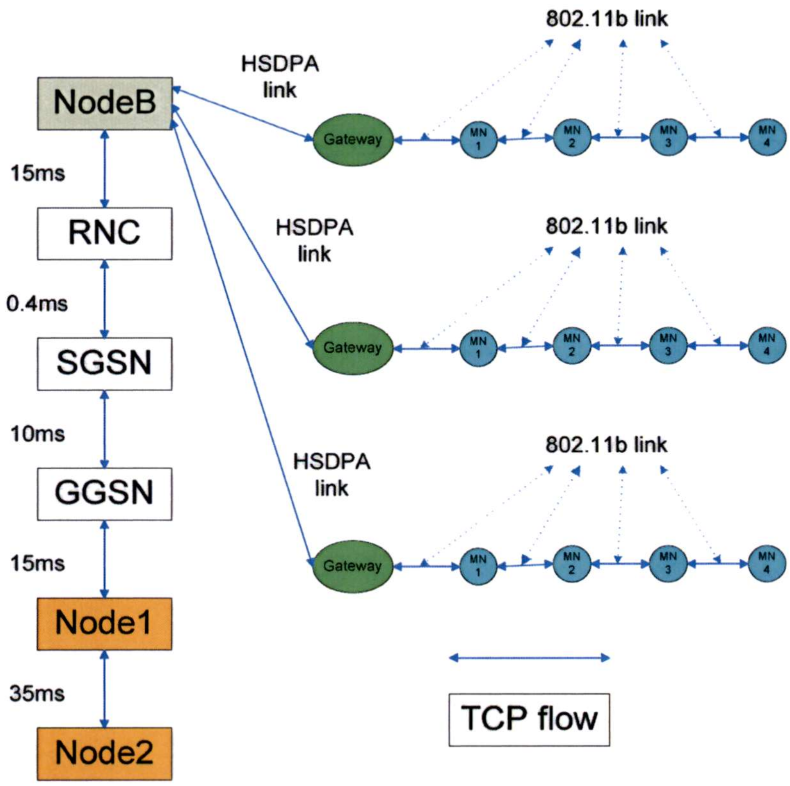

Figure 3-14 Simulation topology

	1 GW	3 GWs	1 GW	3 GWs	1 GW	3 GWs
	2 hop	1-2-1hop	3 hop	1-3-1hop	4 hop	1-4-1hop
		1.046983		1.179505		1.265860
0m	1.042956	1.040701	0.709396	0.709133	0.534576	0.534673
		1.017945		1.156132		1.250185
		1.041865		1.172815		1.259603
100m	1.043523	1.038038	0.709163	0.709829	0.534935	0.534811
		1.031062		1.167302		1.256670
		1.008539		1.127142		1.211284
200m	1.042024	1.006443	0.709035	0.709189	0.534582	0.534695

		1.002967		1.121324		1.205522
		0.799289		0.837583		0.899706
300m	1.041944	0.791314	0.708742	0.698651	0.534576	0.534804
		0.803002		0.832208		0.906807
		0.766150		0.794446		0.861897
400m	1.042002	0.772108	0.709116	0.688391	0.534343	0.533553
		0.758708		0.794717		0.856304
		0.714004		0.739259		0.792509
500m	1.035602	0.714701	0.708247	0.652368	0.534600	0.525250
		0.713054		0.739238		0.795929
		0.442196		0.432707		0.450147
600m	0.945623	0.451037	0.682656	0.449468	0.527398	0.417959
		0.438052		0.444164		0.457509
		0.463536		0.463435		0.477593
700m	0.950696	0.467992	0.694310	0.461504	0.529811	0.425666
		0.463389		0.463661		0.476885

Table 3-3 TCP throughput of the integrated networks with 1 gateway and 3 gateways in case of different hop count in the ad-hoc networks subfield

3.3.1.3 Scenario 3 – Four gateways

The simulation topology of the integrated networks with four gateways is similar with that of the previous part, see Figure 3-15. The parameter setting is still kept no change.

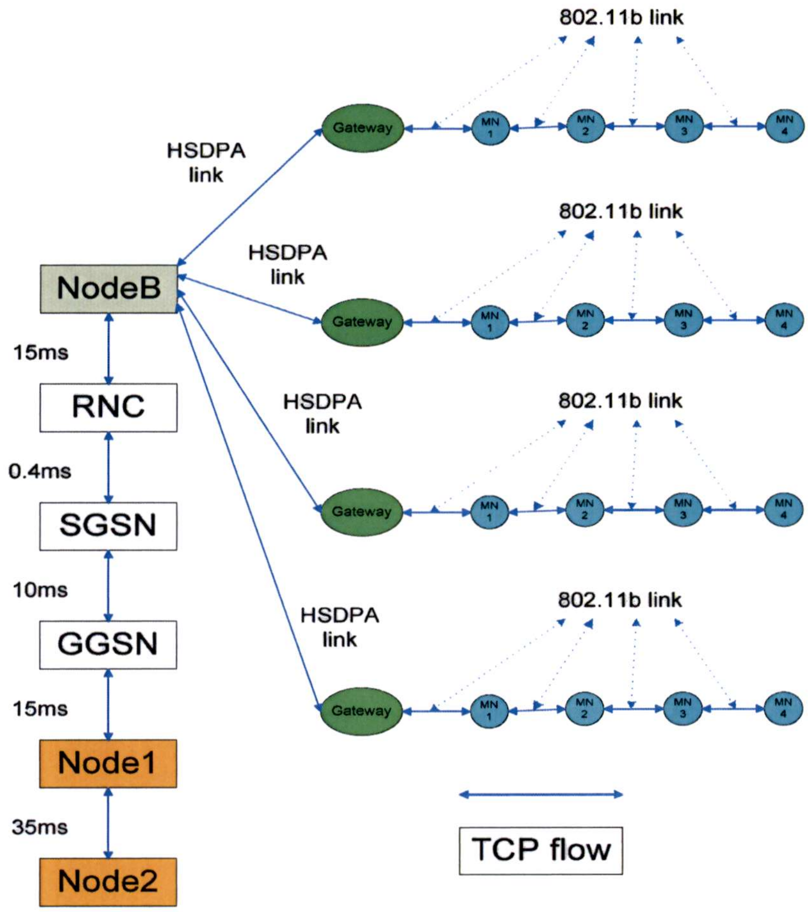

Figure 3-14 Simulation topology

	1 GW	4 GWs	1 GW	4 GWs	1 GW	4 GWs
	2 hop	1-2-1-1hop	3 hop	1-3-1-1hop	4 hop	1-4-1-1hop
0m	1.042956	0.778621	0.709396	0.795802	0.534576	0.845469
		0.776356		0.710021		0.534873
		0.767658		0.791283		0.840074
		0.762870		0.783692		0.829655
100m	1.043523	0.775158	0.709163	0.791386	0.534935	0.841373
		0.772086		0.709653		0.534467
		0.766991		0.786579		0.838299
		0.763939		0.781693		0.831697
200m	1.042024	0.750624	0.709035	0.760446	0.534582	0.808881
		0.748026		0.709566		0.534357
		0.744793		0756282		0.804672
		0.741247		0.753477		0.801640
300m	1.041944	0.597084	0.708742	0.595556	0.534576	0.614201
		0.582338		0.590861		0.523433
		0.594330		0.595638		0.611536
		0.589808		0.592429		0.610330
		0.570627		0.571966		0.583346

400m	1.042002	0.571019	0.709116	0.566535	0.534343	0.512725
		0.568118		0.571052		0.584896
		0.567521		0.569115		0.584030
500m	1.035602	0.530977	0.708247	0.528734	0.534600	0.541466
		0.527750		0.528292		0.483915
		0.529250		0.530034		0.540543
		0.527676		0.528027		0.542209
600m	0.945623	0.322011	0.682656	0.319451	0.527398	0.323185
		0.324391		0.323630		0.322358
		0.319964		0.319176		0.311334
		0.320943		0.319368		0.318625
700m	0.950696	0.340807	0.694310	0.337568	0.529811	0.341346
		0.338518		0.340207		0.333988
		0.341707		0.334137		0.341322
		0.336103		0.338004		0.342573

Table 3-4 TCP throughput of the integrated networks with 1 gateway and 4 gateways in case of different hop count in the ad-hoc networks subfield

According to these three tables, it is manifest that from 300m, the unfairness becomes obvious. Because the target of this part is to investigate the impact of the HSDPA subfield on the end-to-end TCP throughput, only distance parameters deciding the channel condition of the HSDPA subfield will be considered. Take the two gateway nodes for example, from Table 4-2, when the distances of 0m, 100m and 200m are selected to indicate the channel quality in the HSDPA subfield, the TCP throughput of the 2-hop MN controlled the second GW in the integrated networks with two GWs is almost the same as that of the 2-hop MN through only one GW in the single one GW integrated networks. However, from 300m, the formers become obviously less than all the latters in terms of different distances, which indicates the unfairness between the GWs in the integrated networks with two GWs. The first GW makes some extent of influence on the second GW. At this moment, it is potential to improve the end-to-end TCP throughput of the 2-hop MN controlled the second GW in the two GW integrated networks. Observed from the Table 3-3 and Table 3-4, there are the similar regulations in the three and four GWs integrated networks with that in the integrated networks with two GWs.

3.3.2 Different hop count in the IEEE 802.11b ad-hoc networks subfield

In this section, the impact of the ad-hoc networks subfield on the TCP throughput of the whole integrated networks will be investigated. There are two various factors of hop count and error rate of the error model in total in the wireless ad-hoc networks subfield. Here, only the hop count will be considered, while the other factor of the error rate will be kept as 0% in stable. In order to gain the most clear result on the hop count, we will directly utilize the result that be got above. The distance of 0m and 700m in the HSDPA subfield will be chosen as the channel quality parameters of two GWs, respectively.

	1 GW	2 GWs	1 GW	2 GWs	1 GW	2 GWs
	2 hop	1-2hop	3 hop	1-3hop	4 hop	1-4hop
0m		1.343874		1.420435		1.570316

700m	0.753120	0.541339	0.606444	0.492818	0.488281	0.417590

Table 3-5 TCP throughput of different hop count

From the Table 3-5 above, we can see that there is definitely the unfairness between two GWs in the integrated networks with the two GWs it is possible to improve the integrated networks performance. In order to gain how much to be improved on the TCP throughput, the improved ratio can be calculated as follows:

2 hop: improvable ratio = 0.753120 / 0.541339 = 1.391217
3 hop: improvable ratio = 0.606444 / 0.492818 = 1.230564
4 hop: improvable ratio = 0.488281 / 0.417590 = 1.169283

According to these ratios, we can find that it is 2 hops that is the most obvious to observe the unfairness.

