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A Multi-hop Aware Scheduling Mechanism for HSDPA and IEEE 802.11 Integrated Network

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Acknowledgement

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.

Initially, I would like to thank Jinglong Zhou, MSc for his guidance and encouragement to me during the whole of my Master thesis project. Thanks for his time, patience and sharing of his research methods about science. And I would also like to thank Dr. Anthony Lo as my closer supervisor and lecturer at Delft University of Technology. Moreover, I would like to thank Prof. Ignas Niemegeers for his wonderful supervising and exact attitude on science.

Next, I would like to thank the WMC group of faculty Electric Engineering of the Delft University of Technology for accepting me to work on my interesting thesis project.

Furthermore, I want to thank all my friends such as Xing Zhang, ChenChen Jiang, Jiangjie He, Yuan Ren for your useful advice.

Last but not least, I would like to thank my family whose completely support enables me to concentrate on studying throughout my thesis project. With your love and caring, eventually I finish my master project and get closer to my life goal!

Abstract

Nowadays, there are lots of demands by Internet applications (e.g. IP based multimedia applications). For higher data rate, there exist two technologies: the third generation (3G) cellular mobile networks and the wireless local area networks (WLAN) technology have big distinctions, which can meet different users' demands of accessing the Internet. For the 3G cellular networks technology, one of the standards is the Universal Mobile Telecommunications System (UMTS) and its enhanced version High Speed Downlink Packet Access (HSDPA) which can offer up to 14.4Mbit/s peak data rate. At the same time, the IEEE 802.11 WLAN that is able to use 54Mbit/s data rate for IEEE 802.11g. However, the two communication techniques have their own characteristics. The cellular network can only provide a relative lower data rate while it can support a broad coverage range, whereas the IEEE 802.11 can only support a limited communication distance but can provide a relative higher bit rate. In order to leverage their own advantages of these two networks techniques, the UMTS/HSDPA cellular and the wireless IEEE 802.11 integrated network model was developed in the thesis [4] [5] using the Network Simulator (NS-2).

Through the work of the [4] [5], a new hybrid user equipment (UE) in the UMTS/HSDPA was designed to connect the two networks mentioned above. It is called the hybrid gateway (GW). There are lots of single gateway node simulation results of the existed integrated networks model [4] [5]. In this thesis, the simulation for multiple flows in the integrated networks was executed; and a vast number of scenarios on the integrated networks were simulated. We attain some valuable simulation results. One of which is that there is more obvious unfairness for the end-to-end throughput among different flows due to the two subnetworks used in the integrated network. 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 equal, if in the wireless IEEE 802.11 ad-hoc subnetwork there are different numbers of hops away from terminal Mobile Nodes (MN) in each GW coverage, 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 IEEE 802.11 ad-hoc subnetwork and different ad-hoc setting (e.g. different hop count, etc.), the TCP throughput of each terminal node will be distinguished. But we would like each flow achieve similar TCP throughputs if the channel conditions in the HSDPA subnetwork are the same, because we only want to extend the HSDPA services into the wireless ad-hoc networks field with low cost.

A completely new scheduling algorithm is proposed to resolve the unfairness problem described above. It is named Fair Two-Subnetworks-Dependent Scheduling (FTSDS) that the scheduler in the Node B considers not only the HSDPA information but also the ad-hoc network topology and link quality to reschedule each GW in our integrated networks. Finally, since the novel scheduling algorithm was designed, we test if it can reach our goal, 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.

Table of Contents

1 Introduction

In this chapter, the integrated networks of the HSDPA cellular networks and the IEEE 802.11b ad-hoc networks and its relevant applications will be introduced. The description of the subject of this thesis will be given in Section 1.1. 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.

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, 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 characteristics each other. 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 the 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 enhanced version 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 2Mbit/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.

As the enhancement of the UMTS, the HSDPA [17] achieves the high speed downlink data link, providing up to 14.4Mbit/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 performed by the Node B. For the scheduling mechanism, there are various types in terms of different scheduling methods that can be used in HSDPA such as the Round Robin and the channel quality dependent scheduling, etc.

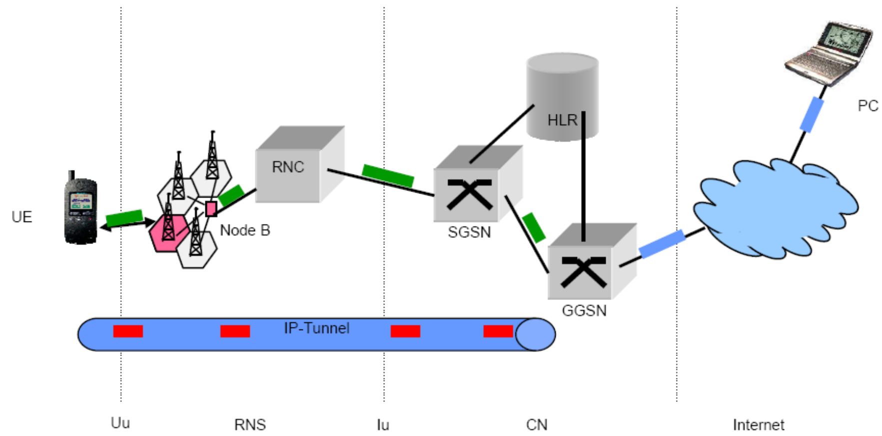

Figure 1-1 UMTS Architecture [2]

As another popular technology for accessing the Internet, the WLAN [37] provides higher data rates but small 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 into two Infrastructure and ad-hoc completely distinguished types.

The former [37] 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].

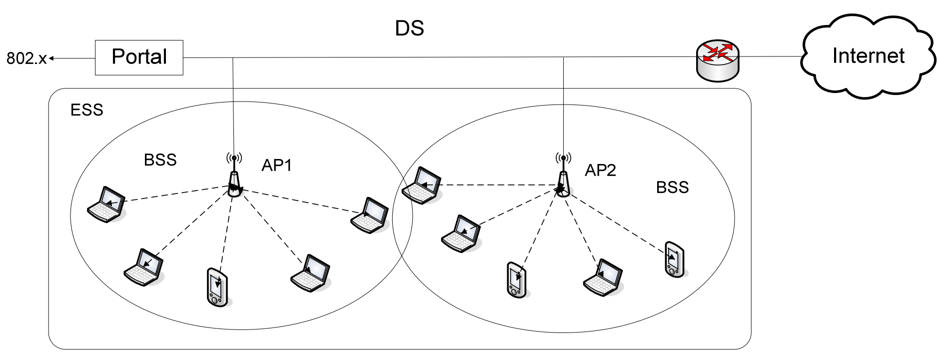

Figure 1-2 Infrastructure WLAN system architecture [37]

The latter is a special WLAN that does not need the fixed AP like the former one, 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. 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.

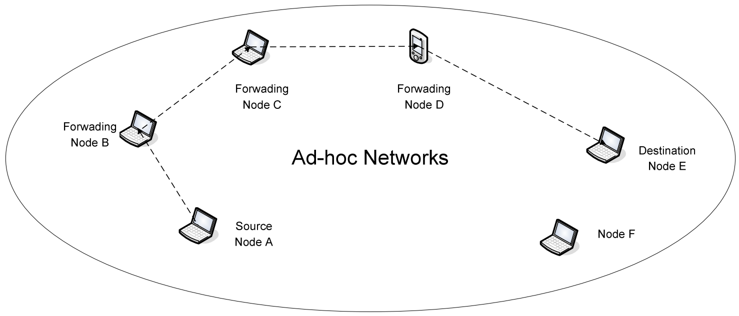

Figure 1-3 Ad-hoc networks [37]

In order to utilize the benefits of all kinds of wireless access the Internet methods completely, a special type of network which is called integrated network was proposed in the theses [4] [5]. A type of special gateway which can integrate the two networks: the cellular networks and the WLAN was also proposed in [4] [5]. The gateway has the two network interfaces that can connect the two different networks: UMTS cellular networks and the wireless ad-hoc networks. The performance of single TCP flow over the integrated network was investigated a lot in [4] and [5]. The integrated networks topology is depicted in Figure 1-4 [5]. The work of the thesis [5] realized the connection of the UMTS and wireless ad-hoc integrated networks in the NS-2 simulator and did lots of simulations to test its performance, and eventually gain a host of very useful results. The thesis [4] implemented the enhanced UMTS (i.e. HSDPA) and wireless ad-hoc integrated networks and also did a lot of simulations in terms of different scheduler type of the BS. However, the two theses above realized and simulated the integrated networks with the only one gateway. We need to simulate more than two gateways integrated networks and get some valuable results.

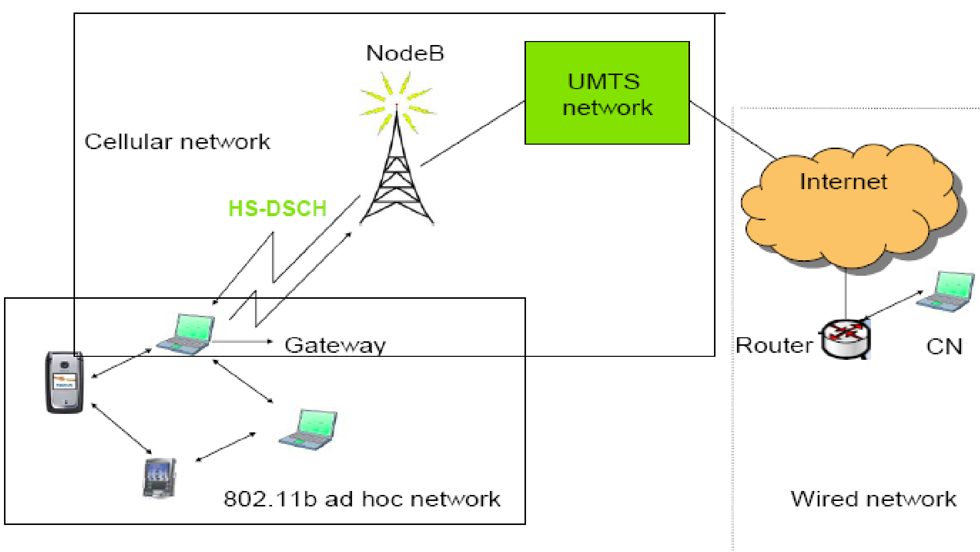

Figure 1-4 Integrated networks topology [5]

1.2 Motivation and goal of thesis

1.2.1 Motivation and benefit

• More realistic

Although there are various advantages in the UMTS/HSDPA cellular and IEEE 802.11 ad-hoc integrated networks, the previous work [4] [5] [6] only investigated the performance of the integrated networks with single gateway. It is not enough to collect all the characteristics about the integrated networks. In order to attain the performance of the integrated networks in the situations closer to the real world, the integrated networks with multiple gateways needs to be investigated. Here, the integrated networks with multiple gateways were simulated so as to make our research on the integrated networks closer to the reality.

• Increased service range

Because there are multiple gateways used in our integrated networks that enable terminal nodes in the wireless ad-hoc subnetwork to utilize the HSDPA services to access the Internet, these gateway nodes can definitely extend the HSDPA service range further than the integrated networks with single gateway.

• Solve the unfairness and improve the end-to-end throughput

Since in our integrated networks the multiple gateway nodes are used to connect the HSDPA cellular subnetwork with the wireless ad-hoc subnetwork, it is rather likely that there is unfairness occurring among these gateways in our integrated networks. The novel scheduling mechanism will be able to combine the information about the two subnetworks in our integrated networks to reschedule each gateway so as to gain more fairness. Meanwhile, it is due to improve the unfairness among all the gateway nodes that the new scheduling algorithm can increase the end-to-end throughput of certain terminal nodes in the courage of some gateways though it is possible to degrade the performance of the whole system to some extent.

1.2.2 Thesis goal

The purpose of this thesis is to simulate 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 simulations need to be designed to validate the performance of the new scheduling mechanism in the integrated networks.

All work mentioned above will be finished through utilizing the Network Simulator 2 (NS-2) [7] [8]. The NS-2 is a widely applicable, open source and universal network simulator. It is mainly used in the IP-based networks environment. The NS-2 implements all kinds of simulations of TCP and UDP etc. network protocols and provides various data source generators (e.g. FTP and

CBR, etc.). It can also simulate queuing management of routers and all sorts of routing and multicast protocols in the wired and wireless networks. The NS-2 model of the UMTS/HSDPA and wireless ad-hoc integrated networks has been developed in the thesis [4] [5] and a host of scenarios of the integrated networks with single gateway has also been simulated in [4] [5], however, the performance of the integrated networks with multiple gateways is unknown, so we need to investigate it firstly. But it could be predicted that as the multiple gateways share the channel in the HSDPA cellular subnetwork and the different situations of each gateway in the wireless ad-hoc subnetwork, there is certainly the unfairness occurring among all the gateways. My task is to design a novel scheduling algorithm of the Node B to reschedule each gateway to gain more fairness.

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 original integrated networks with single one gateway, its network simulator (NS-2) [7] model [4] [5] [6] and existed scheduling metrics in wired and HSDPA networks are given in Chapter 2. Chapter 3 simulates the integrated networks with multiple gateways 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 gateways in terms of not only the HSDPA subnetwork but also the wireless ad-hoc subnetwork. 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

Our work is about the fairness in the integrated networks with multiple gateways and multiple flows, designing a new scheduler type in terms of two subnetworks in our integrated networks, so we present some related work about the HSDPA and ad-hoc integrated networks firstly. Then we will discuss existed scheduling schemes in wired networks and HSDPA cellular networks, respectively.

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

In this section, the architecture and protocol stack of our integrated networks with one gateway will be described simply again.

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 simulated to gain a host of useful results on the integrated networks. The integrated networks system architecture is depicted 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 Figure 2-1 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 nodes in the wireless ad-hoc networks.

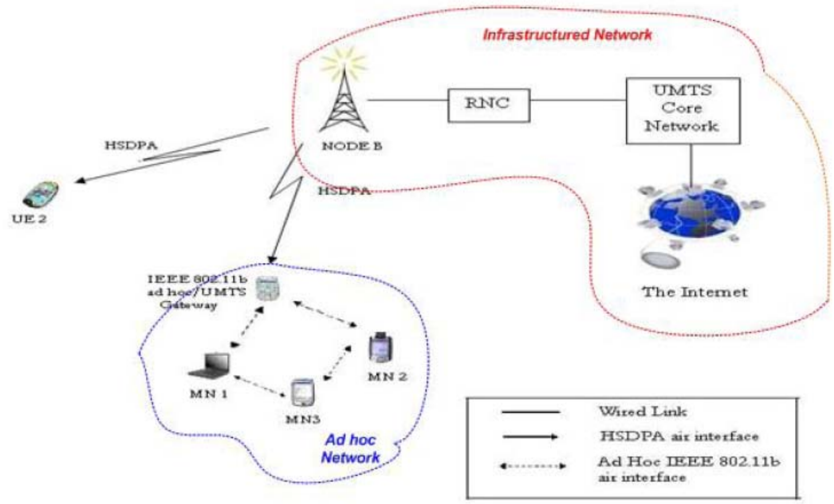

Figure 2-1 System architecture of integrated networks with one gateway [4]

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 Figure 2-2, 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.

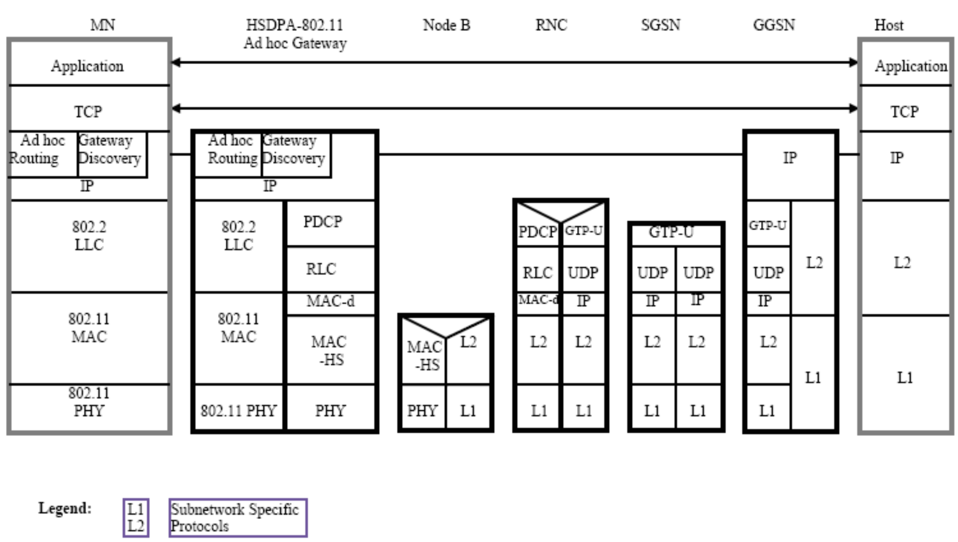

Figure 2-2 Integrated HSDPA and IEEE 802.11 ad-hoc network protocol architecture [6]

According to the protocol stack of the GW shown in Figure 2-2 above, the integrated network is implemented in the Network Simulator NS-2, the NS-2 model of the GW is designed as the following Figure 2-3. From Figure 2-3, 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.

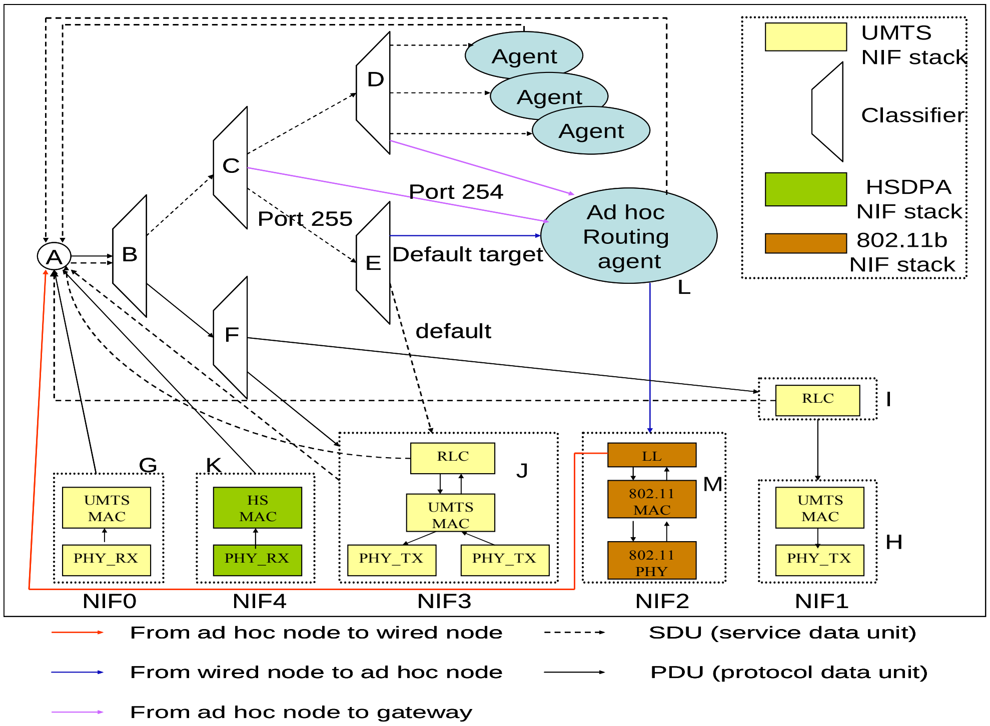

Figure 2-3 Hybrid UE (Gateway) implementation [5]

2.2 Scheduling mechanism

Although there are some difference 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 and play similar role in this two types of network. In the Internet this functionality is carried out by routers, while the Node Bs have 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 schemes as follows.

2.2.1.1 First In First Out (FIFO)

In fact, the FIFO [32] [37] is not a real scheduling method because it does not do anything in the packets queuing. No matter which packet will be served firstly as long as it arrives at the router earlier. 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 method would make the small packets after the large packets wait for a long time to be served.

2.2.1.2 Fair Queuing (FQ)

Based on the FIFO, we add the priority dependence into the queuing, 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.

In spite of the benefit of the priority dependent queuing, 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, thus, here the Fair Queuing [33] [37] scheduling is proposed to resolve this problem.

The FQ generates a queue for each data flow and get each queue send a packet every 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 overcome the disadvantage that the FQ cannot distinguish the packet priority, the weight concept has to be added into each queue to schedule in terms of the different weight of each queue, which is named Weighted Fair Queuing (WFQ) [35] [37].

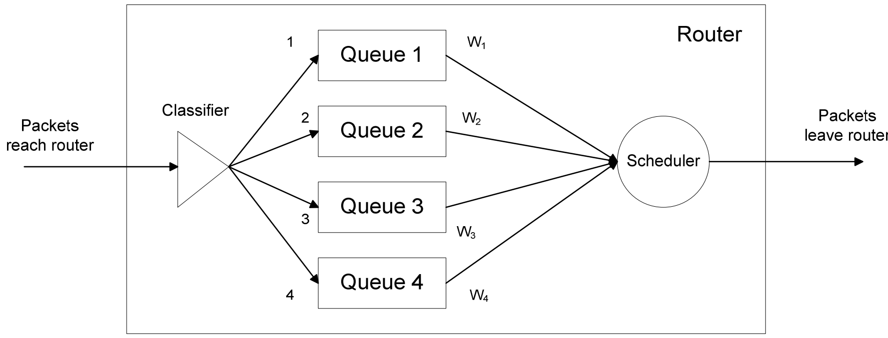

Figure 2-4 WFQ operational principle [37]

As can be seen from Figure 2-4 [37], 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 in front 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 its 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 priority and the fairness becomes critical. It is well-known that this functionality is performed 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] [38] [39] 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 advancements 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 makes 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] [38] 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 further 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.

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 fairer than the second one and more efficient power use than the first one.

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.

The Figure 2-5 [38] shows the difference between the Round Robin, MAX C/I and FCDS scheduling methods.

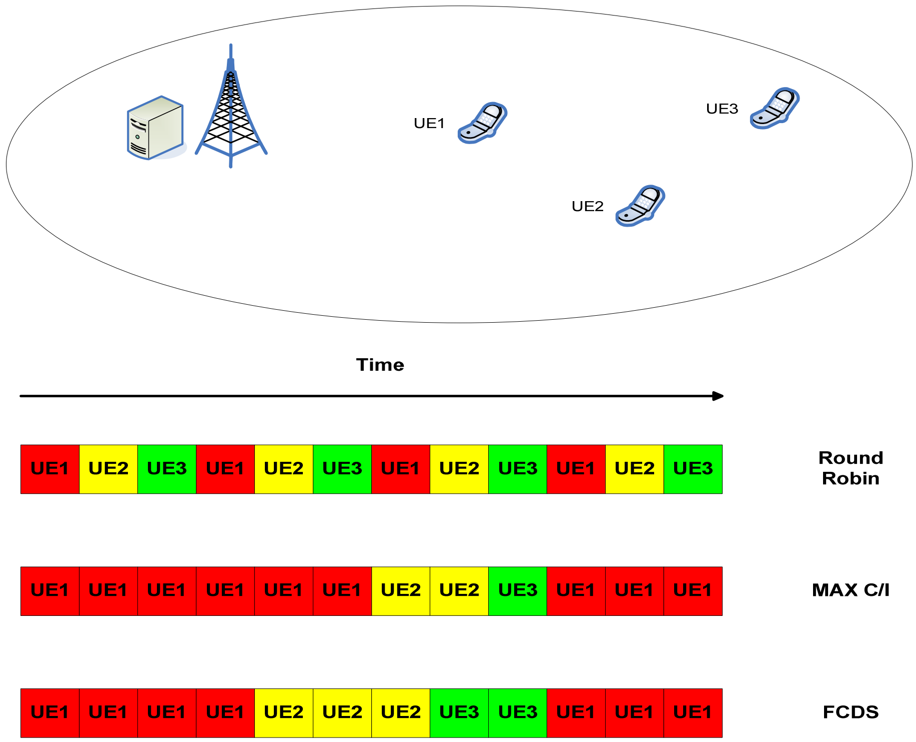

Figure 2-5 Round Robin, MAX C/I and FCDS [38]

3 Integrated networks with multiple flows and new scheduling mechanism

In this chapter, simulations of the integrated networks with multiple ad-hoc gateways between the HSDPA cellular subnetwork and the ad-hoc subnetwork are performed. How to improve the performance of the special integrated networks with the multiple gateways will be focused on. We specially focus the fairness sharing resources as our target. Based on the simulation results, we found that there is indeed unfairness for different flows sharing the resources and none of previous HSDPA scheduling mechanism can solve the problem. N. B., here each flow travels through different gateways and one flow travels over only one gateway.

As the radio and bandwidth resources are limited, the usage of more traffic flows will definitely lead to decrease the available resources per flow, which will eventually cause the performance degradation of terminal nodes in corresponding ad-hoc subnetwork. 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 suffers bad condition for the same gateway. This is the critical reason why we should not only consider the HSDPA channel quality, but also to consider the ad-hoc networks field for 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. These performance simulation and analysis have been done in [5] in details. Here the performance is only considered from the TCP throughput. 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.

We list our simulation parameters in the following Table 3-1.

HSDPA subnetwork	
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 subnetwork	
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
Simulator Configuration	
Simulation Time (s)	200

Table 3-1 Simulation Parameters

In the simulation, we use maximum four different gateways and four flows, however, only one Node B is used. The gateway may have the same or different quality of HSDPA channel.

3.1 Measurement with single gateway node

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

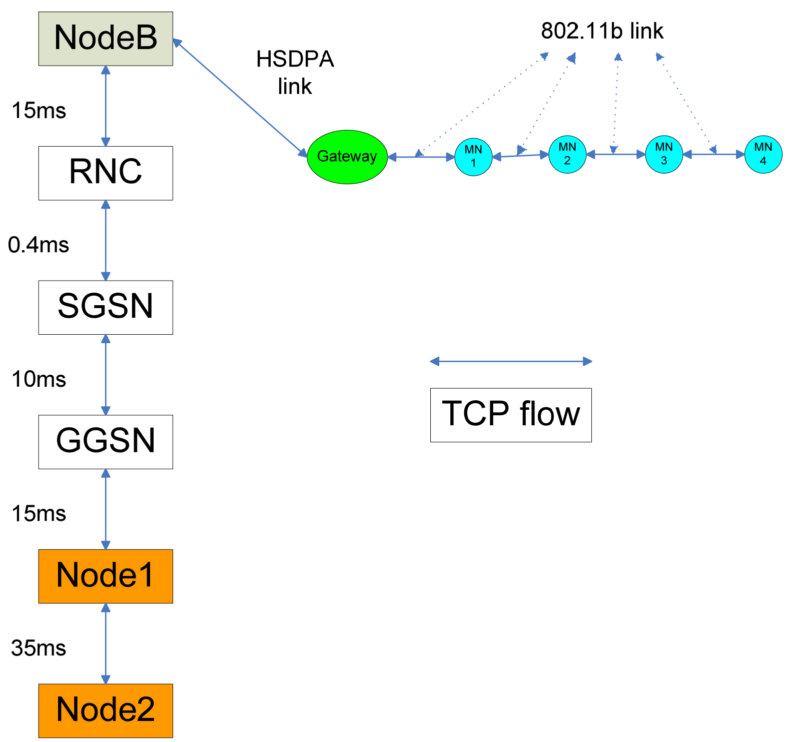

Figure 3-1 Simulation topology

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 2-2. The setting of each link can also be seen in Figure 3-1 (e.g. the delay of 0.4ms between SGSN and RNC, etc.). Furthermore, the IEEE 802.11 ad-hoc subnetwork needs to be specialized. The ad-hoc subnetwork 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.

The purpose of this part is to see 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 theory, the first TCP throughput limits the second one.

According to the thesis [5], the end-to-end TCP throughput of the integrated networks is related to 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 have a fair comparison of different traffic flows, TCP throughput needs to be maximum in one flow first. 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 to be considered. Based on our simulation results, 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.

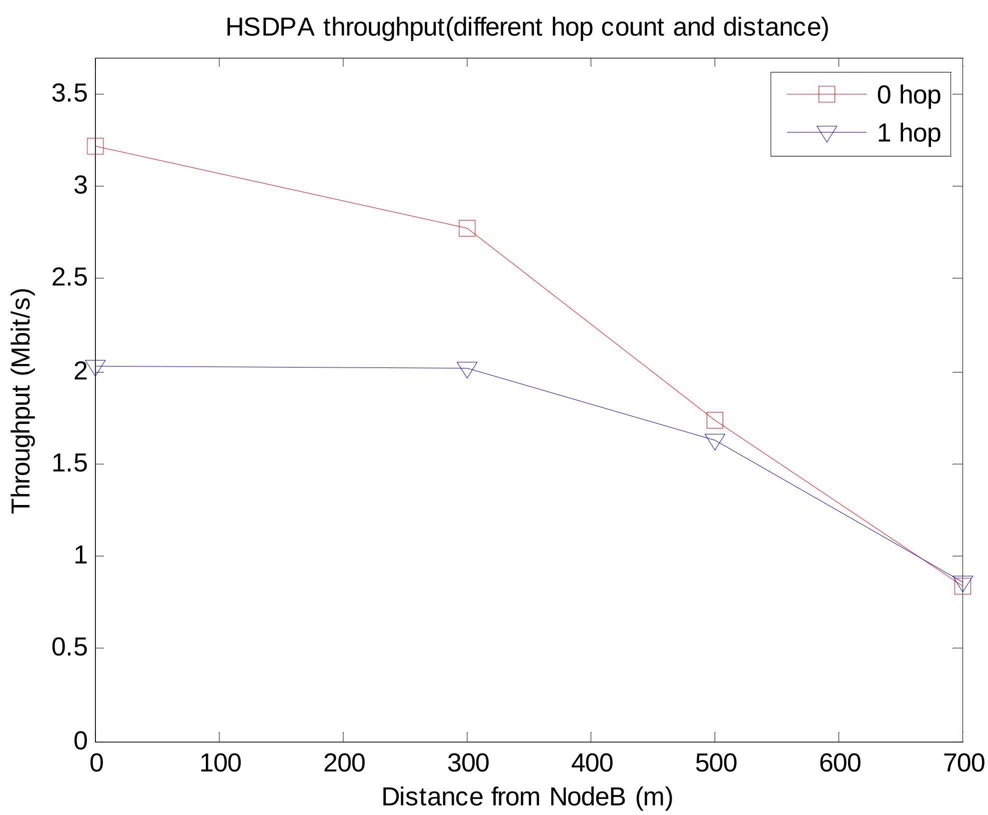

Figure 3-2 HSDPA throughput (CSMA/CA)

From 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 Measurement with two gateway nodes

In this section, the topology of our new simulation of the integrated networks with two ad-hoc gateway nodes can be seen in 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 (I), the Channel Quality Indicator (CQI) value which is fed back by the gateway nodes to the I and the Hop Count of the ad-hoc subnetwork, 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.