3.3.3 Different error rate in the IEEE 802.11b ad-hoc networks subfield

The influence of the different hop count in wireless ad-hoc networks subfield on the whole integrated networks has been studied above, so the impact of the different error rate in the same subfield will be investigated in this section. Here we only do the simulation of three and four gateway nodes with 0%, 1% and 10% error rate, respectively. Eventually, the two Table 3-6 and Table 3-7 can be got.

3.3.2.1 Scenario 1 – Three gateways

	1 GW	3 GWs	1 GW	3 GWs	1 GW	3 GWs
	2 hop	1-2-1hop	3 hop	1-3-1hop	4 hop	1-4-1hop
0% error	1.043220	1.046715	0.709268	1.179458	0.534624	1.265832
		1.041778		0.709386		0.534725
		1.018914		1.163923		1.256374
1% error	1.005116	1.070585	0.680187	1.201691	0.512506	1.277955
		1.005544		0.680759		0.512285
		1.046888		1.183223		1.271123
10% error	0.353077	1.265086	0.127016	1.349800	0.056770	1.378479
		0.164906		0.072879		0.046042
		1.273519		1.296001		1.308498

Table 3-6 TCP throughput of the integrated networks with 1 gateway and 3 gateways in case of different hop count in the ad-hoc networks subfield

3.3.2.2 Scenario 2 – Four gateways

	1 GW	4 GWs	1 GW	4 GWs	1 GW	4 GWs

	2 hop	1-2-1-1hop	3 hop	1-3-1-1hop	4 hop	1-4-1-1hop
0% error	1.043220	0.778629	0.709268	0.795747	0.534624	0.845658
		0.775320		0.709591		0.534711
		0.768149		0.790824		0.839747
		0.764763		0.785281		0.835387
1% error	1.005116	0.781029	0.680187	0.803857	0.512506	0.860797
		0.779664		0.680666		0.512491
		0.773251		0.798603		0.853129
		0.770043		0.792941		0.848297
10% error	0.353077	1.006068	0.127016	0.922391	0.056770	1.070325
		0.151503		0.079614		0.047559
		0.962572		0.999325		1.036756
		0.973710		1.059099		1.144574

Table 3-7 TCP throughput of the integrated networks with 1 gateway and 4 gateways in case of different hop count in the ad-hoc networks subfield

The comparison method is similar with that of the section 3.3.1. But the compared factor is not the link condition in the HSDPA subpart but the error rate in the wireless ad-hoc networks subpart. From the two tables above, it is apparent that the larger the error rate is, the more obvious the unfairness is.

3.4 Further research on the new scheduling mechanism

Since the unfairness between the different flows destinated to the different terminal nodes through the different GWs (In other words, each GW has the only one TCP flow.) in our integrated networks has been studied in details in the previous section 4.3, which in turn, we will further investigate how much probability each flow should be selected to enable them to reach the balance among another. In the following part, some more obvious scenarios will be developed as the models of designing a new scheduler type.

3.4.1 Two flows (two GWs) and no wireless packet error rate

In this part, a typical simulation scenario will be considered again, i.e., the integrated networks with two gateways covering one and two hop Mobile Nodes in their coverage range, respectively. And the channel qualities of the two GWs in the HSDPA subfield are different between each other, two distances of 0m and 700m used for the two GWs. But the packet error rates in the IEEE 802.11b ad-hoc networks subfield are set the same value of 0%, i.e. no error in wireless ad-hoc networks subpart. The specific simulation topology and parameter setting can be shown as the following Figure 3-15 and Table 3-8 again.

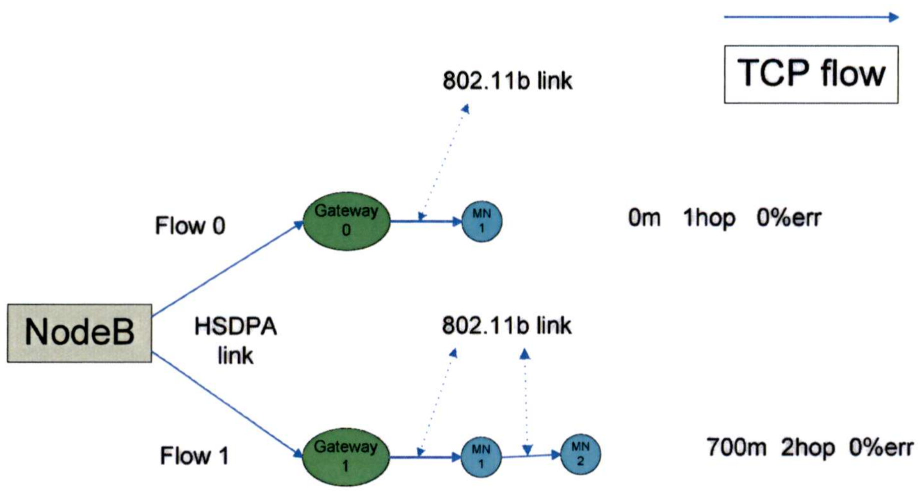

Figure 3-15 Simulation topology

Parameters			1 GW	2 GWs (Round Robin)
CQI	Hop Count	Error Rate	2 hop	1-2hop
0m	1hop	0%err		1.343874
700m	2hop	0%err	0.753120	0.541339

Table 3-8 Parameters configuration and TCP throughput of the scheduler type of Round Robin

From the Table 3-8, we can get the improved ratio like the previous section 3.3.2:
Improvable Ratio = 0.753120 / 0.541339 = 1.391217

Because the Round Robin metric is selected as the scheduling type of the Node B, the choice percentage of each flow is the same value of 50%. The improved ratio only represents the level that the TCP throughput can be increased, however, it cannot show how much selective probability of the flow which occurs the unfairness should be grown (the choice percentage of the other corresponding flow will decrease.) to improve the performance degradation caused by adding gateway number. In order to find the special choice probability making each flow reach the balance, we will do all the simulation of the selective percentage from 50% to 100%. The Figure 4-16 will be attained as follow. As the TCP throughput of the flow 1 is apparently larger than that of the flow 0 while the choice percentage of the flow 1 is configurated as 90% (the other corresponding selective probability of the flow 0 is 10%) , the simulation of the choice percentage from 90% to 100% will be not needed doing.

As can be seen from the Figure 3-16, it is obvious that as the selective probability of the flow 1 arrives approximate 70% (the choice percentages of the other flow 0 is set as the value of 30%) from the beginning point of 50% (the probability of the Round Robin metric) , the whole two flows can reach the balance eventually.

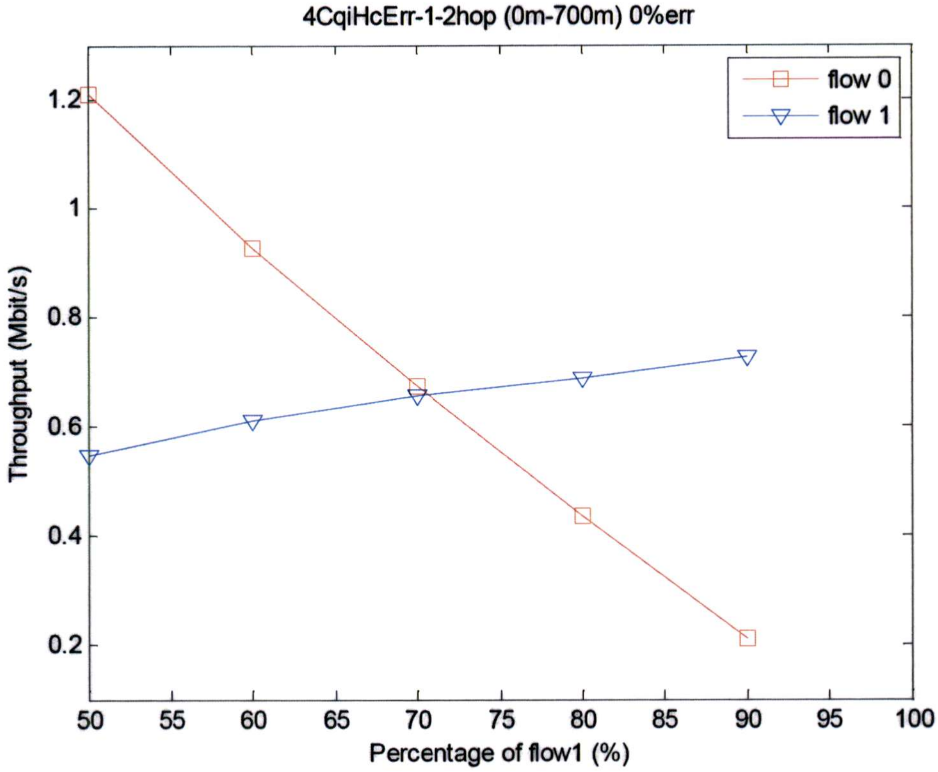

Figure 3-16 TCP throughputs of the integrated networks with two changeable choice percentage flows through two GWs

3.4.2 Two flows (two GWs) and 10% error rate

The simulation topology and parameter setting are the same as those of the before part 3.4.1, except for the wireless error rate changed as 10%, seeing Figure 3-17 and Table 3-9.

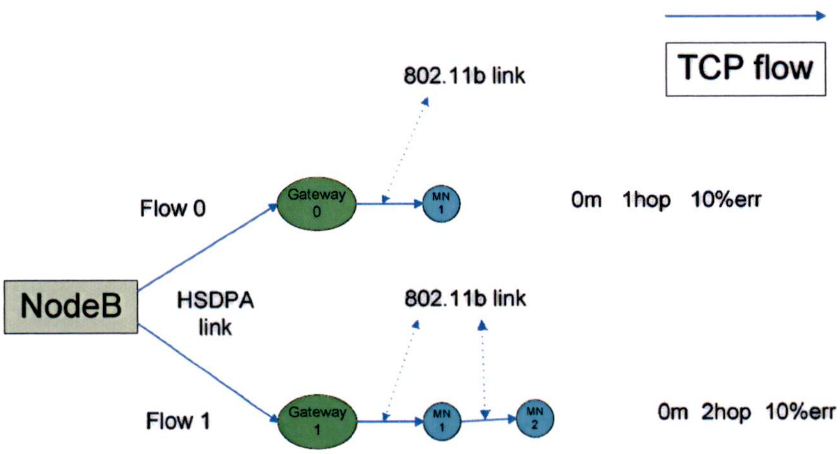

Figure 3-17 Simulation topology

Parameters			1 GW	2 GWs (Round Robin)
CQI	Hop Count	Error Rate	2 hop	1-2hop
0m	1hop	10%err		1.314974
0m	2hop	10%err	0.199690	0.133570

Table 3-9 Parameters configuration and TCP throughput of the scheduler type of Round Robin (10%err)

Like the section above, we can calculate:
Improvable Ratio = 0.199690 / 0.133570 = 1.495021

Using the same method, the Figure 4-18 can also be obtained:

From the Figure 4-18, it is manifest that when the flow 1 is selected at the choice probability of 95%, the two flows can be balanced eventually.