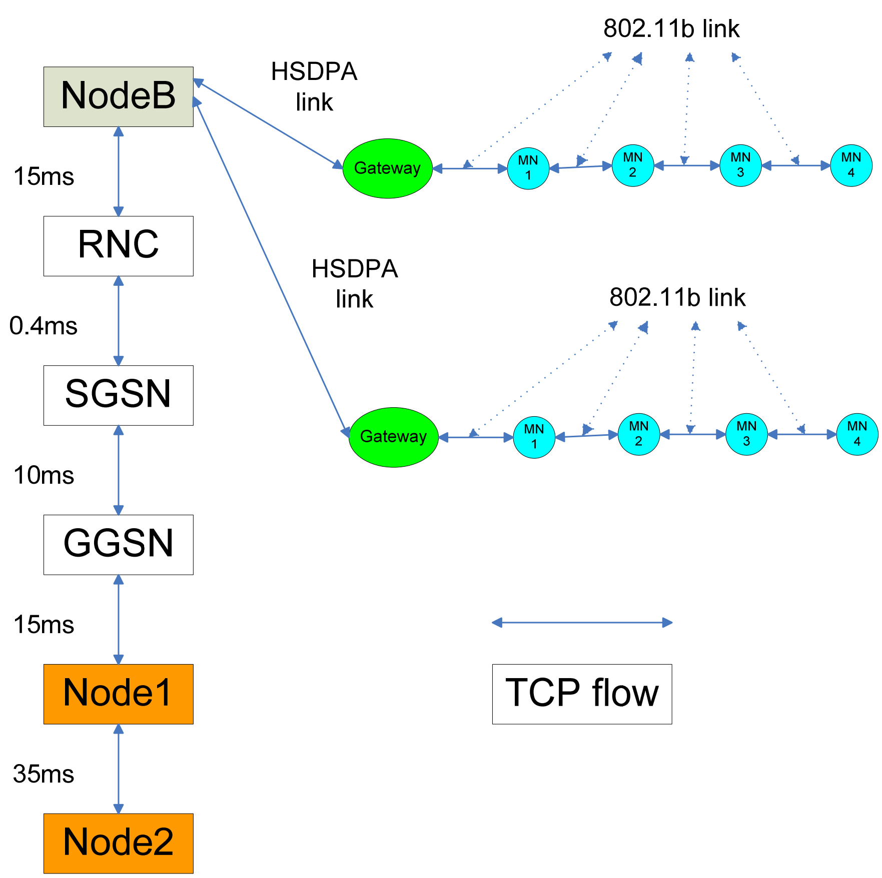

Figure 3-3 Simulation topology

3.2.1 Measurement with round robin scheduling scheme for different configurations.

In this section, we would like 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 subnetwork and hop count in the IEEE 802.11 ad-hoc subnetwork. 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 Two gateways have the same HSDPA channel

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, which means, in the high speed downlink shared channel (hs-dsch) two hybrid UEs (ad-hoc gateway) use the same packet error trace, i.e. these two gateways have the same link conditions. Here the packet error traces of a value of 100m are chosen. To overcome the random property of HSDPA channel, there are ten packet error traces produced for the simulation. In order to gain more exact simulation results, we run every packet error traces, i.e. ten times of simulation and present the average throughput as our result.

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

In this part, the first ad-hoc gateway node is always 1-hop mobile node, while the second gateway node can be 1-, 2-, 3- and 4-hop mobile nodes in each simulation of the integrated networks, respectively, seeing Figure 3-4. According to their TCP throughput, the Figure 3-5 presents the result:

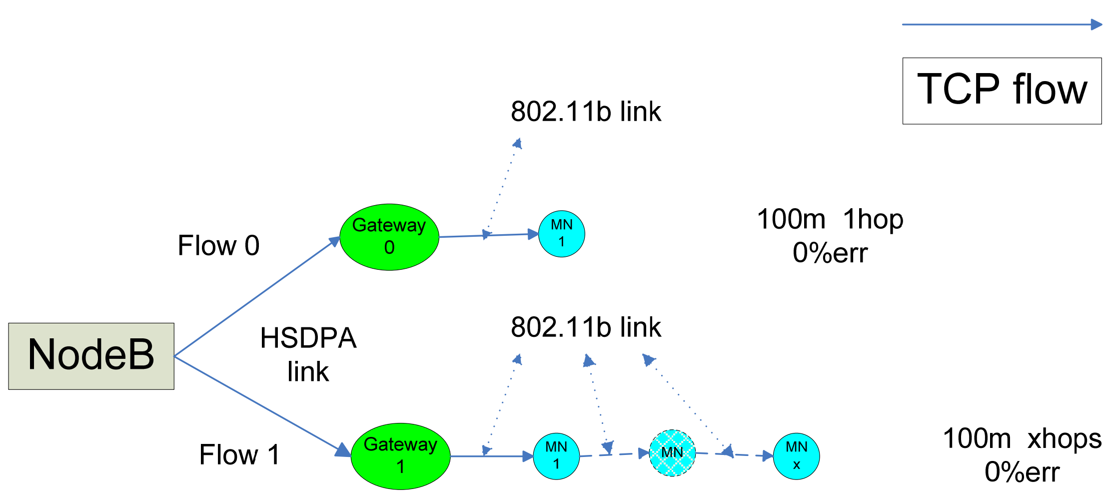

Figure 3-4 Simulation topology

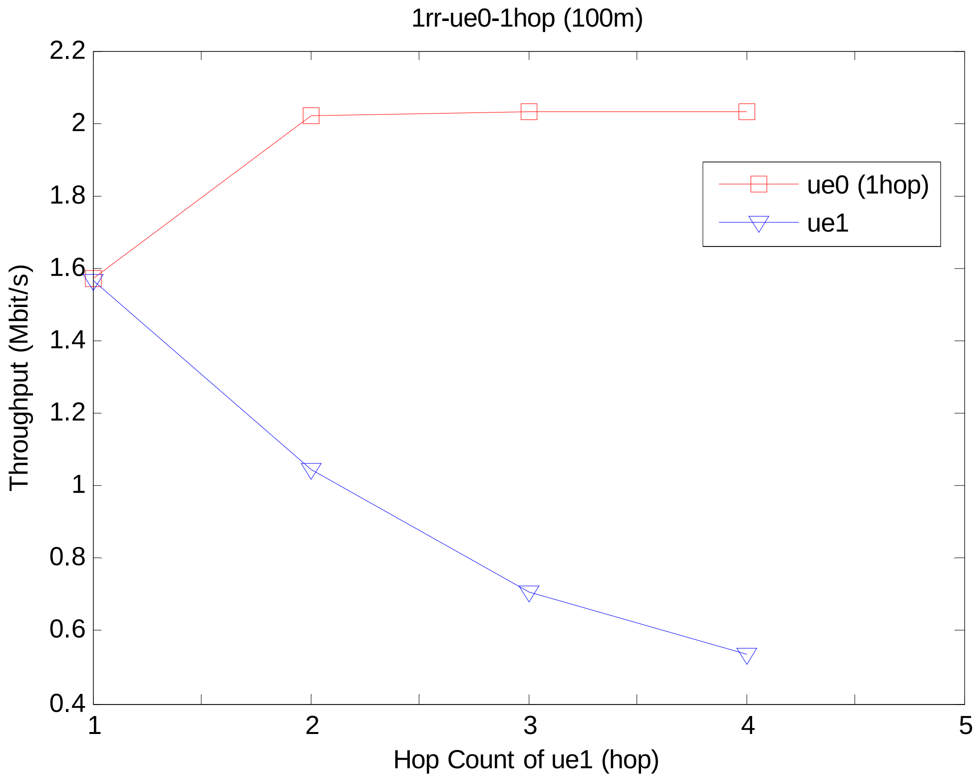

Figure 3-5 TCP throughput of First gateway: 1hop; Second gateway: 1, 2, 3, 4hops

Because here in our integrated networks the Round Robin is adopted as the scheduler type of the Node B in the HSDPA cellular subnetwork and the channel quality of the HSDPA subnetwork is set the same, the end-to-end TCP throughput should be equal between two flows over the two different gateways (one flow travels through one gateway) when in the wireless ad-hoc subnetwork there are the same hop counts. As can be seen from Figure 3-5, it is manifest that when the hop counts of the two flows are the same 1 hop, the throughputs of the two flows are almost equal value of 1.6Mbit/s. Moreover, we can see that there is the unfairness happening in the integrated networks obviously. The larger the differences in the hop count between the two flows are, the clearer the unfairness is, i.e., the larger the difference in the throughput between the two flows is. For example, when there is 1 hop of the flow 0 but the hop of the flow 1 is 2 hops, the throughput of the flow 0 increases but the one of the flow 1 decreases, because the total throughput that the whole system can provide is fixed. The total throughput is a constant quantity. However, from the Figure 3-5, we can see that there seems to be some problems about the integrated network. For the 1 hop of the flow 0 and the 3 or 4 hops of the flow1 scenarios, when throughput of the flow 1 decreases, the throughput of the other flow 0 should have increased, but it does not rise to keep stable at about 2Mbit/s of the throughput. The reason of the throughput of the flow 0 remaining unchanged is that the throughput of 2Mbit/s is the limited value when 100m of the HSDPA channel quality and 1 hop of the ad-hoc subnetwork are configured in the integrated network, which is proved by the Figure 4-20 in the thesis [5].

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

The scenario 2 is similar to the scenario 1. The difference is that the first gateway node has 2-hop mobile nodes in the ad-hoc subnetwork, whereas the other one has 2-, 3- and 4-hop mobile nodes, seeing Figure 3-6. The Figure 3-7 shows the simulation result:

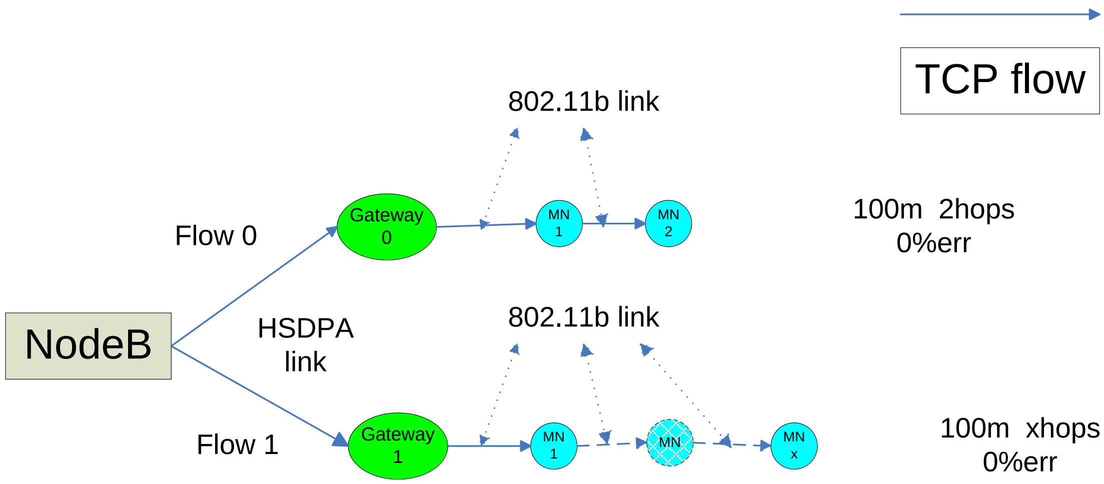

Figure 3-6 Simulation topology

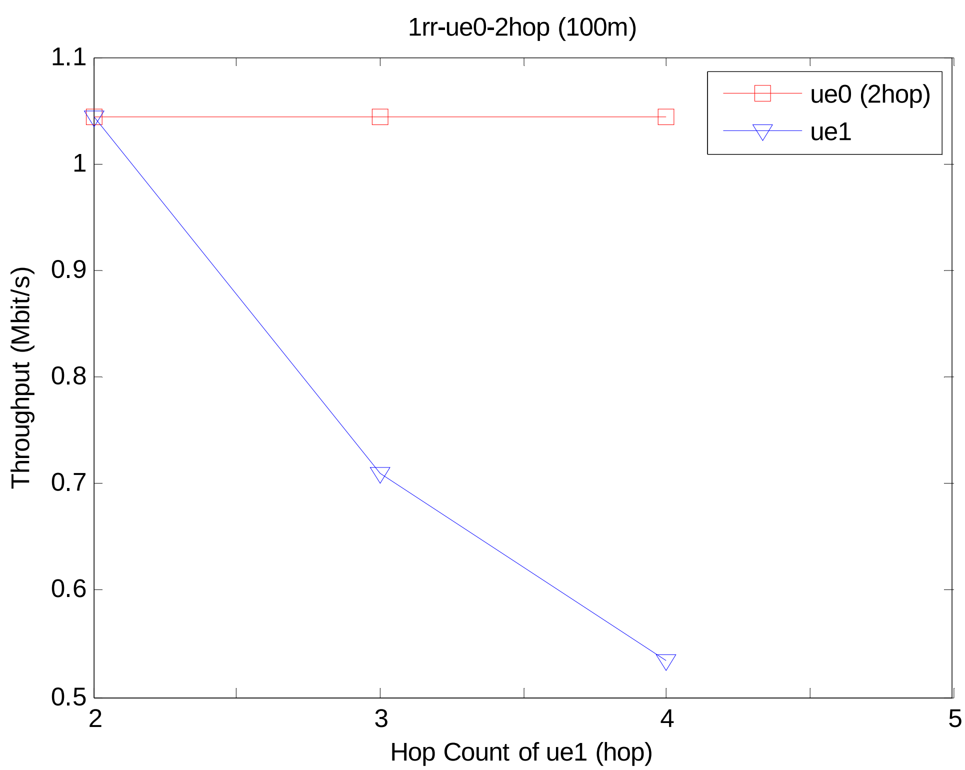

Figure 3-7 TCP throughput of First gateway: 2hops; Second gateway: 2, 3, 4hops

We can see that there are the similar regulations between the scenario 2 and the scenario 1. When the hop counts of the two flows are the equal 2 hop, the TCP throughput of each flow is almost the same value of 1.04Mbit/s. Once there are the differences between the hop counts in each flow, the unfairness will occur. However, when hop count of the flow 1 increases and the throughputs of the flow 1 decrease, the throughputs of the other flow 0 should have increased but keep stable at about 1.04Mbit/s. There is the same reason that the throughput of 1.04Mbit/s is the maximum value when 100m of the HSDPA channel quality and 2 hops of the ad-hoc subnetwork are configured in the integrated network, which is also proved by the Figure 4-20 in the thesis [5].

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

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 subnetwork, seeing Figure 3-8. The result is shown in figure 3-9.

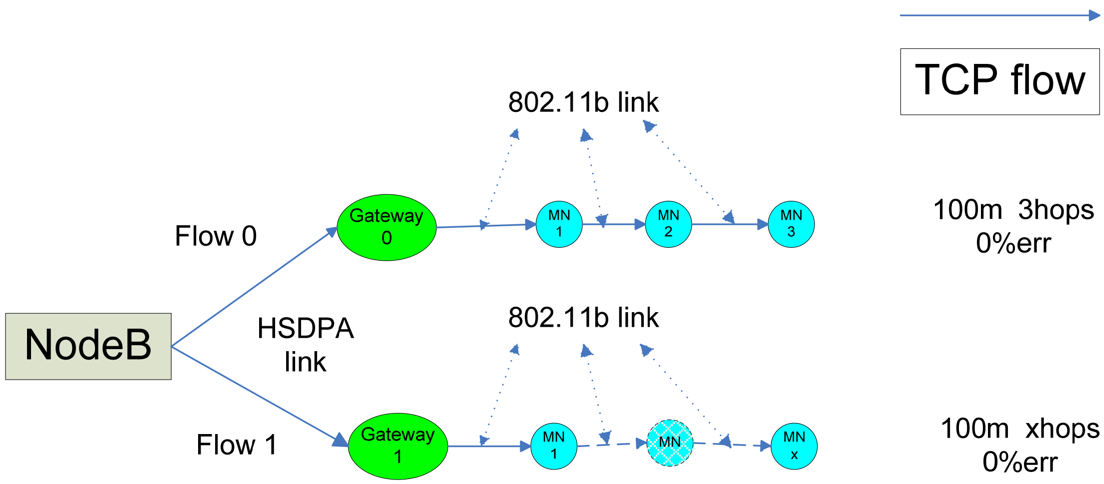

Figure 3-8 Simulation topology

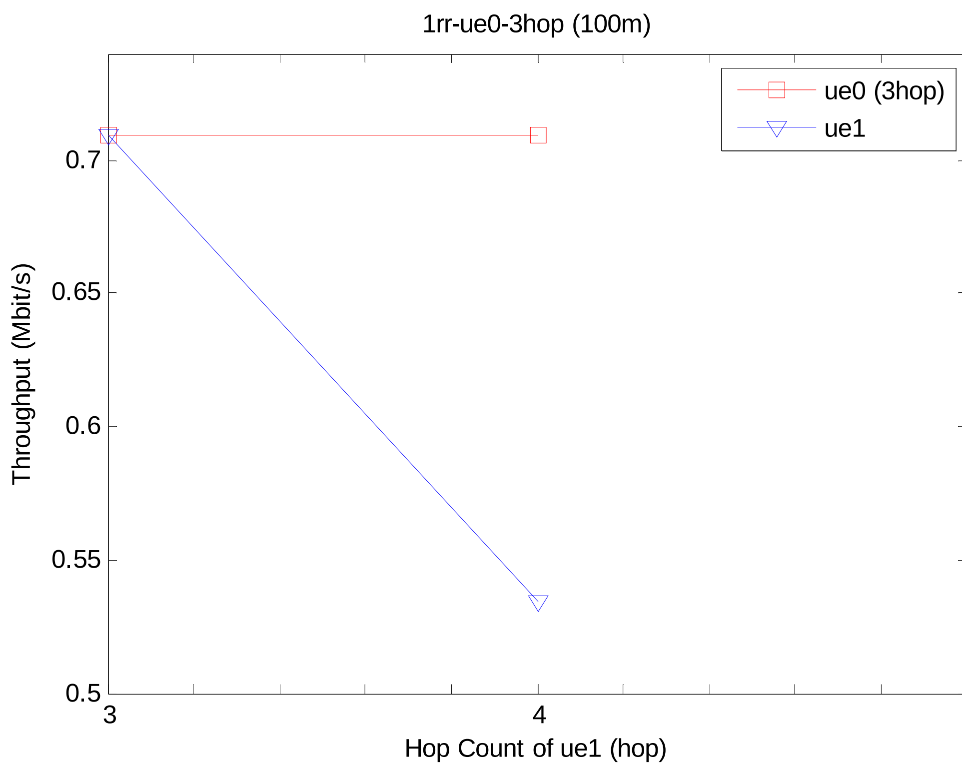

Figure 3-9 TCP throughput of First gateway: 3hops; Second gateway: 3, 4hops

Here if the hop counts of the two flows are equal values of 3 hops, the throughput of each flow is nearly equal value of 0.71Mbit/s. And it is similar that when the flow 0 is 3 hops and the flow 1 is 4 hops, there is a difference happening between the throughputs of the two flows. Besides, there is the same reason that the throughputs of the flow 0 keep unchanged as the previous two scenarios. The throughput of 0.71Mbit/s is the maximum value that the flow 0 can gain when 100m of the HSDPA channel quality and 3 hops of the ad-hoc subnetwork are set in the integrated network, which is also proved by the Figure 4-20 in the thesis [5].

Compared with the three Figures 3-5, 3-7 and 3-9 above, there is the similar phenomenon that due to the same link quality between the Node B and ad-hoc gateways in the HSDPA subnetwork and I hop count between the two gateways in the IEEE 802.11b ad-hoc subnetwork, there is no doubt that the hop count in the ad-hoc subnetwork 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 number of hop away between the two gateways and the TCP receiver node in IEEE 802.11 ad hoc network, the more distinguished TCP throughput of the terminal nodes is.

3.2.1.2 Different HSDPA channel between Node B and two ad-hoc gateways

In this section, Round Robin scheme is selected as the scheduler type of the base station. The effects on the integrated networks performance of the hop count in the ad-hoc subnetwork 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 subnetwork on the whole integrated networks need to be studied, so the hop count schemes are adopted the same as previous section. The difference is that the HSDPA channel condition is different for the two gateways. The scenarios 1, 2 and 3 here are designed similarly with Section 3.2.1.1. We can get the figures of the scenario 1, 2 and 3, respectively.

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

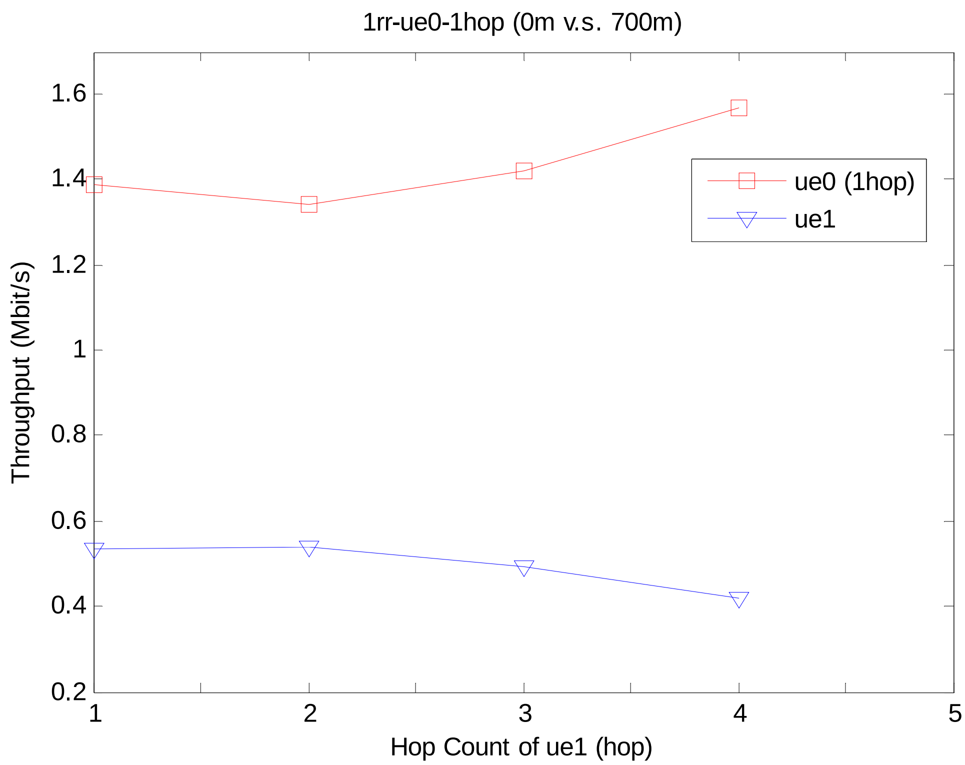

Figure 3-10 TCP throughput of First gateway: 1hop; Second gateway: 1, 2, 3, 4hops

We can see that although in the Node B the Round Robin scheduling scheme is used, the throughputs of two flows are not the same due to the different HSDPA channel conditions. From Figure 3-10, when the hop counts of the two flows are both 1 hop, the throughput 1.4Mbit/s of the flow 0 owning 0m HSDPA channel quality (ideal condition) is much larger than that 0.55Mbit/s of the flow 1 which has 700m distance between the Node B and the gateway. However, the unfairness of the integrated networks is similar to that of the integrated networks with the same HSDPA channel quality. The larger the distinction of the hop count between the two flows is, the more obvious the unfairness is.

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

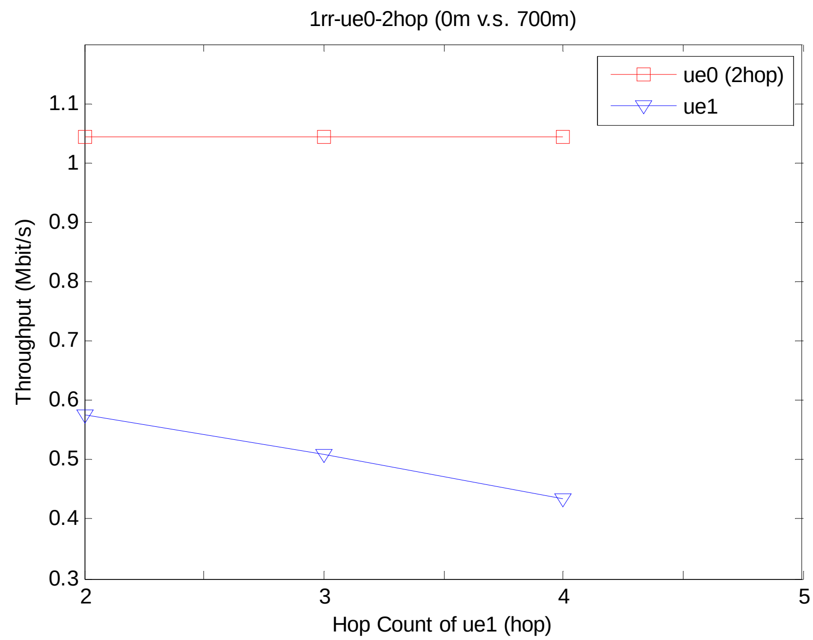

Figure 3-11 TCP throughput of First gateway: 2hops; Second gateway: 2, 3, 4hops

Here there is the similar trend to the previous scenario. When the hop count of the flow 0 increases, its throughput decreases if the hop count of the other flow 1 is kept unchanged. And the throughput of the flow 1 should increase. But from Figure 3-11, the throughput does not increase because the throughput of the flow 0 has reached the maximum value.

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

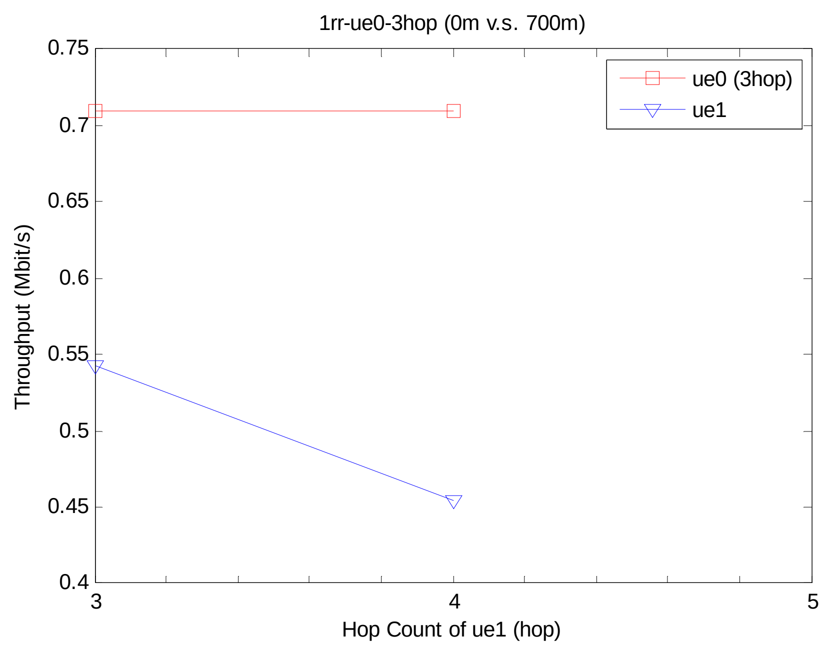

Figure 3-12 TCP throughput of First gateway: 3hops; Second gateway: 3, 4hops

As can be seen from Figure 3-12, there is the similar regulation that once the hop counts of the two flows are different, the distinction between the two TCP throughputs becomes larger.

Based on the result presented above, we got similar conclusion as 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 Node B

Since we already see that the basic round robin method introduce unfairness among different flows, we are wondering other existing scheduling method can alleviate this problem. In our new integrated networks simulation, there are three typical I 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 (I) and ad-hoc gateway node (GW). In other words, the former is that the I 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 I. 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 assigned first priority. 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 the same as those of Scenario 1 in the subpart 3.2.1.1 and the subpart 3.2.1.2 of Section 3.2.1. In order to compare with the two other scheduling schemes easily, we represent the result here:

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

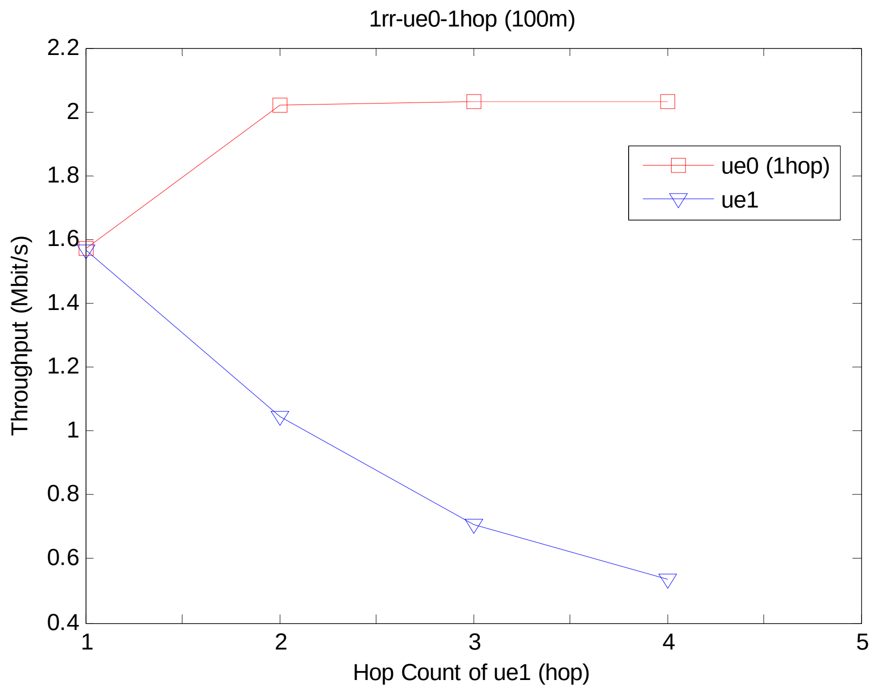

Figure 3-5 TCP throughput of round robin scheduling for the same channel

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

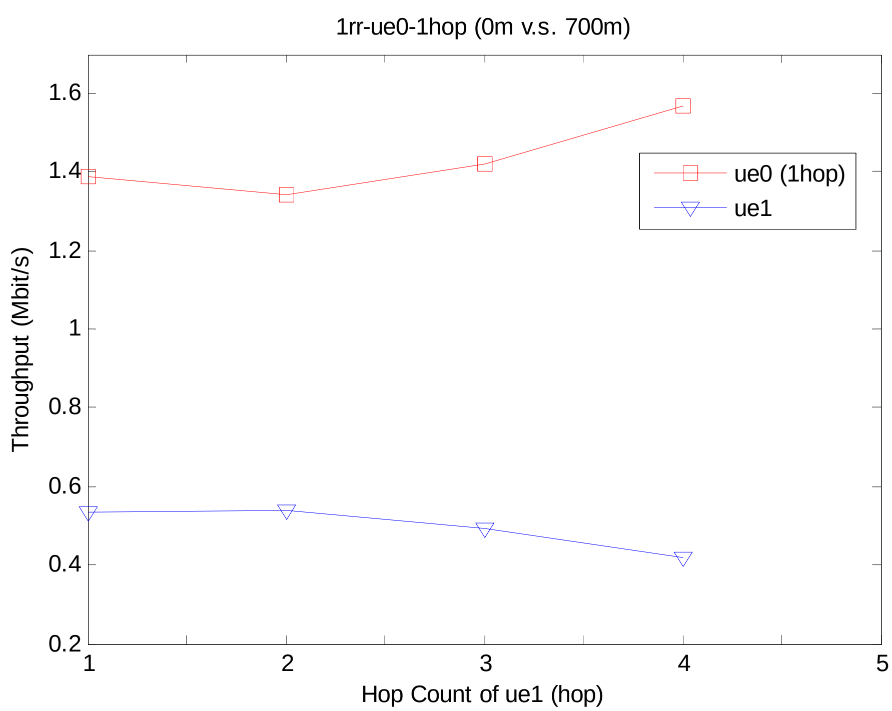

Figure 3-10 TCP throughput of round robin scheduling for two channels

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 the same as in the subsection 3.2.1, and the other parameters configuration is also the same as the previous simulation except that the MP scheduler is used in Node B. 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 I and the two ad-hoc gateway nodes.