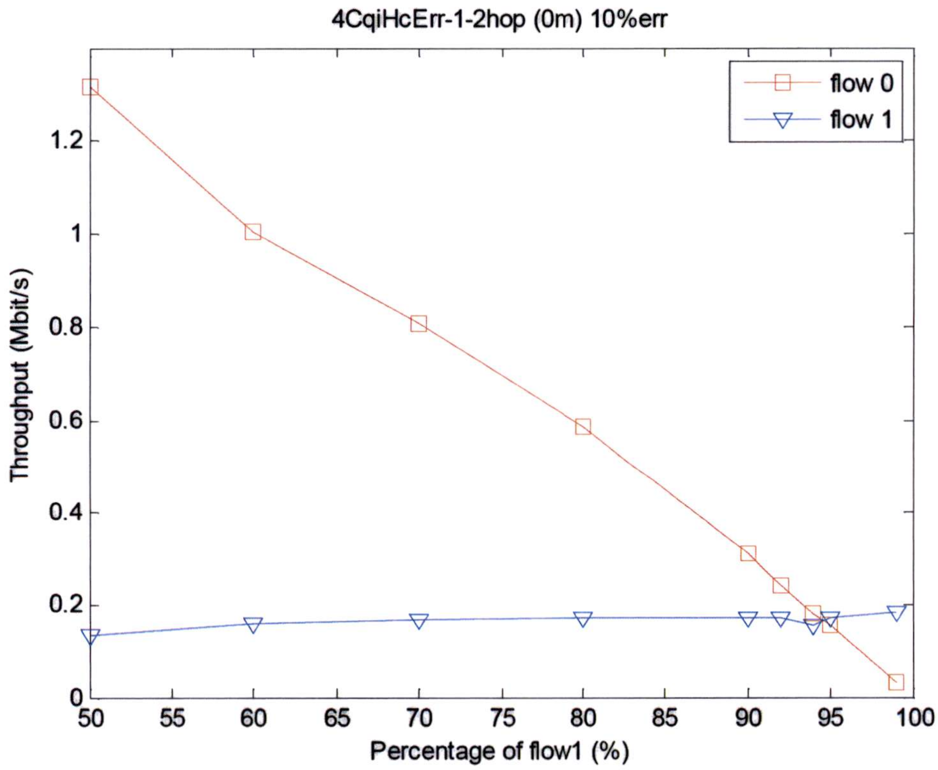

Figure 3-18 TCP throughputs of the integrated networks with two changeable choice percentage flows through two GWs (10%err)

3.4.3 Three flows (three GWs) and no error rate

In this part, the simulation topology and parameter setting are the same as those of the previous part 3.4.1, except for extension of three gateways, seeing Figure 3-19 and Table 3-10.

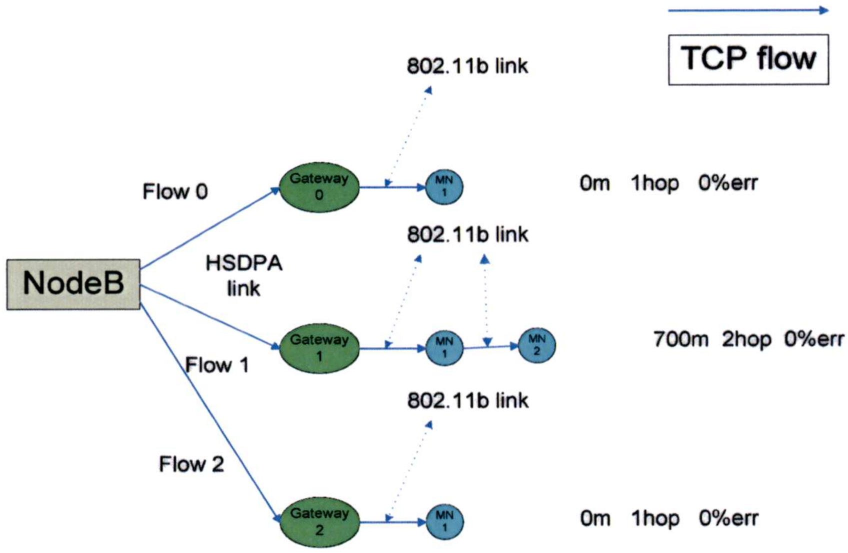

Figure 3-19 Simulation topology

Parameters			1 GW	2 GWs (Round Robin)
CQI	Hop Count	Error Rate	2 hop	1-2-1hop
0m	1hop	0%err		0.900658
700m	2hop	0%err	0.753120	0.391226
0m	1hop	0%err		0.896678

Table 3-10 Parameters configuration and TCP throughput of the scheduler type of Round Robin

Improvable Ratio = 0.753120 / 0.391226 = 1.925025

According to the Figure 3-20, it is apparent that when the selective probability of the flow 1 reaches about 50% (the choice percentages of the other two flows are configurated as the same value of 25%, respectively) from the starting point of 33.3% (the probability of the Round Robin metric) , the three flows can be balanced eventually.

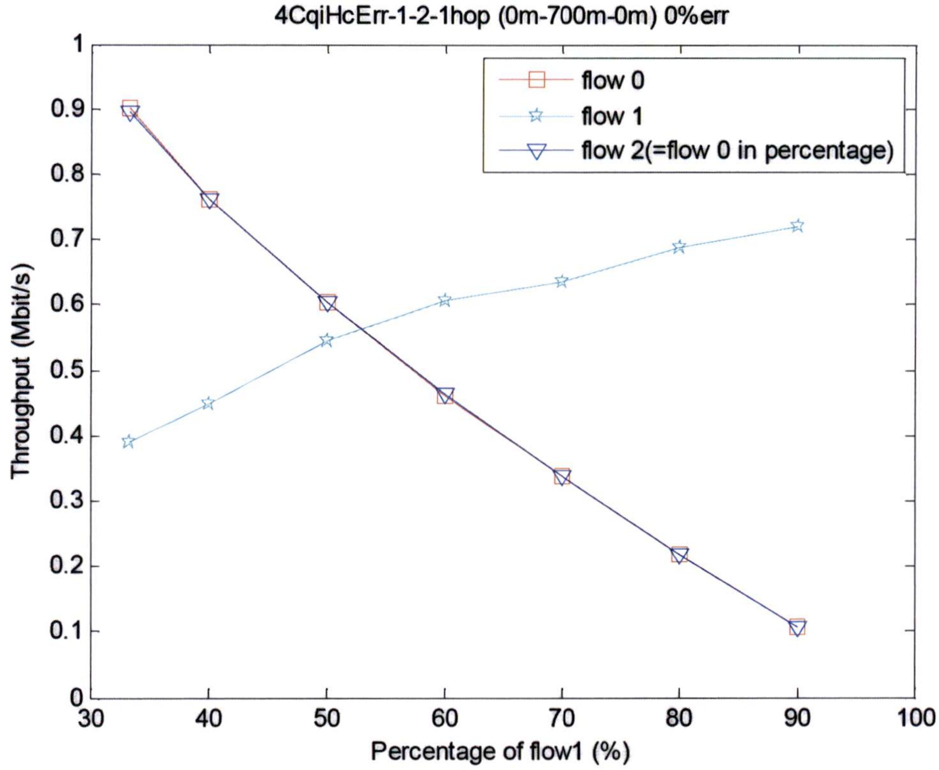

Figure 3-20 TCP throughputs of the integrated networks with three changeable choice percentage flows through three GWs

3.4.4 Four flows (three GWs) and no error rate

In this part, the simulation topology and parameter configuration are the same as those of the before part 3.4.1, except for extension of four gateways, seeing Figure 3-21 and Table 3-11.

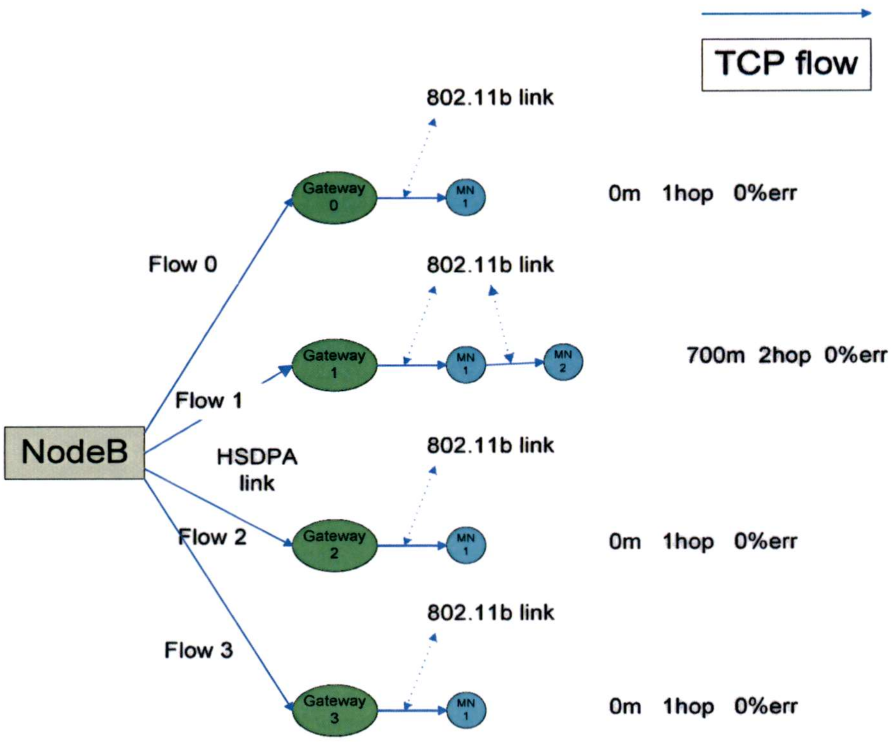

Figure 3-21 Simulation topology

Parameters (Round Robin)			1 GW	2 GWs
CQI	Hop Count	Error Rate	2 hop	1-2-1-1hop
0m	1hop	0%err		0.686525
700m	2hop	0%err	0.753120	0.291395
0m	1hop	0%err		0.684467
0m	1hop	0%err		0.682172

Table 3-11 Parameters configuration and TCP throughput of the scheduler type of Round Robin

Improvable Ratio = 0.753120 / 0.291395 = 2.584533

As be seen from the Figure 3-22, it is obvious that as the selective probability of the flow 1 arrives approximate 40% (the choice percentages of the other three flows are set as the same value of 20%, respectively) from the beginning point of 25% (the probability of the Round Robin scheme) , the whole four flows can reach the balance eventually.