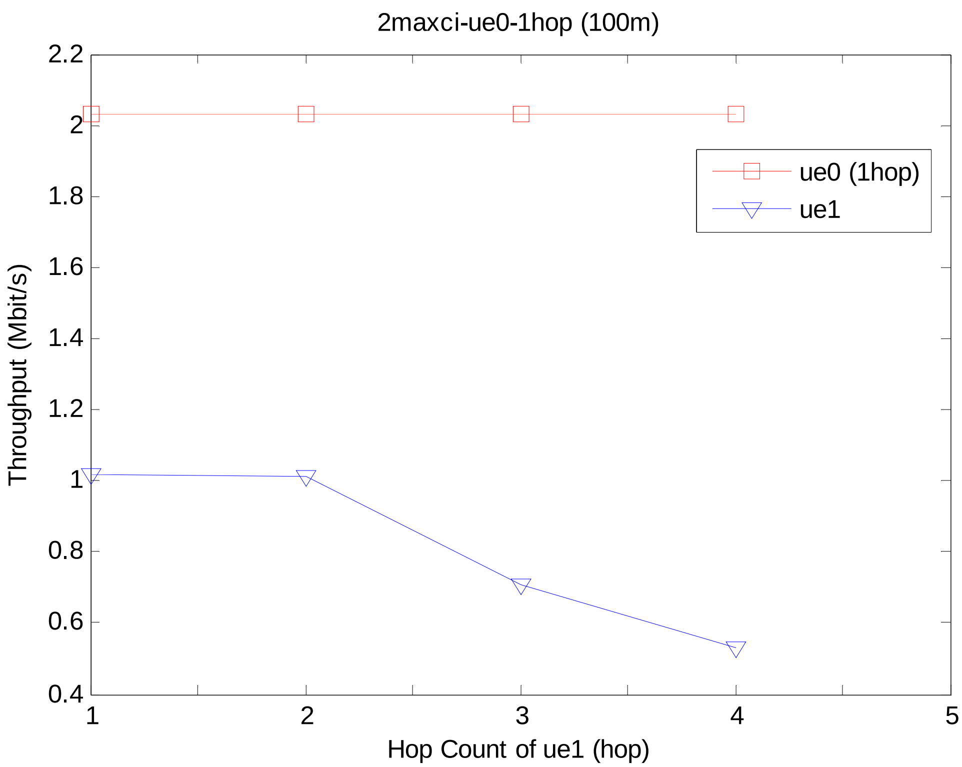

Figure 3-13 TCP throughput of MP scheduling for the same channel

According to Figure 3-13, the unfairness of the MP scheduling scheme integrated networks is similar to that of the Round Robin metric ones. However, here we find a problem in the MP scheduling. Although there are big differences between the MP scheduling and the Round Robin scheduling metric, the throughputs of the two flows over the two gateways should be nearly equal when the channel qualities of the two gateways in the HSDPA cellular subnetwork are configured the same 100m distance parameters. It is possible that the first flow limits the second flow.

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

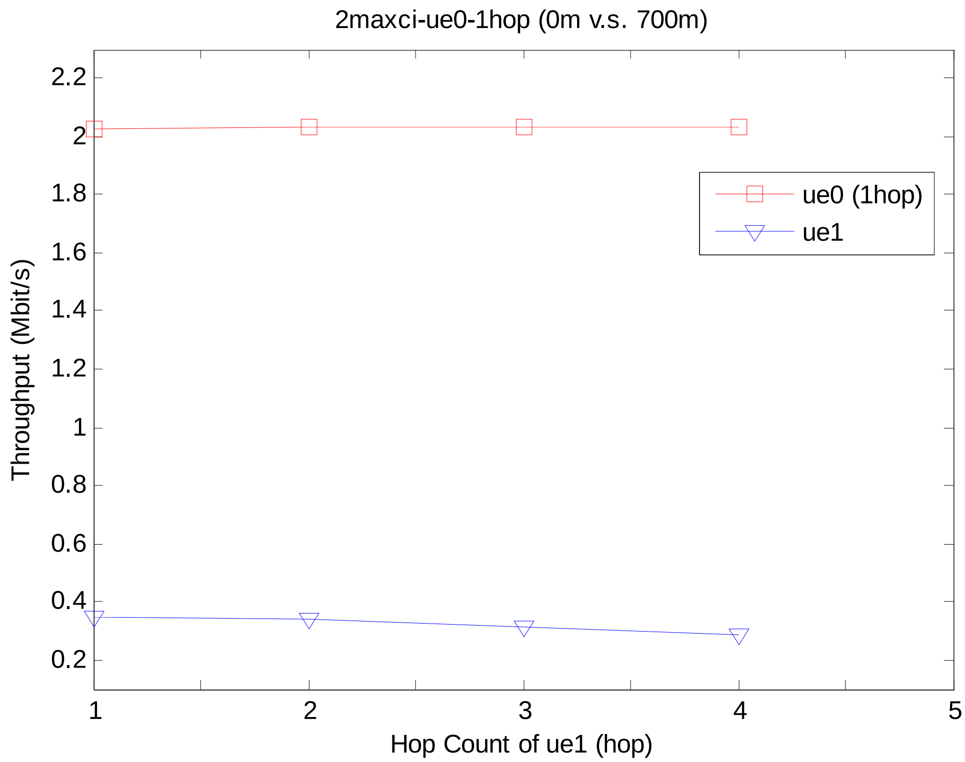

Figure 3-14 TCP throughput of MP scheduling for two channels

Compared with the Round Robin scheduling of Figure 3-10, the MP scheduling is shown clearly in Figure 3-14. The better the channel condition of a certain flow in the HSDPA cellular subnetwork is, the larger its available throughput is. For instance, the throughput of the flow 0 set 0m HSDPA distance parameter is much larger than that of the flow 1 configured 700m.

3.2.2.3 Fair Channel-Dependent Scheduling

The simulation in this part is similar to subsection 3.2.2.2. However, the FCDS scheduling mechanism is selected as the scheduler type of the Node B. According to different link quality between the I and the two ad-hoc gateway nodes, the two similar scenarios are considered:

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

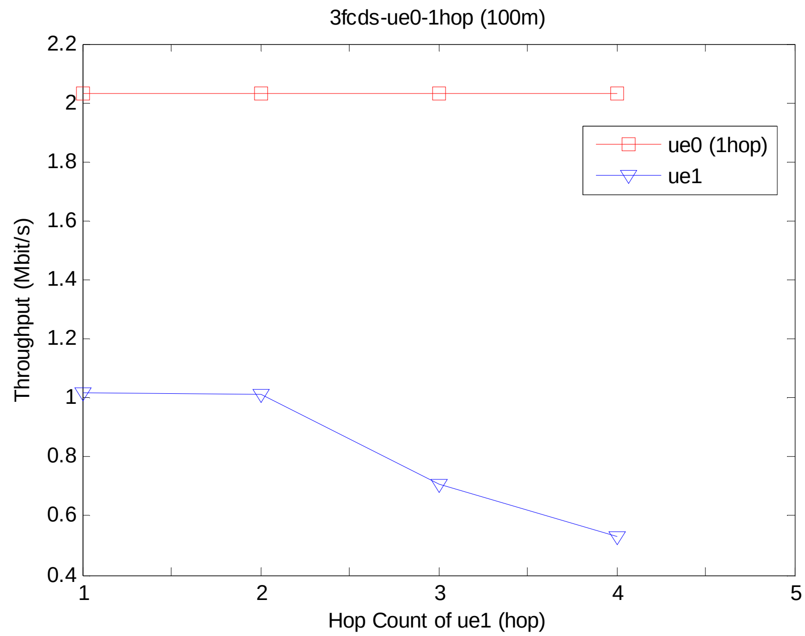

Figure 3-15 TCP throughput of FCDS scheduling for the same channel

We can see that Figure 3-15 is almost the same as Figure 3-13. As a result, when the channel quality in the HSDPA subnetwork is the same, the FCDS scheduling cannot improve the performance of the integrated networks obviously.

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

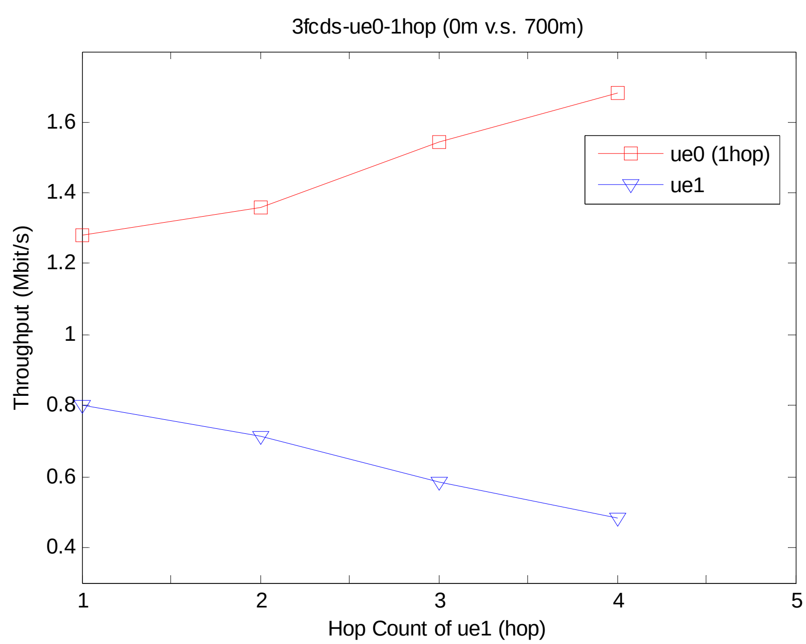

Figure 3-16 TCP throughput of FCDS scheduling for two channels

Compared with Figure 3-15, only if the channel conditions in the HSDPA subnetwork are different, FCDS can improve the performance of our integrated networks. It can obviously increase the throughput of a certain flow set the bad channel quality. For example, in Figure 3-16 the throughput of the flow 1 is increased from 0.55Mbit/s in Round Robin scheme to 0.8Mbit/s when the hop counts of the two flows are the same 1 hop.

3.2.2.3 Discussion

As been seen from all the figures 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 I and the gateway node in the HSDPA subnetwork, but the hop count in the ad-hoc subnetwork 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 Unfairness caused by scheduling

Based on the simulation result of Section 3.2, we have concluded that the performance of the integrated networks is impacted by two subnetworks at the same time, i.e. the HSDPA subnetwork and the ad-hoc subnetwork. 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 subnetworks influence on the integrated networks performance in details need to be done. Actually, the previous Section 3.2 has shown some trend. One of them is significant that if there are two gateways sharing the hs-dsch in the HSDPA subnetwork, 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 subnetwork is, there is more unfairness between two TCP receiver nodes in the two ad-hoc subnetwork 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 to design some new simulation scenarios to get the detail information about the extent of the impact of the two subnetworks 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 subnetwork

In this part, the impact of channel quality of the HSDPA subnetwork 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 easier, the simulations of the integrated networks with single gateway spacing different distances from the Node B in HSDPA subnetwork are 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 accurate 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 gain the available results about end to end TCP throughput with different HSDPA channel conditions in the following table 3-2.

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

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

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 subnetwork and the hop count in the ad-hoc subnetwork, To further understand the unfairness problem, the three gateway and four gateways scenarios are also used in the simulation, etc. For the three gateways scenario, 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 3-17. And there is also the same parameter configuration with that of the previous part.

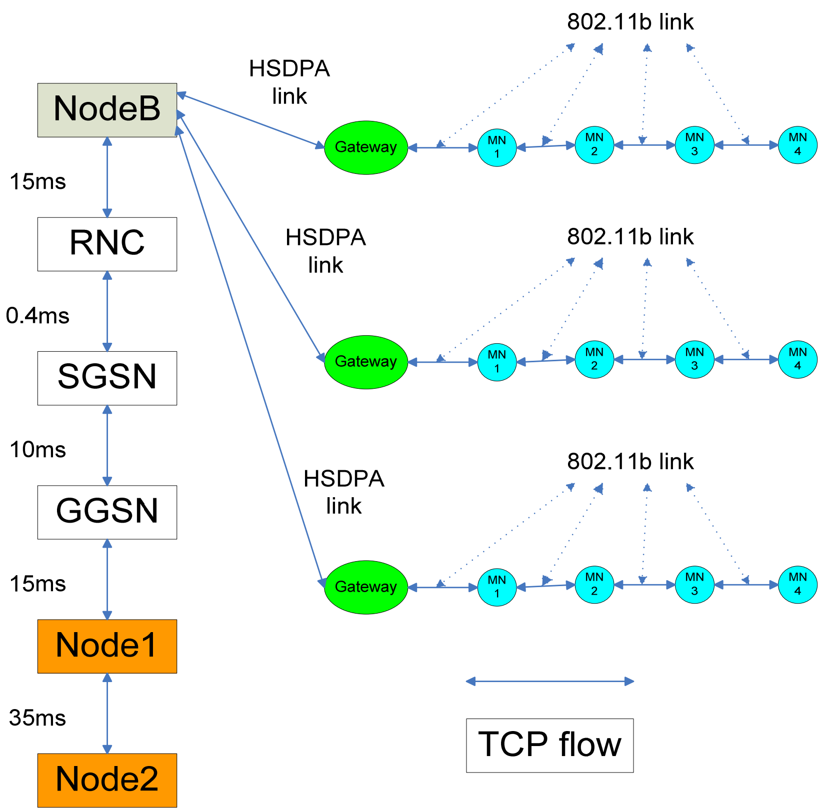

Figure 3-17 Simulation topology

	1 GW 2 hop	3 GWs 1-2-1hop	1 GW 3 hop	3 GWs 1-3-1hop	1 GW 4 hop	3 GWs 1-4-1hop
0m	1.042956	1.046983	0.709396	1.179505	0.534576	1.265860
		1.040701		0.709133		0.534673
		1.017945		1.156132		1.250185
100m	1.043523	1.041865	0.709163	1.172815	0.534935	1.259603
		1.038038		0.709829		0.534811
		1.031062		1.167302		1.256670
200m	1.042024	1.008539	0.709035	1.127142	0.534582	1.211284
		1.006443		0.709189		0.534695
		1.002967		1.121324		1.205522
300m	1.041944	0.799289	0.708742	0.837583	0.534576	0.899706
		0.791314		0.698651		0.534804
		0.803002		0.832208		0.906807
400m	1.042002	0.766150	0.709116	0.794446	0.534343	0.861897
		0.772108		0.688391		0.533553
		0.758708		0.794717		0.856304
500m	1.035602	0.714004	0.708247	0.739259	0.534600	0.792509
		0.714701		0.652368		0.525250
		0.713054		0.739238		0.795929
600m	0.945623	0.442196	0.682656	0.432707	0.527398	0.450147
		0.451037		0.449468		0.417959
		0.438052		0.444164		0.457509

700m	0.950696	0.463536	0.694310	0.463435	0.529811	0.477593
		0.467992		0.461504		0.425666
		0.463389		0.463661		0.476885

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

3.3.1.3 Scenario 3 – Four gateways

The simulation topology of the integrated networks with four gateways is shown in Figure 3-18. The parameter setting is still the same.