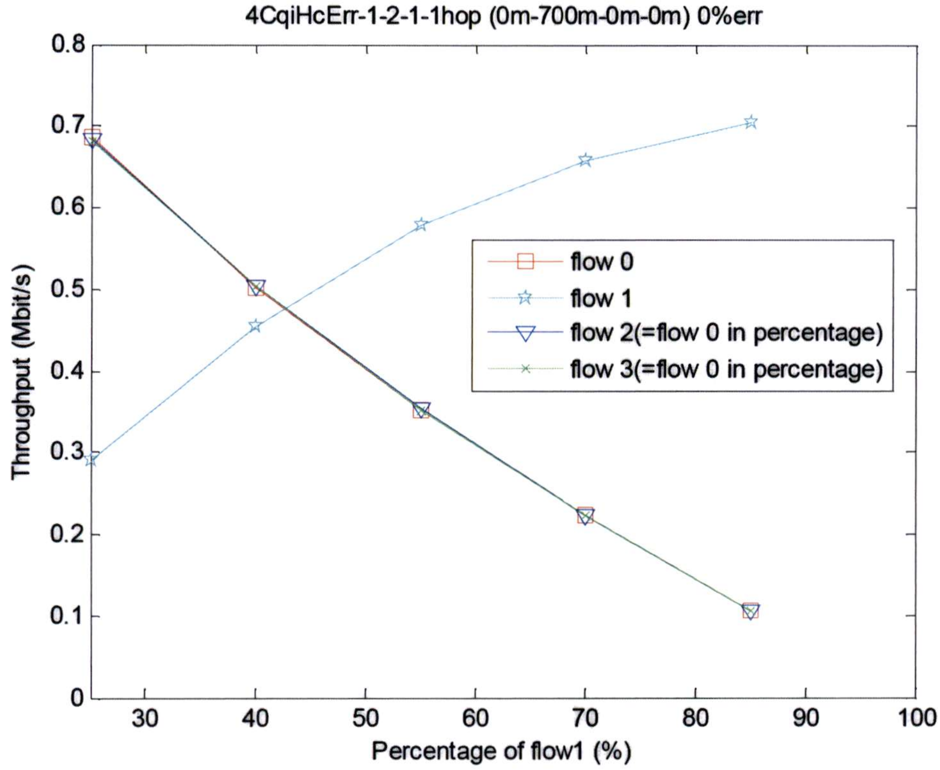

Figure 3-22 TCP throughputs of the integrated networks with four changeable choice percentage flows through four GWs

3.5 New scheduling algorithm design

Based on the work of the first four sections, a completely new scheduling algorithm will be designed in this chapter. Not only will the HSDPA subfield in our special integrated networks be considered, but the wireless ad-hoc networks subfield will also be thought about in this new scheduling mechanism, while all the original scheduling algorithms only consider the HSDPA subfield, seeing in details in the Chapter 2. Although the new scheduling scheme is implemented in the MAC-hs layer of the Node B, the physical layer and the Air Interface (Uu) modeling between the Node B and the hybrid UE (i. e. GW) needs to be modified for enabling the additional information about the number of hop and the error rate of the wireless ad-hoc networks subpart to be feed from the hybrid UE (i. e. GW) back to the Node B. These knowledge is necessary for the Node B to schedule all the GWs, because it is the information that our new scheduling algorithm depends on.

3.5.1 Physical layer modeling modification

The general physical layer model is given in [10]. As can be seen from the Figure 3-23, each 2ms TTI every UE connected the HS-DSCH transports a Channel Quality Indicator (CQI) value back to the Node B. The Node B utilizes these CQI values to decide which UE has the highest priority and Transport Block Size (TBS) of the own of each UE. However, due to two fields existed in our integrated networks, only the CQI information is not enough but additional knowledge on the wireless ad-hoc networks subfield also needs to be told the Node B to schedule the UEs according to all the information indicating the situation of the two subparts. The new physical layer model is shown in the Figure 3-24.

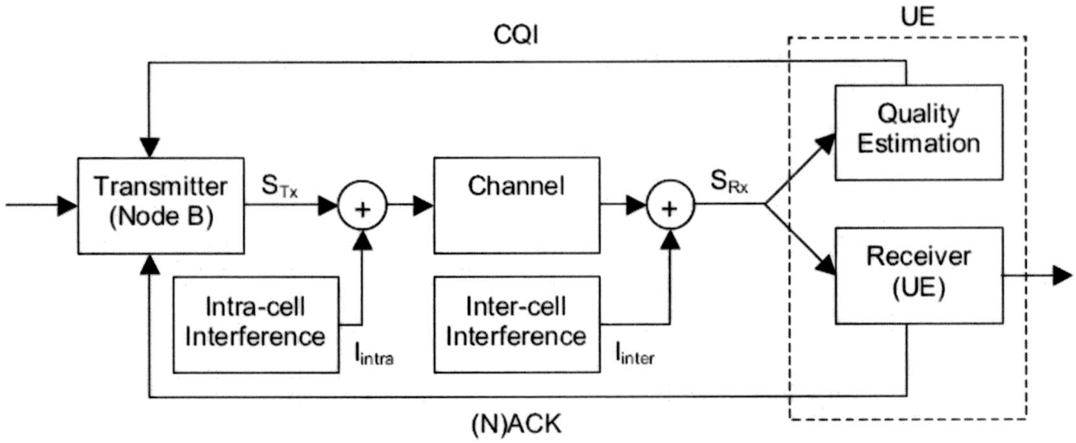

Figure 3-23 Physical layer model [10]

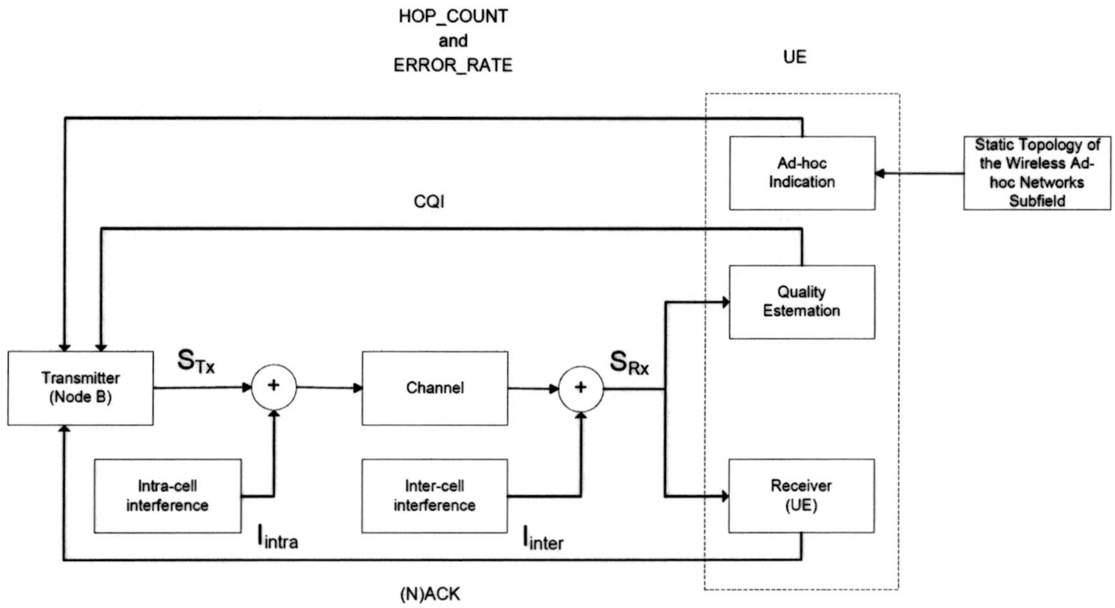

Figure 3-24 New physical layer model

3.5.2 New scheduling algorithm-Fair two-subfields-dependent scheduling

Because our new scheduling algorithm is considering the information of the two subfields (the HSDPA and the ad-hoc) in our integrated networks to reschedule all the hybrid UEs (GWs) so as to attain more fairness. If the designing method of the new scheduling scheme needs think about not only the fairness but also the prority of each GW, we could design a novel scheduling algorithm in our integrated networks which is similar with the WFQ (seeing the Chapter 2) scheduling metric of the router in wired networks. Based on the thought mentioned above, a new variable: a weight of each GW needs to be defined. The definition of the weight of a certain GW i is as follow:

$$W_i = CQI_i^{\alpha} \cdot Hop\_count_i^{\beta} \cdot \left(Err\_rate_i^{\gamma}\right)^{Hop\_count_i},$$

Where α, β and γ are the index of the three parameter CQI, Hop_count and Err_rate, respectively. They can be configured changeable values in terms of different situations. Meanwhile, the scheduling ratio of the GW i is:

Scheduling ratio of a certain GW i

$$= \frac{W_i}{\sum_{i=1}^{N} W_i}$$

Since the new scheduling algorithm has been designed, it is essential that the best index α, β and γ values need to be fixed. However, we need these best index values meet the situations as many as possible. In order to gain the perfect index values, we have considered a great number of simulation scenarios, which is in turn, the detail weight formula is given firstly and then we will explain the derivation process of the weight formula in more details. By the way, the best weight derivation is just based on the work of the previous section 3.4, because we need find out a group index values that can enable the scheduling ratio (calculated through the formula proposed above) to match the real balance ratio better in terms of the situations as many as possible. The real balance ratio can be collected from the previous section 3.4. Of course, although we have tried our best to consider the situations as many as possible, the simulation scenarios that we can carry out is still finite, thus, it is rather possible that the fixed weight formula could not be suitable for some special cases. Based on the consideration, we can adapt the weight formula to meet the special cases better. In other words, if there is a special simulation scenario, a new weight formula would be possible to be needed creating.

If all the GWs has the same CQI values,

Weight of a certain GW i (CQI_i, Hop_count_i, Err_rate_i)

$$= CQI_i \bullet Hop\_count_i^{0.1} \bullet \left(\sqrt[3]{Err\_rate_i}\right)^{Hop\_count_i},$$

else

Weight of a certain GW i (CQI_i, Hop_count_i, Err_rate_i)

$$= CQI_i \bullet Hop\_count_i \bullet \left(\sqrt[3]{Err\_rate_i}\right)^{Hop\_count_i},$$

CQI: 0 ~ 30
Hop_count: 1 ~ 4
Err_rate: 0% ~ 100% (0 ~ 5 ranks: $\sqrt[3]{0}$ to $\sqrt[3]{100}$)

In order to simplify the calculation, we will get the integrity classes and extend all the error rate 100 times. And then the cubic root of them will be gained, so they will become 5 ranks from $\sqrt[3]{0}$ to $\sqrt[3]{100}$.

3.5.3 Derivation of new scheduling algorithm

The new scheduling scheme – Fair two-subfields-dependent scheduling has been proposed in the previous section, however, we do not state how to get it. Here, the progress of deriving the scheduling algorithm will be described in details as follows.

3.5.3.1 CQI and hop count

In this part, we focus on gaining the relation between the weight and CQI and hop count. So the error rates are all set as 0%, namely no packet lost, in all the simulations.

In the first, we still consider some typical simulations, i. e., the integrated networks with 2 gateways. The first GW is set as the distance of 0m between itself and Node B and 1 hop count in its wireless ad-hoc subfield, while the second GW is configured as the distance of 700m and more than 2 hops. But the average values of CQI need to be calculated for getting the average weight.

According to the statement above, we will get the following parameter configuration, seeing the Table 3-12.

Average of CQI	Hop count	Error rate
0 m: 24	1 hop	0%
700 m: 15	More than 2 hop	0%

Table 3-12 Parameter configuration

(1) While making the weight = $CQI_i \bullet Hop\_count_i$, (ignoring the influence of the error rate due to the same error rate)

Based on the work of the previous Chapter 4, the eventual balance ratio can be collected. Meanwhile, in terms of the weight formla above, we can also gain the corresponding scheduling ratio. All the ratio will be shown the following Table 3-13.Compared with the two ratio, we

	Scheduling ratio	Balance ratio
0 m 1 hop 700 m 2 hop	44% 56%	30% 70%
0 m 1 hop 700 m 3 hop	35% 65%	25% 75%
0 m 1 hop 700 m 4 hop	29% 71%	21% 79%

Table 3-13 Scheduling ratio and balance ratio

(2) When enabling the weight = $CQI_i \bullet Hop\_count_i^{1.3}$, we will get the ratios as follows according to the same method.

	Scheduling ratio	Balance ratio
0 m 1 hop 700 m 2 hop	40% 60%	30% 70%
0 m 1 hop 700 m 3 hop	28% 72%	25% 75%
0 m 1 hop 700 m 4 hop	21% 79%	21% 79%

Table 3-14 Scheduling ratio and balance ratio

Compared with the two tables above, it is manifest that when the weight = $CQI_i \bullet Hop\_count_i^{1.3}$, the scheduling ratio can match the balance ratio better. However, here we only consider the distance of 700m. When the other distances are set as CQI parameters, the average values of CQI are definitely larger than that of 700m, namely CQI > 15. As a result, the scheduling ratio of 0m and 1 hop in each simulation will decrease, i. e., 44%, 35% and 29% in Table 3-13 will reduce. So the weight = $CQI_i \bullet Hop\_count_i$ will be selected eventually.

However, when we test the weight formula, there is a problem happened. While the same distance set as CQI parameters, for example, the same distance of 500m is configured, the results are shown in Table 3-15.

Parameter	Throughput
500 m 1 hop 500 m 2 hop	0.611784 0.934479
500 m 1 hop 500 m 3 hop	0.485836 0.698117
500 m 1 hop 500 m 4 hop	0.397386 0.533244

Table 3-15 Throughput of the same distance of 500m

In order to resolve the problem, we need to adopt another weight formula when the same distance is configured as the CQI parameters of the two GWs. According to the same method above deriving the weight formula, some different weight index number will be test respectively such as 0.5 (sqrt), 0.33 (cbrt), 0.2 and 0.1. Eventually the index of weight 0.1 is chosen.

To sum up, while ignoring the impact of the error rate, the weight formula is fixed as follows:

If all the UEs has the same CQI value,

Weight of a certain GW i (CQI_i, Hop_count_i)

$$= CQI_i \bullet Hop\_count_i^{0.1}$$

else

Weight of a certain GW i (CQI_i, Hop_count_i)

$$= CQI_i \bullet Hop\_count_i$$

3.5.3.2 Hop count and error rate

Since the relationship between the weight and the hop count and the error rate will be investigated here, the distances as CQI parameter are the same in all the simulations. The parameter setting is given in Table 3-16.

Average of CQI	Hop count	Error rate
0 m: 24	1 hop	10%
0 m: 24	More than 2 hop	10%

Table 3-16 Parameter configuration

For enabling calculation easier, the error rate will be extended 100 times and then get cubic root value. Eventually, the error rate will be classified as 5 ranks from $\sqrt[3]{0}$ to $\sqrt[3]{100}$.

(1) From the mathematic angle,

If weight = $CQI_i \bullet Hop\_count_i \bullet \left(\sqrt[3]{Err\_rate_i}\right)^x$,

according to our scheduling ratio formula and the parameter table 3-12, we get

$$\text{scheduling ratio} = \frac{24 \bullet 1 \bullet \left(\sqrt[3]{10}\right)^x}{24 \bullet 1 \bullet \left(\sqrt[3]{10}\right)^x + 24 \bullet 2 \bullet \left(\sqrt[3]{10}\right)^x}.$$

At this time, the scheduling ratio has nothing to do with the error rate. However, in this situation it definitely owns some relation with the error rate in terms of the work of the first four sections. So the index x has to have something with the hop count.

(2) From the theory angle,

As each MN is added an error model and the error rate of the one error model is set as 10%, the total error rate is $1-(1-10\%)^{Hop\_count_i}$. In other words, the total error rate owns some relationship with the hop count. So it is a certainty that the weight has something to do with the hop count.

Assuming the weight = $CQI_i \bullet Hop\_count_i \bullet \left(\sqrt[3]{Err\_rate_i}\right)^{Hop\_count_i}$,

the scheduling ratio will be calculated and then put in Table 3-17 as well as the balance ratio in this simulation scenario.

	Scheduling ratio	Balance ratio

0 m 1 hop 10% 0 m 2 hop 10%	19% 81%	5% 95%
0 m 1 hop 10% 0 m 3 hop 10%	7% 93%	< 5% > 95%
0 m 1 hop 10% 0 m 4 hop 10%	3% 97%	< 5% > 95%

Table 3-17 Scheduling ratio and balance ratio

Compared with the scheduling ratio and the balance ratio in Table 3-17, it can be seen that these two series values match well between each other. As a result, the weight = $CQI_i \bullet Hop\_count_i \bullet \left(\sqrt[3]{Err\_rate_i}\right)^{Hop\_count_i}$ will be fixed eventually.

4 Simulation scenarios and results of new scheduling mechanism

In this chapter, since the new scheduling scheme has been proposed in the previous Chapter 3, it is essential to test its performance in the integrated networks. Here, some typical simulation scenarios will be designed to collect the performance improvement information for our integrated networks. Because it is in terms of the work of the Chapter 4 that the new scheduling method is designed, the simulation scenarios in this chapter are similar with those of the previous Chapter 4. Besides, the basic network topology and parameter configuration are also similar with those of the Chapter 4. In the end, it needs remind the readers that the objects compared with the TCP throughput of our new scheduling mechanism is that of the Round Robin scheme. The Round Robin method selects each GW at the equal probability, whereas the new scheduling scheme chooses each GW at different percentage in order to make the TCP throughput difference owing to adding a wireless ad-hoc networks field less.

4.1 Integrated networks with two ad-hoc gateway nodes

In this section, we firstly consider the integrated networks with two ad-hoc gateways. There are three factors impacting on the performance as follows: the CQI value illustrating the link quality between the Node B and GW in the HSDPA subfield, the hop count and the error rate in the wireless ad-hoc networks subfield. According to the similar way as the Chapter 4 to investigate the three factors, two of them need to be fixed to study how the other one influences the performance of the integrated networks.

4.1.1 No error rate in wireless ad-hoc networks subfield – 0% error rate (no packet lost)

To start with, the error rate of wireless ad-hoc subpart in our integrated networks is configured as 0%, namely no packet lost in the wireless ad-hoc subfield. Thus, in this situation it is only two factors: CQI and hop count that impact on the performance of the integrated networks. Afterwards, the following two scenarios are designed to research on these two factors.

Scenario 1 – Same distance between the Node B and 2 GWs in the HSDPA subfield

The networks topology and parameter setting are shown in Figure 4-1.

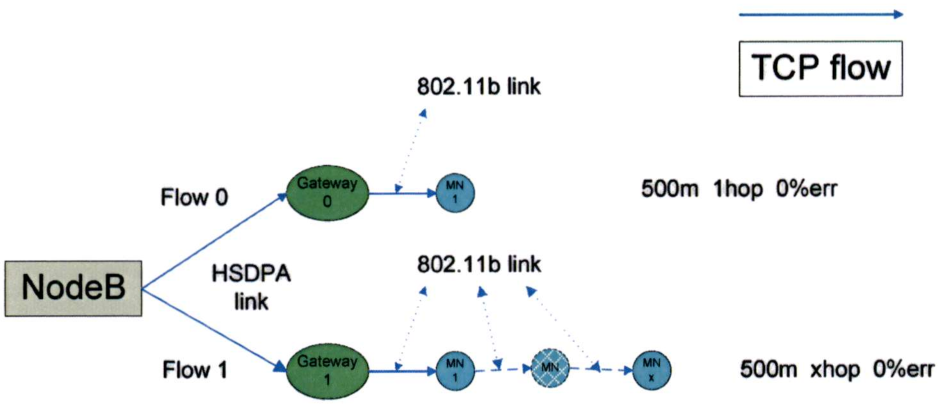

Figure 4-1 Simulation topology

1-2hop		1-3hop		1-4hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
0.961756	0.868588	1.108927	0.872754	1.227658	0.876163
0.854603	0.858381	0.668842	0.676621	0.523483	0.525291
Improved ratio = (0.858381 – 0.854603) / 0.854603 = 0.442%		Improved ratio = (0.676621 – 0.668842) / 0.668842 = 1.163%		Improved ratio = (0.525291 – 0.523483) / 0.523483 = 0.345%	

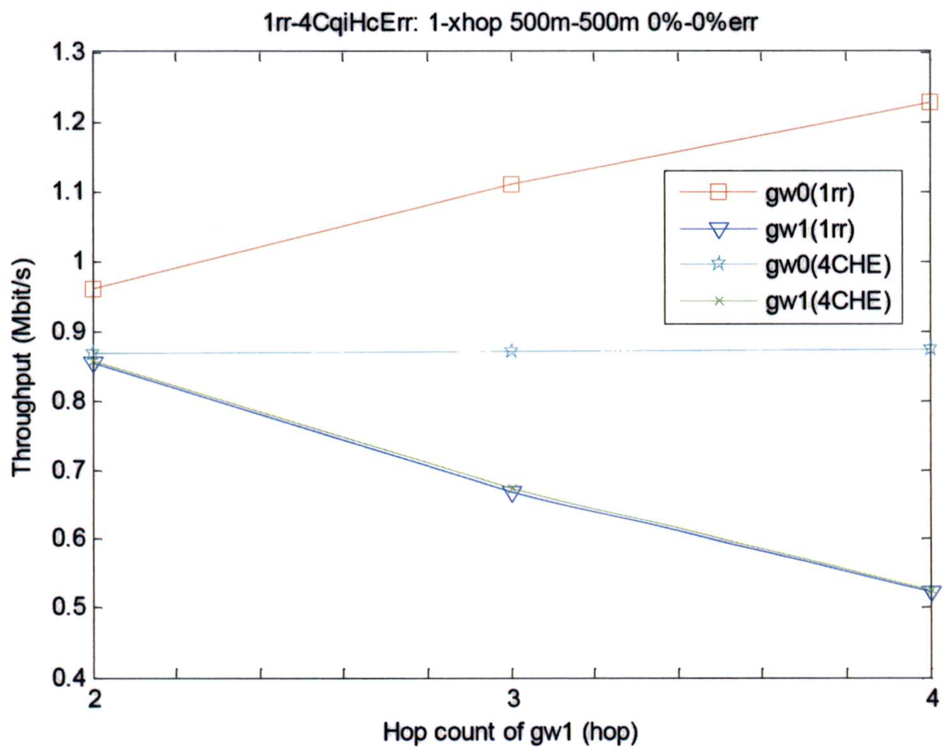

Figure 4-2 Round Robin V.S. FTSDS

Scenario 2 – Different distances between the Node B and GW in the HSDPA subfield

The networks topology and parameter configuration are illustrated in Figure 4-3.