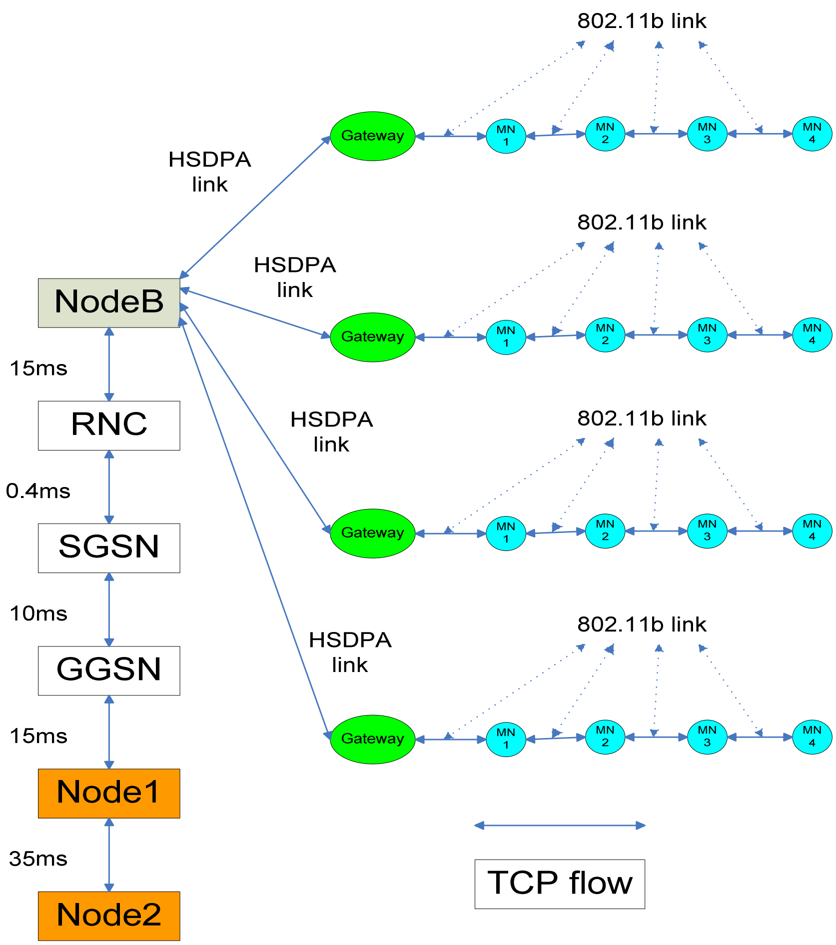

Figure 3-18 Simulation topology

	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
400m	1.042002	0.570627	0.709116	0.571966	0.534343	0.583346
		0.571019		0.566535		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 subnetwork

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 subnetwork on the end-to-end TCP throughput, only distance parameters deciding the channel condition of the HSDPA subnetwork will be considered. Take the two gateway nodes scenario for example, from Table 4-2, when the distances of 0m, 100m and 200m are selected to indicate the channel quality in the HSDPA subnetwork, 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. Based on those result, there is rea bility 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 scenarios with that in the integrated networks with two GWs.

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

In this section, the impact of the ad-hoc subnetwork 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 subnetwork. 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 subnetwork 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	0.753120	1.343874	0.606444	1.420435	0.488281	1.570316
700m		0.541339		0.492818		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 and it is possible to improve the integrated networks performance. In order to know how much throughput can be improved on the TCP throughput, we calculated the potential improved ratio for each scenario 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 subnetwork

The influence of the different hop count in wireless ad-hoc subnetwork on the whole integrated networks has been studied above, so the impact of the different error rate in the ad hoc network will be investigated in this section. Here we only carried out 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 present the simulation result.

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
		1.070585		1.201691		1.277955

1% error	1.005116	1.005544	0.680187	0.680759	0.512506	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 subnetwork

We can see that when the error rate of the wireless ad-hoc subnetwork increases from 0% to 10%, the unfairness becomes more obvious that the throughputs of the flow 1 in the three GWs scenario decreases more and more compared with that of the corresponding flow which has the same hop count in single GW scenario. For instance, in the 10% error rate the throughput of the flow 1 that has 2 hops in the three GWs scenario is 0.164906Mbit/s, it decrease more than 50% compared with the throughput value of 0.353077Mbit/s of the flow owning the same 2 hops in the single GW scenario. However, in the 0% error rate the former value of 1.041778Mbit/s is near to the latter value of 1.043220Mbit/s.

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 subnetwork

Here there is the similar trend to the previous scenario. In spite of extension of four gateways, the unfairness is still shown clearly from the Table 3-7. When the error rate is configured from 0% to 10%, the unfairness becomes more obvious.

The comparison method is similar with that of 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 with worse quality of IEEE 802.11 links (i.e. the error rate is higher), the more obvious the unfairness is.

3.4 Further research on the weighted scheduling

Since the unfairness between the different flows designated 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 3.3, which in turn, to investigate the potential of weighted ratio on improving the throughput, we did the experiment to investigate the throughput of the two flows under all circumstances of different weight assigned to different flows.

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

In this section, 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. However, the channel qualities of the two GWs in the HSDPA subnetwork 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 subnetwork are set the same value of 0%, that is, no error in wireless ad-hoc networks subpart. The specific simulation topology and parameter setting can be shown as the following Figure 3-19 and Table 3-8 again.

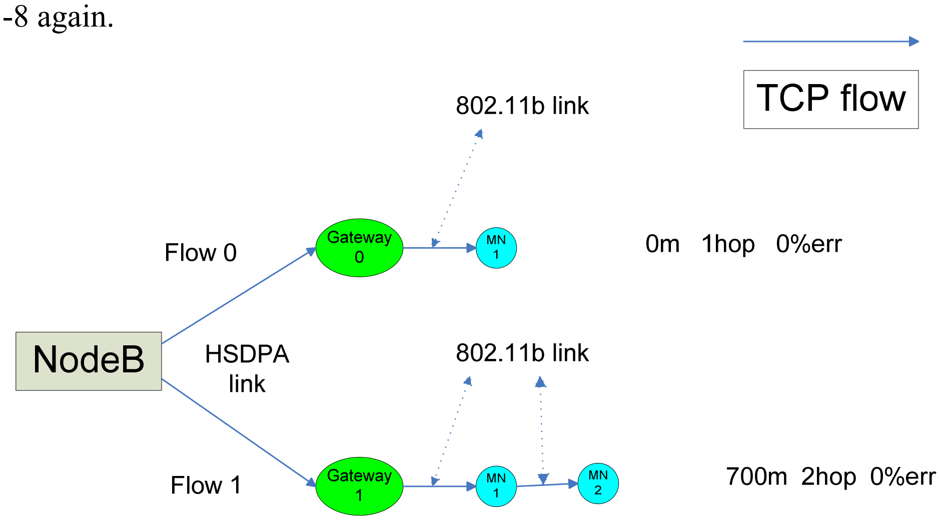

Figure 3-19 Simulation topology

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 potentially increased, however, it cannot show how much selective probability of the flow which occurs the unfairness should be grown (the chosen 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 that can make the throughput of each flow reach the balance (i.e., reach the better fairness), we will do all the simulation of the selective percentage from 50% to 100%. Figure 3-20 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 configured 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 Figure 3-20, 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 two TCP flows can reach the same eventually.

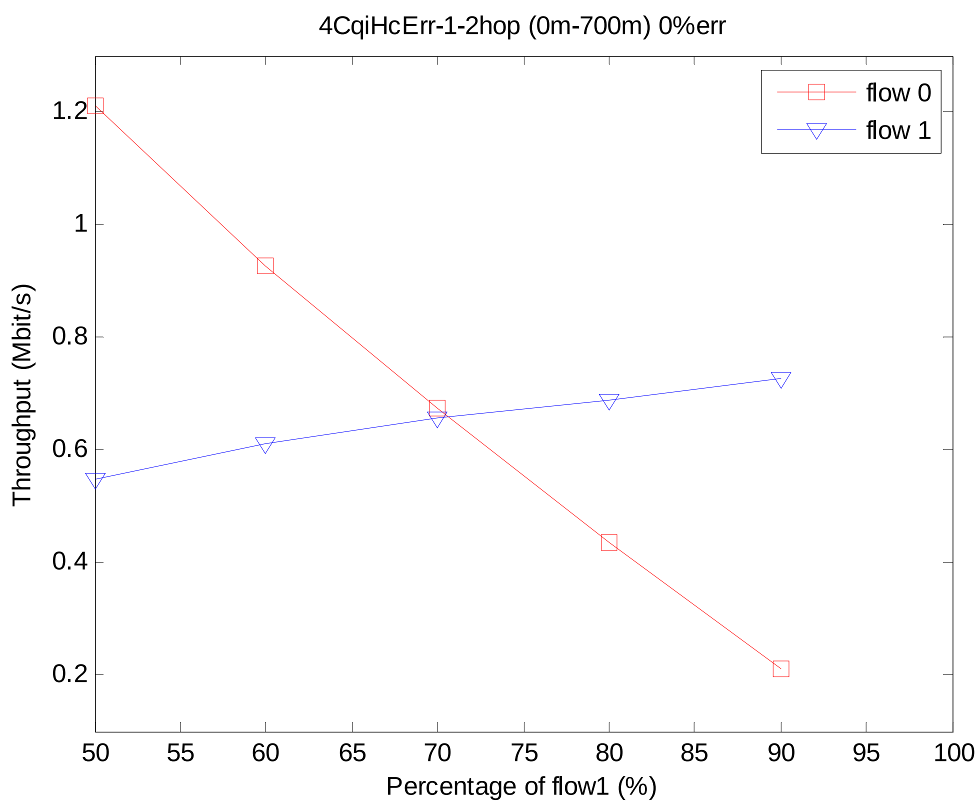

Figure 3-20 TCP throughputs of the integrated networks with two changeable choice percentage flows through two GWs

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 3-21 and Table 3-9.

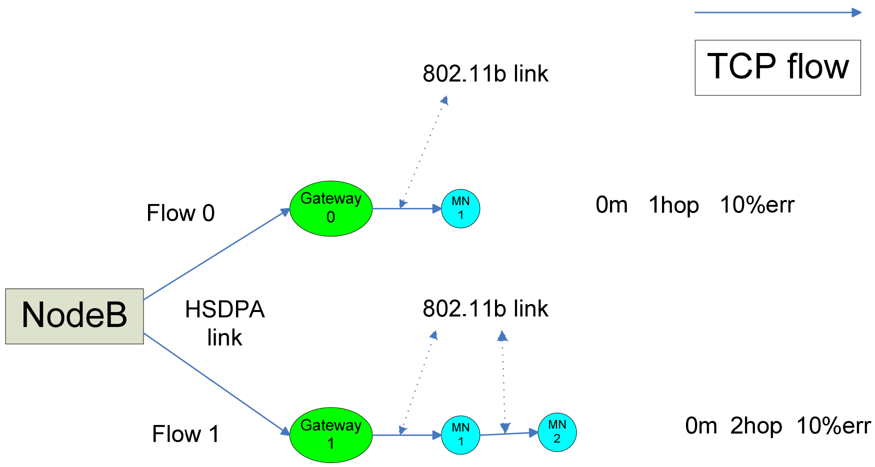

Figure 3-21 Simulation topology

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 the improved ratio as follow:
Improvable Ratio = 0.199690 / 0.133570 = 1.495021

Using the same method, the Figure 3-22 can also be obtained:

From the Figure 3-22, it is manifest that when the choice probability of the flow 1 increases to 95% (the selective percentage of the other flow 0 is set as the value of 5%) from the beginning point of 50% (the probability of the Round Robin metric), the two flows can be balanced eventually. Compared with the choice percentage in the previous Section, when there is the error rate existing in the wireless ad-hoc subnetwork, the unfairness between the two flows is more than that of no error rate. As a result, the larger selective probability of the flow 1 should be configured.

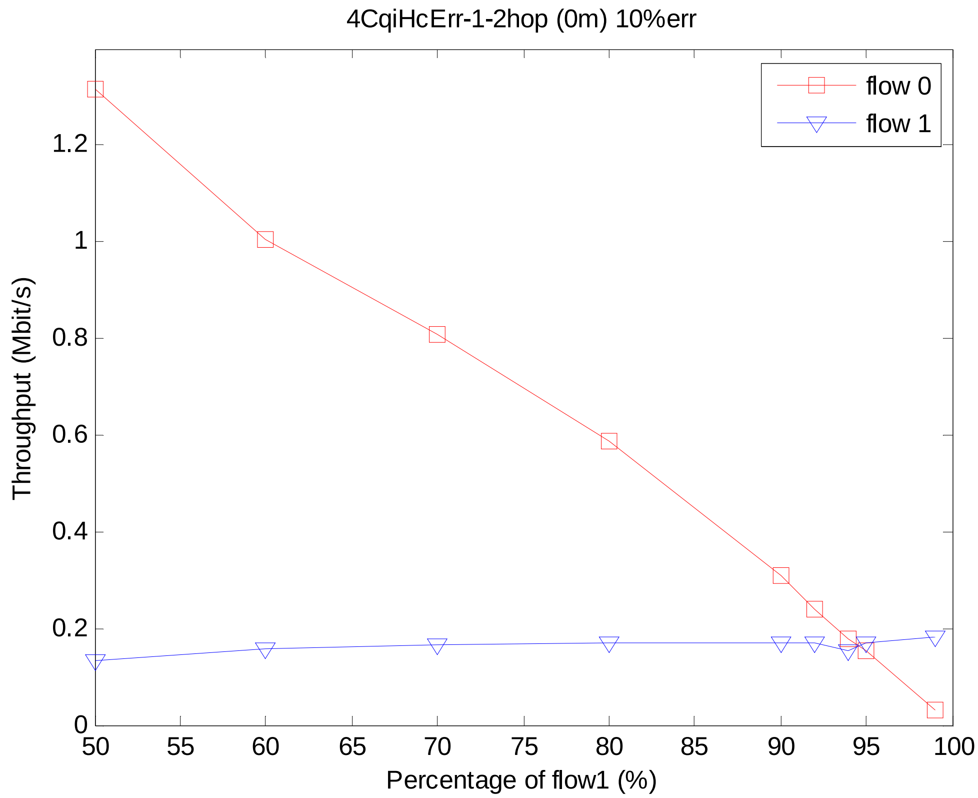

Figure 3-22 TCP throughputs of the integrated networks with two changeable choice percentage flows through two GWs (10%err)

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 3-23 and Table 3-10.