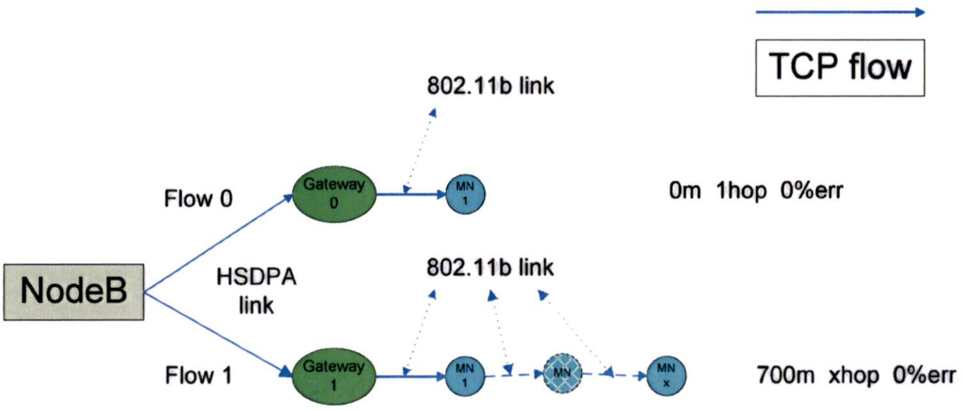

Figure 4-3 Simulation topology

1-2hop		1-3hop		1-4hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
1.343874	1.059538	1.420435	0.840710	1.570316	0.720622
0.541339	0.613044	0.492818	0.549630	0.417590	0.463763
Improved ratio = (0.613044 – 0.541339) / 0.541339 = 13.246%		Improved ratio = (0.549630 – 0.492818) / 0.492818 = 11.528%		Improved ratio = (0.463763 – 0.417590) / 0.417590 = 11.057%	

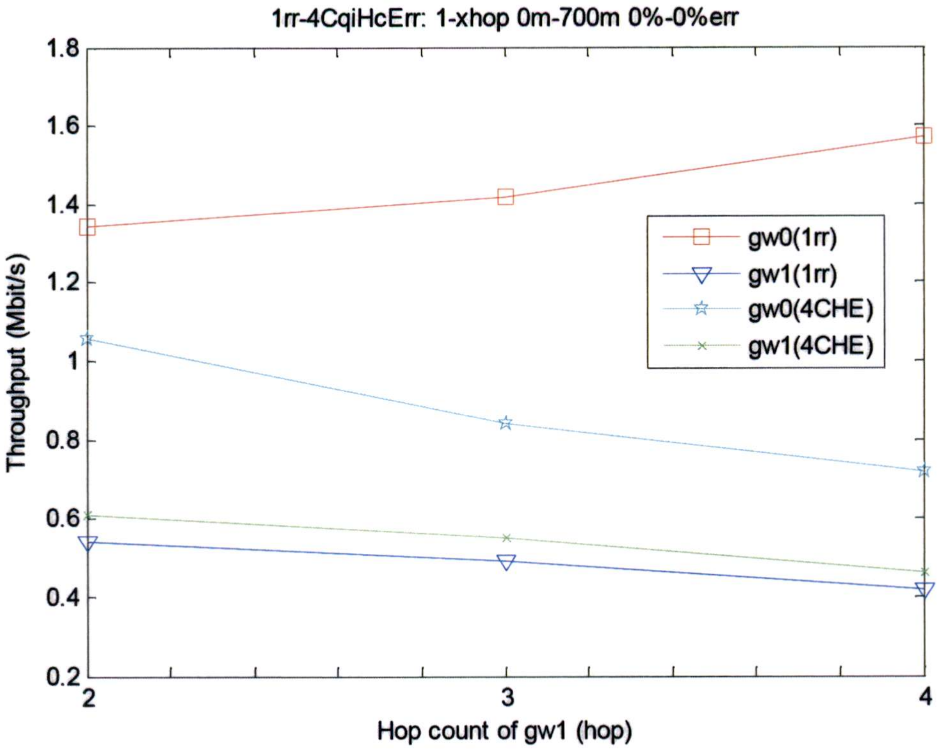

Figure 4-4 Round Robin V.S. FTSDS

4.1.2 Existed error rate in wireless ad-hoc networks subfield

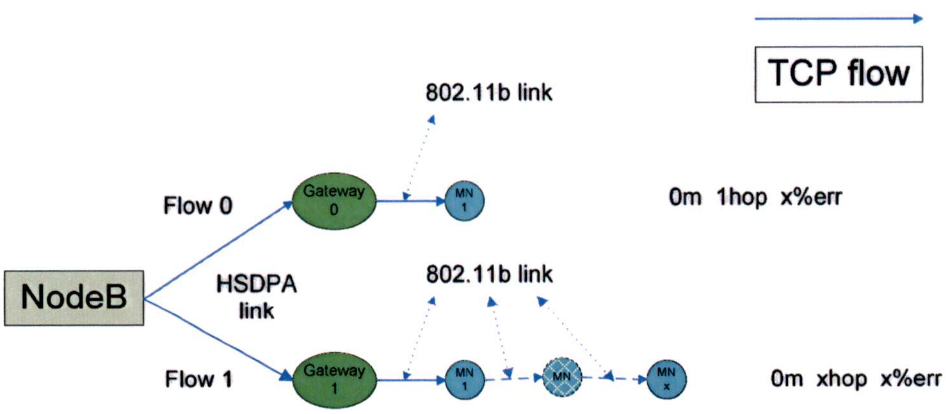

Figure 4-5 Simulation topology

Scenario 1 – 5% error rate in wireless ad-hoc networks subfield

1-2hop		1-3hop		1-4hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
1.794806	1.099659	1.744435	0.718952	1.793604	0.432521
0.763996	0.843672	0.511826	0.567152	0.363162	0.419986
Improved ratio = (0.843672 – 0.763996) / 0.763996 = 10.429%		Improved ratio = (0.567152 – 0.511826) / 0.511826 = 10.890%		Improved ratio = (0.419986 – 0.363162) / 0.363162 = 15.647%	

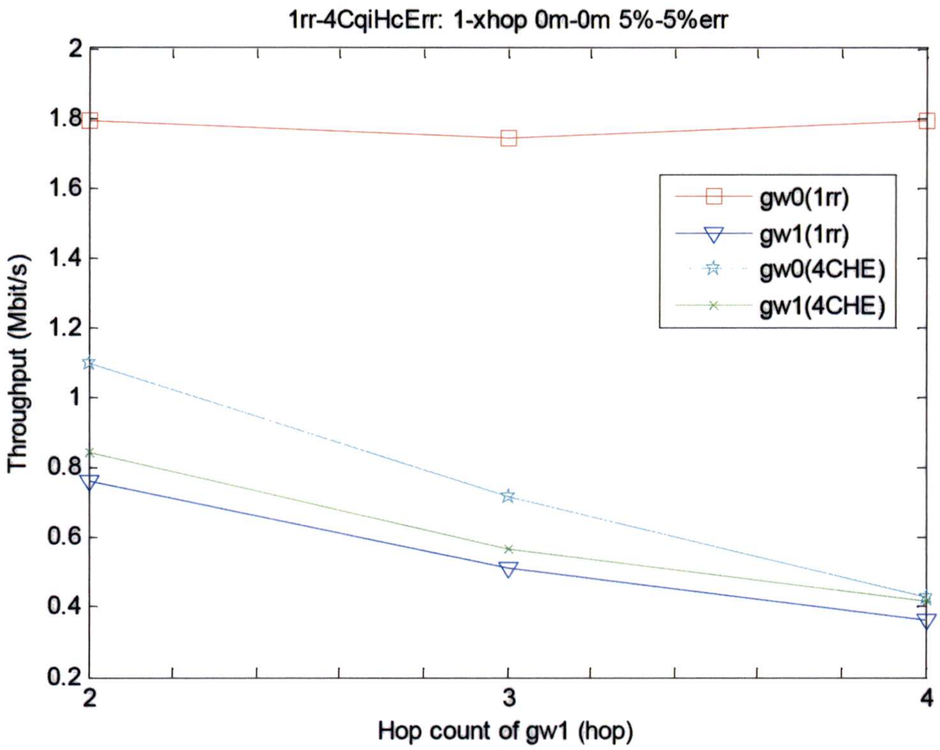

Figure 4-6 Round Robin V.S. FTSDS

Scenario 2 – 7% error rate in wireless ad-hoc networks subfield

1-2hop		1-3hop		1-4hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
1.669727	0.974548	1.602150	0.589986	1.657546	0.309149
0.486017	0.552363	0.290540	0.325515	0.200007	0.263422
Improved ratio = (0.552363 – 0.486017) / 0.486017 = 13.651%		Improved ratio = (0.325515 – 0.290540) / 0.290540 = 12.038%		Improved ratio = (0.263422 – 0.200007) / 0.200007 = 31.706%	

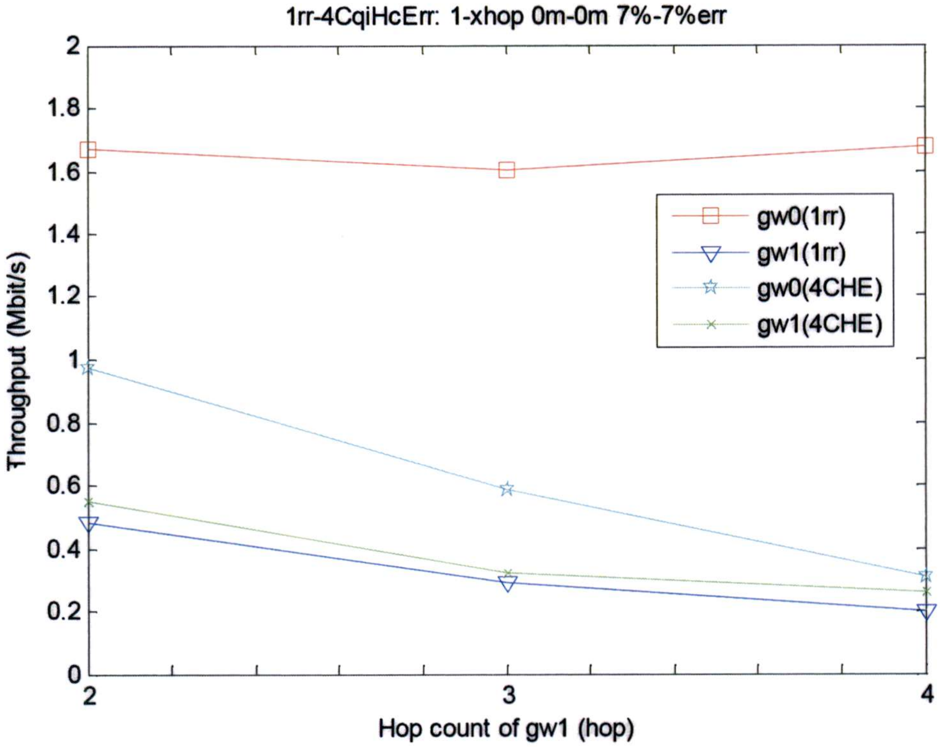

Figure 4-7 Round Robin V.S. FTSDS

Scenario 3 – 10% error rate in wireless ad-hoc networks subfield

1-2hop		1-3hop		1-4hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
1.314974	0.904466	1.262676	0.456089	1.285968	0.213657
0.133570	0.156012	0.068250	0.072597	0.049410	0.057690
Improved ratio = (0.156012 – 0.133570) / 0.133570 = 16.802%		Improved ratio = (0.072597 – 0.068250) / 0.068250 = 6.369%		Improved ratio = (0.057690 – 0.049410) / 0.049410 = 16.758%	

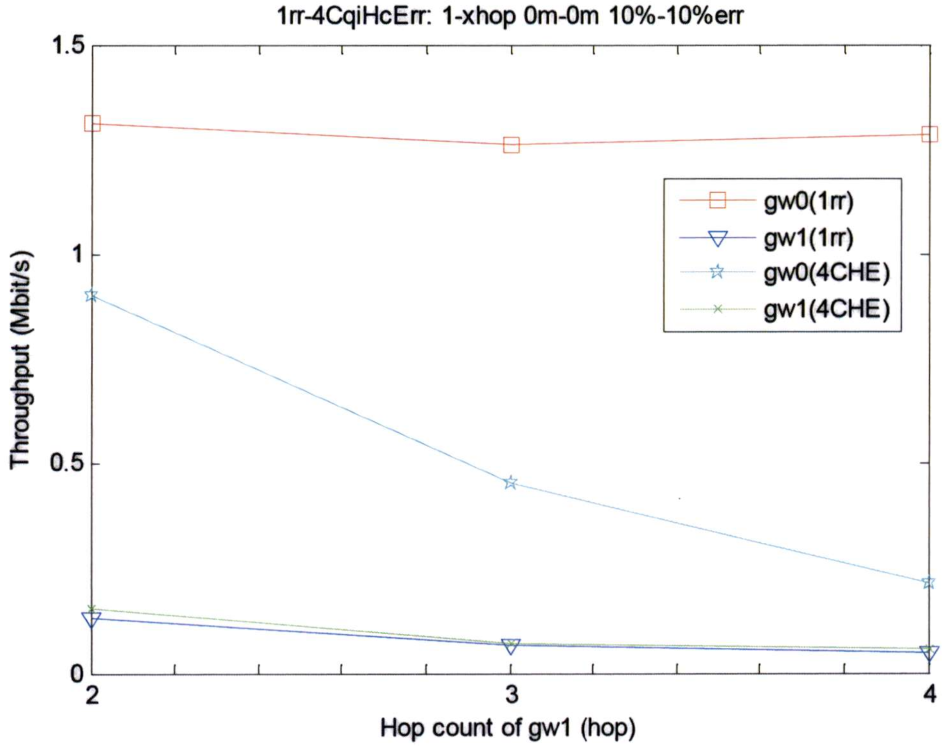

Figure 4-8 Round Robin V.S. FTSDS

4.2 Integrated networks with multiple ad-hoc gateway nodes

4.2.1 Integrated networks with three ad-hoc gateways

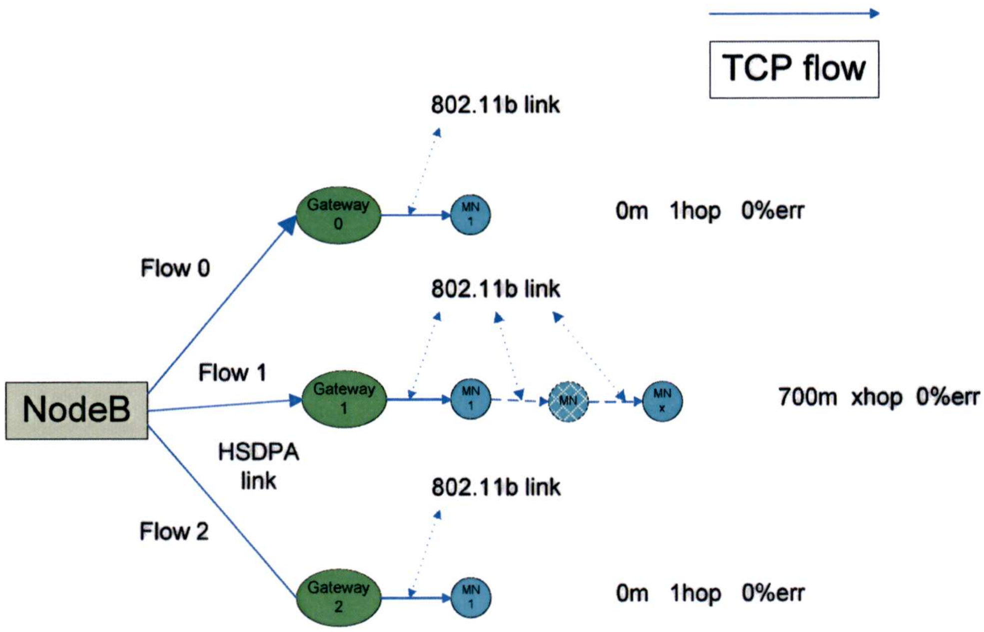

Figure 4-9 Simulation topology

1-2-1hop		1-3-1hop		1-4-1hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
0.900658	0.774778	0.903112	0.633943	0.929416	0.555539
0.391226	0.492281	0.385400	0.495938	0.354285	0.438112
0.896678	0.808191	0.899124	0.672126	0.925216	0.585650
Improved ratio = (0.492281 – 0.391226) / 0.391226 = 25.830%		Improved ratio = (0.495938 – 0.385400) / 0.385400 = 28.681%		Improved ratio = (0.438112 – 0.354285) / 0.354285 = 23.661%	