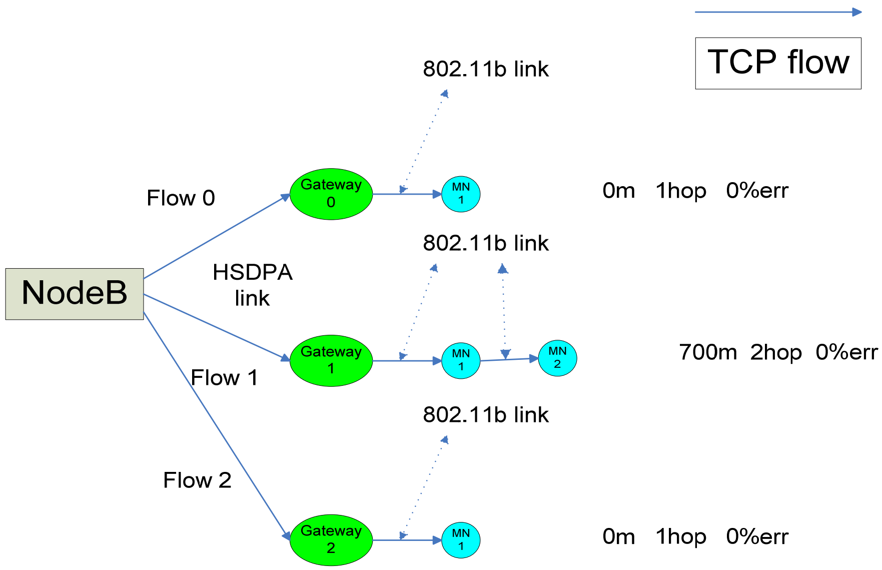

Figure 3-23 Simulation topology

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 3-24, it is apparent that when the selective probability of the flow 1 reaches about 50% (the choice percentages of the other two flows are configured 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.

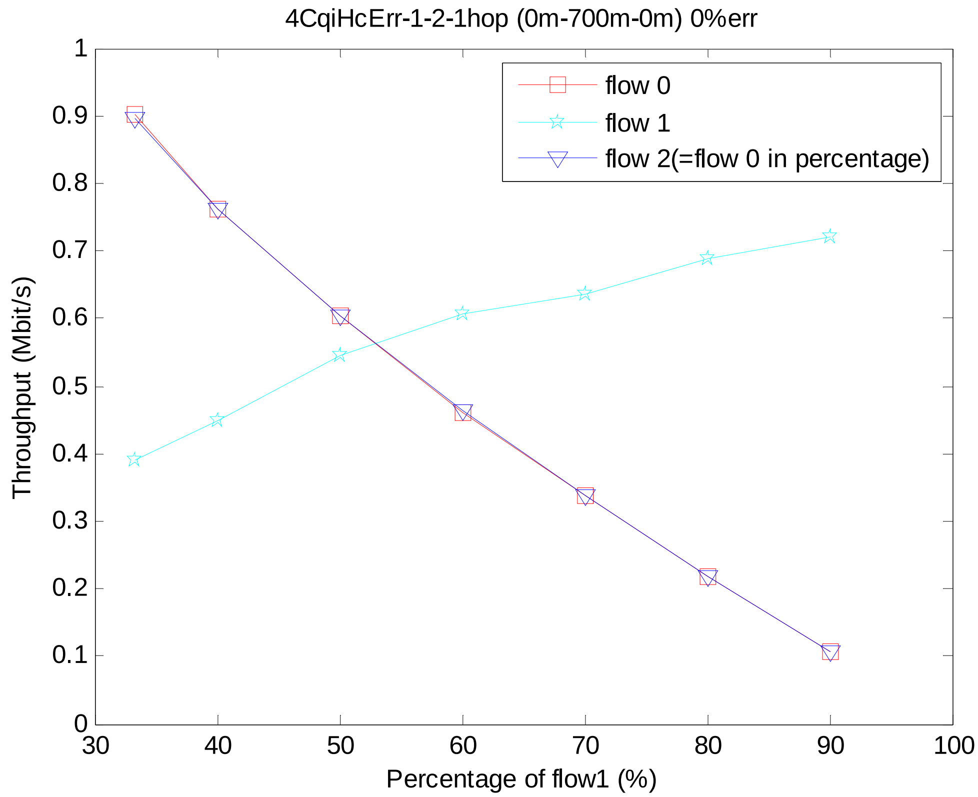

Figure 3-24 TCP throughputs of the integrated networks with three changeable choice percentage flows through three GWs

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 3-25 and Table 3-11.

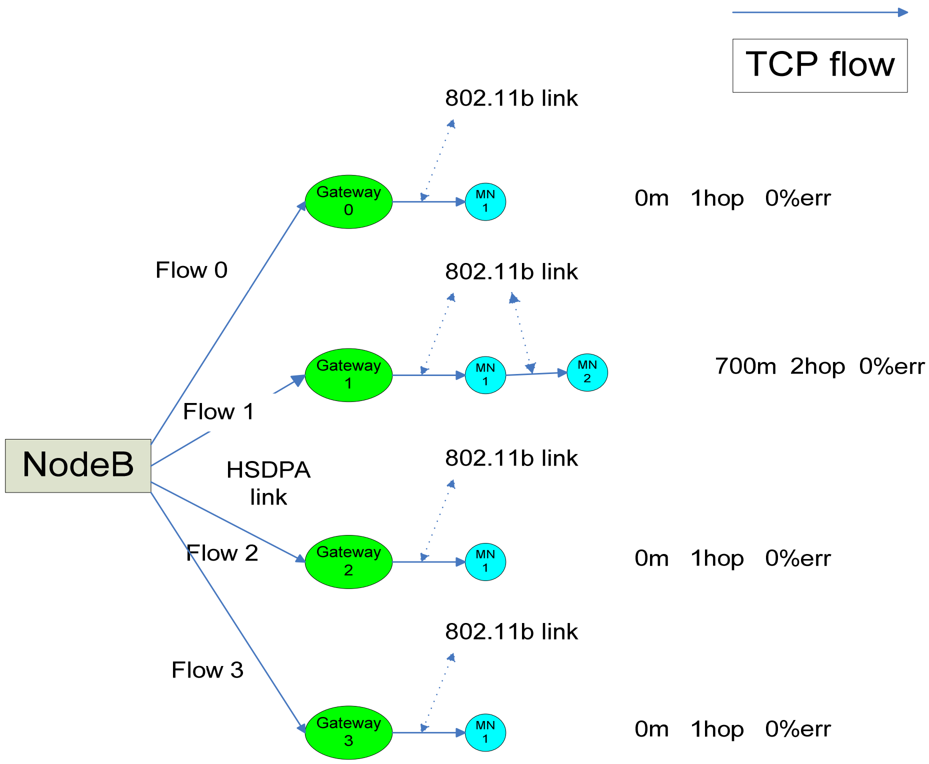

Figure 3-25 Simulation topology

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 Figure 3-26, 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.

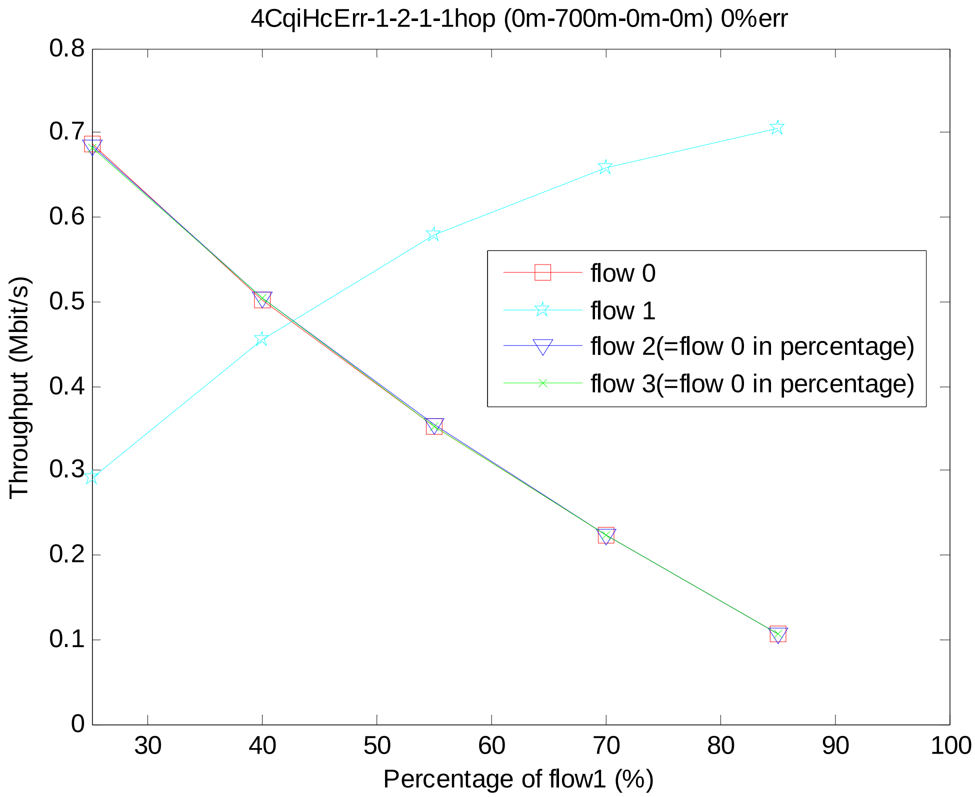

Figure 3-26 TCP throughputs of the integrated networks with four changeable choice percentage flows through four GWs

3.5 The proposed new scheduling algorithm

Based on the results of the previous sections, a completely new scheduling algorithm will be designed in this chapter. Not only will the HSDPA subnetwork in our special integrated networks will be considered, but the wireless ad-hoc subnetwork will also be taken into consideration in this new scheduling mechanism, while all the original scheduling algorithms only consider the HSDPA subnetwork, 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. The 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 Figure 3-27, 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 subnetwork 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 Figure 3-28.

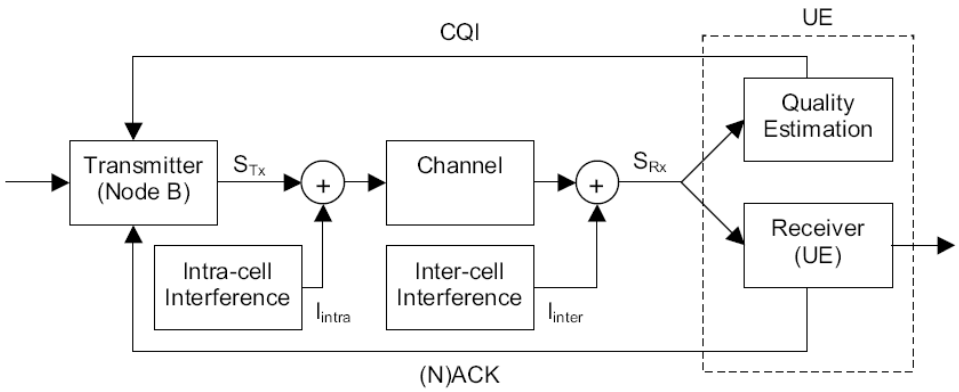

Figure 3-27 Physical layer model [10]

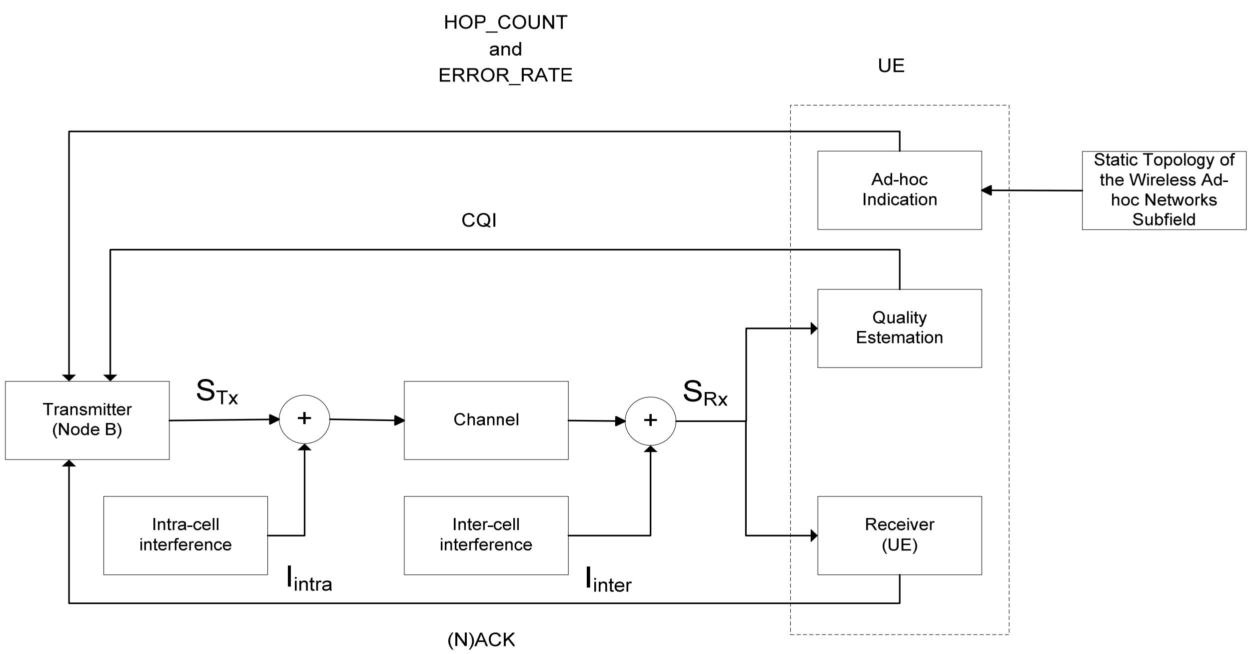

Figure 3-28 New Scheduling system

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

Because our new scheduling algorithm is considering the information of the two subnetworks (the HSDPA and the ad-hoc) in our integrated networks to reschedule all the flows 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 priority of each flow, 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 flow needs to be defined. We proposed to use the following formula to decide the weight of a certain flow i:

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

Where α, β are the indexes of the two parameters Hop_count and Err_rate, respectively. They can be configured changeable values in terms of different situations. Further, the radio for each flow is computed by the scheduler of the Node B as:

Scheduling ratio of a certain flow 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 and β values can be found. However, we need these best index values meet most of the scenarios. 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.

Firstly, we will give the detail weight formula as follows:

If all the flows has the same CQI values,

Weight of a certain flow I (CQI_i, Hop_count_i, Err_rate_i)

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

else

Weight of a certain flow I (CQI_i, Hop_count_i, Err_rate_i)

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

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 rates 100 times. And then the cubic root of them will be gained, so they will become 5 ranks from $\sqrt[3]{0}$ to $\sqrt[3]{100}$.