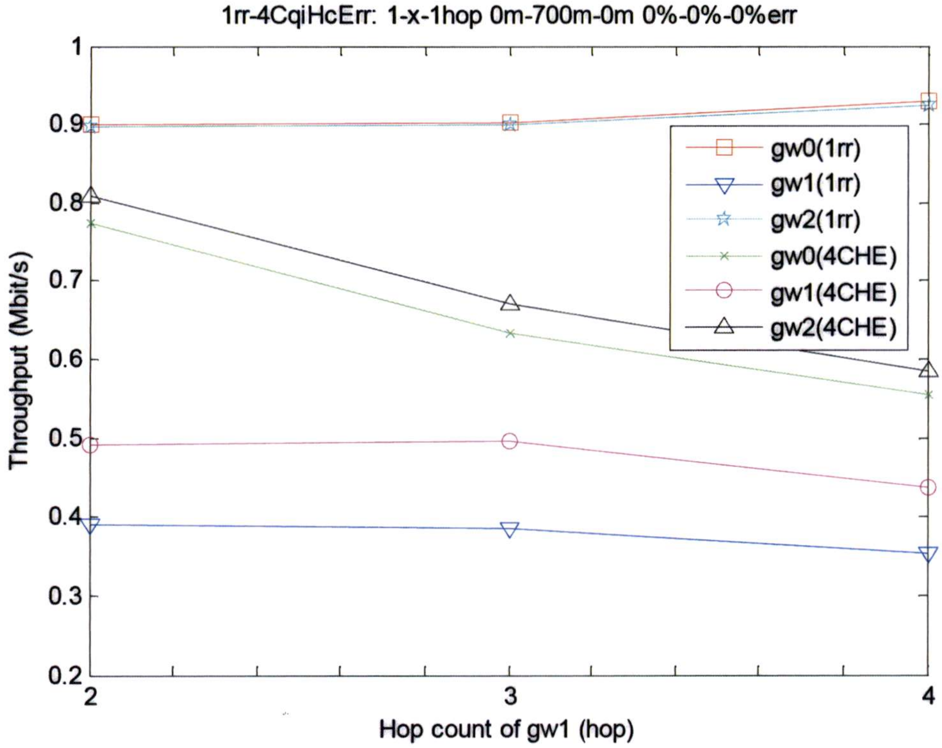

Figure 4-10 Round Robin V.S. FTSDS

4.2.2 Integrated networks with four ad-hoc gateway nodes

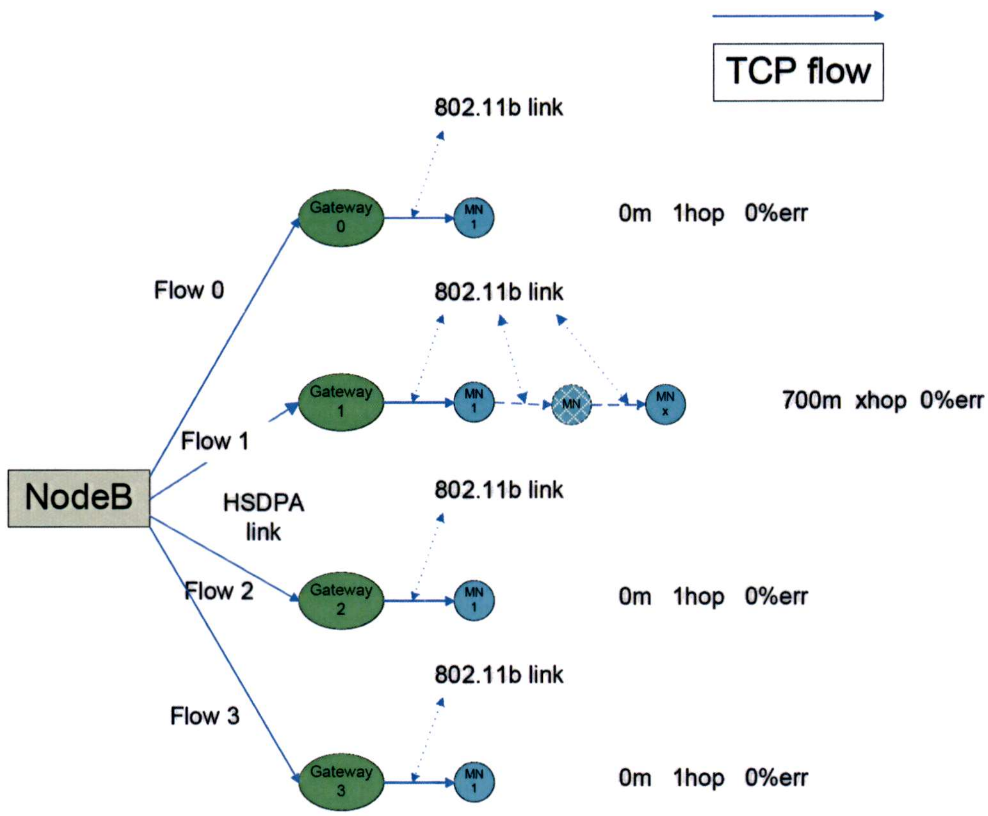

Figure 4-11 Simulation topology

1-2-1-1hop		1-3-1-1hop		1-4-1-1hop	
Round Robin	FTSDS	Round Robin	FTSDS	Round Robin	FTSDS
0.686525	0.613534	0.698442	0.516090	0.700176	0.459057
0.291395	0.393579	0.290646	0.442175	0.285329	0.397472
0.684467	0.615106	0.696318	0.516447	0.698160	0.460009
0.682172	0.658360	0.694442	0.559073	0.696198	0.501659
Improved ratio = (0.393579 – 0.291395) / 0.291395 = 35.067%		Improved ratio = (0.442175 – 0.290646) / 0.290646 = 52.135%		Improved ratio = (0.397472 – 0.285329) / 0.285329 = 39.303%	

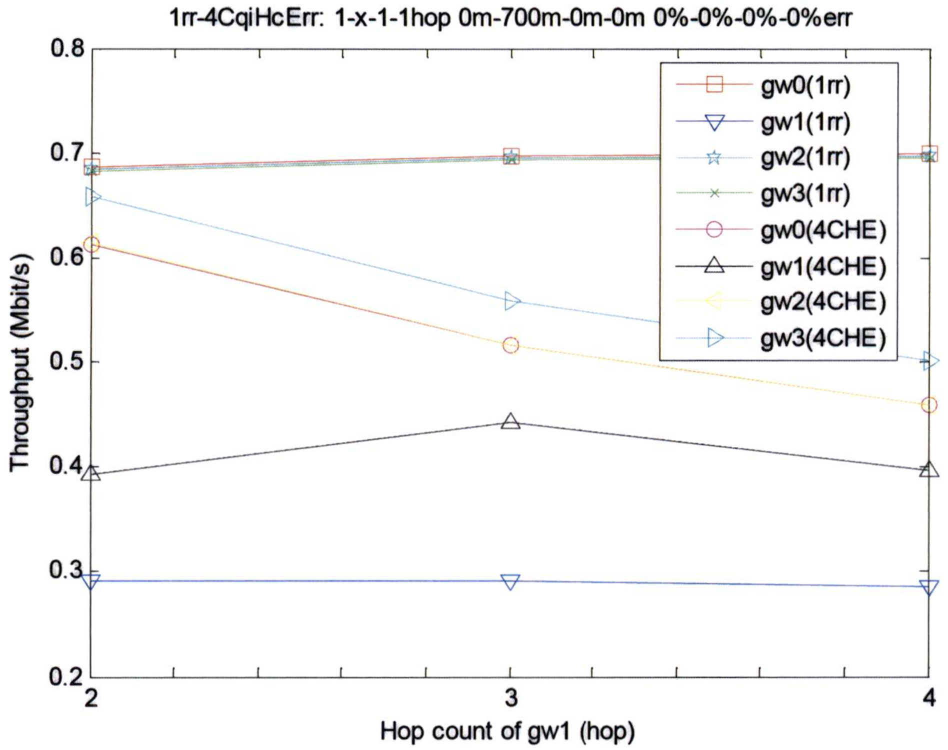

Figure 4-12 Round Robin V.S. FTSDS

5 Conclusions and future work

This chapter will give the summary and future work of this thesis. They are critical for a complete research work.

5.1 Conclusions

The work of this thesis has achieved the integrated networks with multiple gateways and simulated some scenarios for testing the performance of the multiple gateways integrated networks in terms of different scheduling mechanisms of the Node B. Then in order to enable the scheduler of the Node B to schedule the hybrid UEs (i. e. GW) also considering the hop count and the error rate in wireless ad-hoc networks field, we need create a new trace input file in which the power and CQI values are all the same as the old one [6] except for adding two columns indicating the hop count and the error rate in ad-hoc networks field. Moreover, a new scheduling scheme – FTSDS method is proposed to reschedule the GWs to make the TCP throughput of their own coverage terminal nodes more fair. Eventually, we simulate some scenarios to test if it definitely reaches the goal.

Initially, we have implemented the integrated networks with multiple gateway nodes in ns-2. Although there are several configuration modifications in ns-2 codes needed to be guaranteed (the distance between each GW needs ensuring more than 250m), the achievement is significant for our new integrated networks study. Because the thesis [4], [5] and [6] have done a great deal of work on the integrated networks with only one gateway, the integrated networks with multiple gateways become our target in this thesis. A host of its simulations are done to gain the performance knowledge of the integrated networks with multiple gateways. Besides, due to adopted the beyond 3G cellular mobile networks (i. e. HSDPA) technology, the integrated networks with multiple gateways is researched in case of different scheduler type of the Node B.

Next, as the simulations of the multiple gateways integrated networks have been finished above, some interesting results can be got that the TCP throughput of terminal nodes is influenced by two fields. The two subfields: the HSDPA cellular networks subfield and the wireless ad-hoc networks subfield all impact on the performance of the integrated networks, however, the original existed scheduling mechanisms of the Node B schedule only considering the HSDPA subfield but not the ad-hoc subfield at all. Thus, we want to propose a new scheduling scheme that not only be the HSDPA subfield considered, but the ad-hoc subfield is also thought about in scheduling factor selection. As long as the GWs are rescheduled also according to the ad-hoc subfield, the first thing is how to gain the hop count and the error rate in each wireless ad-hoc networks subfield. We modify the physical layer of the GW node so as that it can directly get the ad-hoc subfield information and transmit back to the Node B to reschedule each GW in terms of the two subfields.

Afterwards, since the information about the wireless ad-hoc networks subfield has been collected through the way mentioned above, how to utilize them to reschedule all the GWs in the integrated networks becomes more important. In this thesis, we propose a new scheduling method considering these information on the ad-hoc subfield with original only think about the HSDPA subfield as the referring factor of scheduling all the UEs. This new scheduling mechanism adjusts the selection probability (scheduling ratio) of each GW in terms of the total three information: the channel condition in HSDPA subfield, the hop count and the error rate in ad-hoc subfield to reach the relative balance of the TCP throughput of each terminal node in the coverage range of each GW, namely enabling each GW more fair.

Finally, once the new scheduling method is created, to what extent of improving the performance of the integrated networks with multiple gateways needs to be investigated. Several typical simulation scenarios are designed to check if the new scheduling scheme reaches the design goal to make each GW more fair for the TCP throughput. Through our investigation work, the new scheduling mechanism has reached the eventual design goal.

5.2 Future work

To begin with, furthermore study can be explored on the integrated networks with multiple gateway nodes. Because only one TCP version has been investigated in this thesis, other TCP version and UDP can be studied. In order to make the result more clear, we set the MAC mode of the ad-hoc subfield as CSMA/CA. The RTS/CTS mode can be configured as the MAC of the ad-hoc subfield to research on the integrated networks with multiple gateways. Besides, we only do lots of research on the TCP throughput but not on the Round Trip Time. However, the time performance of a special network is critical, so the Round Trip Time study can be done to gain the further information on the integrated networks with multiple gateways.

Following this, as the simple and static topology of the integrated networks with multiple gateways has been studied in this thesis, more complicated and dynamic topology can be researched. Not only can the hybrid UEs (i. e. GW) can move free, but the other general Mobile Node (MN) can also more free. If the topology is dynamic, a special packet that is produced by the GW would need to be created to collect the instantaneous information on the dynamic topology such as various hop count and the error rate in the wireless ad-hoc networks subfield. The packets would be transmitted from all the UEs to the Node B per TTI (2ms), which in turn, the Node B would reschedule each GW according to the dynamic instantaneous knowledge about the wireless ad-hoc networks subfield. At that time, the dynamic topology will be more close to the real networks scenes.

Abbreviations

ACK	Acknowledge
AM	Acknowledged Mode
AP	Access Point
ARQ	Automatic Repeat Request
AODV	Ad hoc On Demand Vector
BLER	Block Error Rate
BS	Base Station
BSS	Basic Service Set
CN	Core Network
CQI	Channel Quality Indicator
CSMA/CA	Carrier Sensing multiple Access/Collision Avoidance
DCH	Dedicated Channel
DS	Distribution System
ESS	Extended Service Set
EURANE	Enhanced UMTS Radio Access Network
FCDS	Fair Channel-Dependent Scheduling
FTSDS	Fair Two-Subfields-Dependent Scheduling
GW	Gateway
HSDPA	High Speed Data Packet Access
HS-DSCH	High Speed Downlink Shared Channel
IEEE	Institute of Electrical andElectronic Engineers
IP	Internet Protocol
Max C/I	Maximum Carrier to Interference
MAC-hs	Media Access Control – high speed
MN	Mobile Node
NACK	Not ACKnowledge
NIF	Network Interface
NS	Network Simulator
PDCP	Packet Data Convergence Protocol
PDU	Packet Data Protocol
PAN	Personal Area network
PDA	Personal Digital Network
PED	Personal Electronic Devices
PN	Personal Network
QoS	Quality of Service
RLC	Radio link control
RNC	Radio network Controller
RR	Round Robin

RTS/CTS	Request To Send/Clear To Send
RTT	Round Trip Time
SDU	Service Data Protocol
SEACORN	Simulation of Enhanced UMTS access and CORE Networks
SGSN	Serving GPRS Support Node
TB	Transport Block
TBS	Transport Block Size
TCP	Transport Control Protocol
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UTRAN	UMTS Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

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