After that, we will explain the selection process of the parameter in the weight formula in more details in the next section.

3.5.3 Parameter selection of the new scheduling algorithm

The new scheduling scheme – Fair two-subnetworks-dependent scheduling has been proposed in the previous section, however, how to configure the formula is the next question. 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 subnetwork, 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, in 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 = $CQI_i * Hop\_count_i$, (ignoring the influence of the error rate due to the same error rate)

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

	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 = $CQI_i * Hop\_count_i^{1.3}$, 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 obvious that when the weight = $CQI_i * Hop\_count_i^{1.3}$, 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's trace, 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 = $CQI_i * Hop\_count_i$ 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)

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

else

Weight of a certain GW I (CQI_i, Hop_count_i)

$= CQI_i * Hop\_count_i$

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

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 perspective,

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

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 = $CQI_i * Hop\_count_i * \left(\sqrt[3]{Err\_rate_i}\right)^{Hop\_count_i}$ will be fixed eventually.

3.5.3.3 Discussion

In this section, we discussed how we can use some preliminary simulation result to select and decide the parameters in our proposed scheduling mechanism, the performance of our novel scheduling mechanism is evaluated in the following chapter.

3.5.4 Another method of the parameter selection of the new scheduling algorithm

In order to collect the best index values of the two parameters in our weight formula, there is another method that can be used to decide the weight formula eventually. But extensive simulations need to be done here.

We use four flows scenario, one of them is named the flow 1 which is set different topology, the destination of this flow can be different hop counts (i.e. 1, 2, 3 and 4 hops) away from the ad-hoc gateway in the IEEE 802.11 ad-hoc subnetwork, while the other three use the same topology, the destinations of these three flows are all 1 hop away from the gateway. And the HSDPA channel conditions of the three flows are configured the same, but the HSDPA channel quality of the rest flow 1 is set the same or different with the other three flows according to distinct scenarios.

Initially, these simulations need to be separated four groups as follows:

Group1: The ad-hoc gateways with the same channel quality in the HSDPA subnetwork and error free links in the wireless IEEE 802.11 ad-hoc subnetwork.

Group2: The ad-hoc gateways with the same channel quality in the HSDPA subnetwork and 5% error links in the wireless IEEE 802.11 ad-hoc subnetwork.

Group3: The ad-hoc gateways with different channel quality in the HSDPA subnetwork and error free links in the wireless IEEE 802.11 ad-hoc subnetwork.

Group4: The ad-hoc gateways with different channel quality in the HSDPA subnetwork and 5% error links in the wireless IEEE 802.11 ad-hoc subnetwork.

For the simulations of the Group1 and Group3, as the error free links in ad-hoc subnetwork are used, the index β value will not take effect in the weight formula, only different index α values are adopted to adjust the system. Here ten values of the index α are chosen. The Figure 3-29 and Figure 3-30 are depicted to show the results.

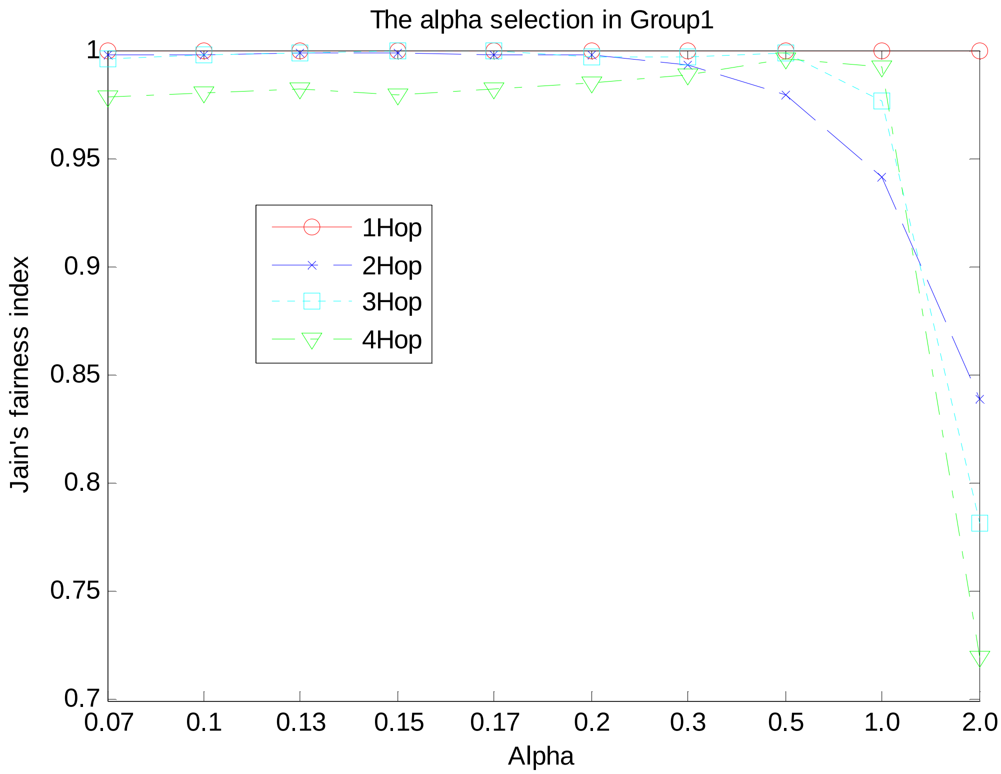

Figure 3-29 The α selection in Group1

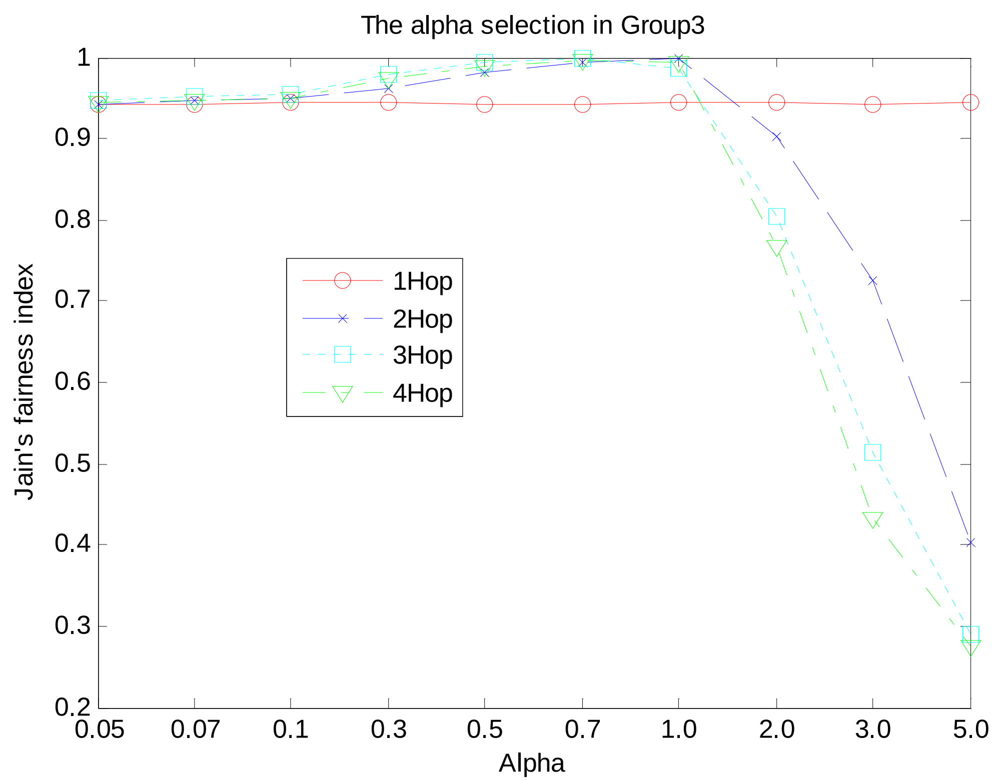

Figure 3-30 The α selection in Group3

For the simulations of the Group2 and Group4, because the 5% error links in ad-hoc subnetwork are used, the index α and β values will both make an influence on the weight of the flow, the different index α and β values are both adopted to adjust the system. Here ten values of the index α and β are chosen, respectively. In other words, there are one hundred groups of the index α and β. The Figure 3-31 and Figure 3-32 is plotted to show the results, which are both three-dimensional figures.

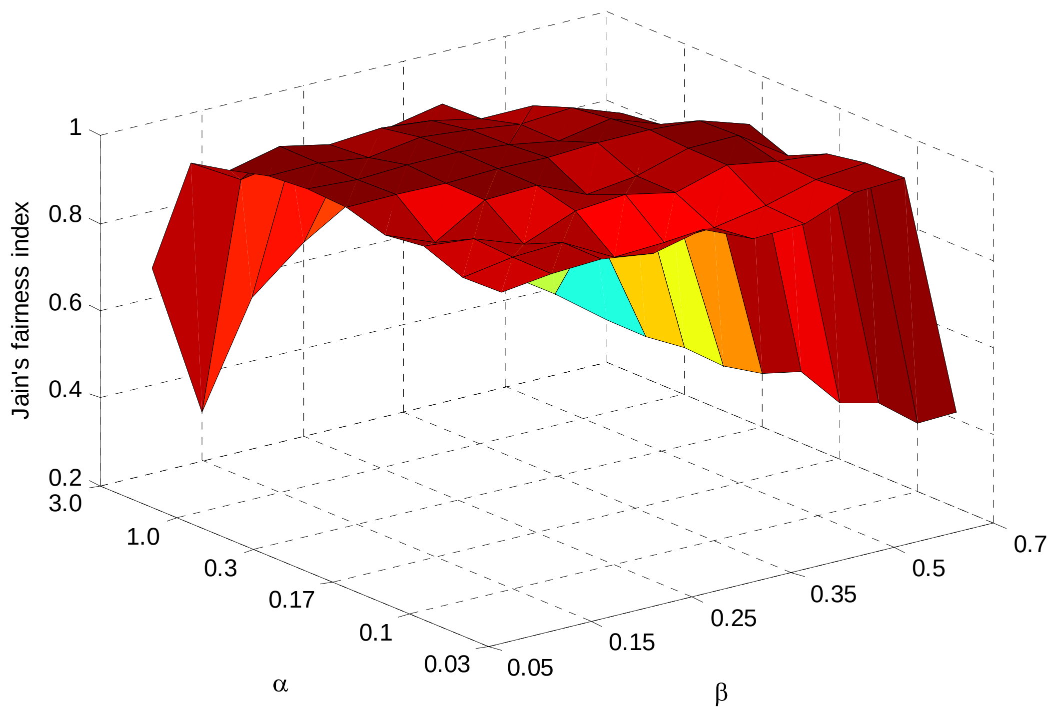

Figure 3-31 The α and β selection in Group2

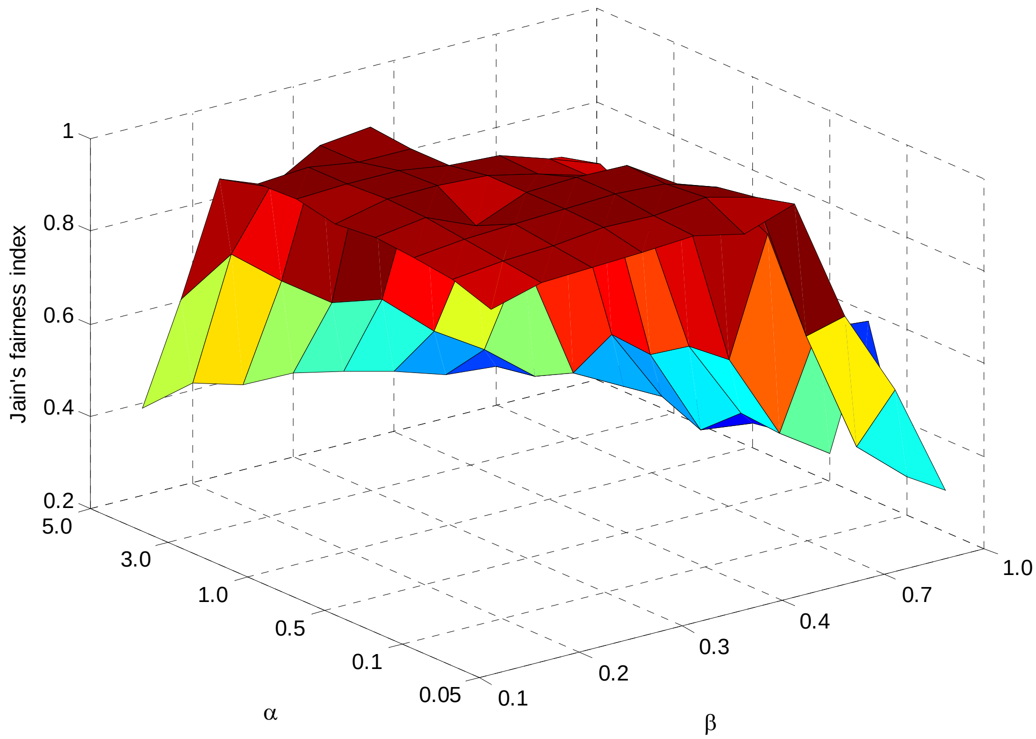

Figure 3-32 The α and β selection in Group4

Through our investigation simulation, we have gained the perfect index α and β values for different scenario group, i.e., when the fairness index is maximum, the corresponding α and β values are just the optimal ones. As shown in the four Figures 3-29, 3-30, 3-31 and 3-32, the optimal α for the Group1 and Group3 is 0.3 and 1.0, respectively. Meanwhile, the optimal α and β values set for the Group2 and Group4 are (0.2, 0.25) and (0.07, 0.3), respectively.

Since the best index α and β values for different group have been attained through the work above, we will utilize the fixed weight formula to validate the performance of our novel scheduling algorithm, which will be carried out the next Chapter 4.

Why the index α and β values collected here are different from the previous chosen values in Section 3.5.3? Because in the previous Section 3.5.3, the index α and β values are selected from a active perspective considering the average values of CQI for different HSDPA channel quality. And that one α and β set is chosen to meet the need of the most of situations. However, here, what we want is the optimal index α and β set. It is possible that the perfect index α and β set is different for each scenario. Furthermore, according to our work above, these index α and β set is definitely distinct. Thus, if we need gain the perfect index α and β set for different situations, it can be simulated to attain. But the extensive simulations need to be carried out, which is a disadvantage though current processors have enough computing ability to processing these preliminary simulations.

In the next Chapter 4, we will firstly use the index α and β values attained in Section 3.5.3 to validate the general performance of the novel scheduling algorithm for the most of scenarios, namely (0.1, 1/3) for same channel in the HSDPA subnetwork and (1.0, 1/3) for different channels. After that, the fairness index will be introduced to compare the Round Robin scheduling and the new FTSDS scheduling and eventually we will get the extent of improvement while utilizing the optimal index α and β set for each group obtained in Section 3.5.4.

4 Performance evaluation of the novel scheduling mechanism

In this chapter, since the new scheduling scheme has been proposed in the previous Chapter 3, it is essential to evaluate its performance in the integrated networks. Here, some typical simulation scenarios will be designed to collect the performance improvement information. Because it is in terms of the work of the Chapter 3 that the new scheduling method is designed, the simulation scenarios in this chapter are similar with those of the previous Chapter 3. Besides, the basic network topology and parameter configuration are also similar with those of the Chapter 3. In the end, Our proposed algorithm is compared with the traditional 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 Two gateways scenario

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 subnetwork, the hop count and the error rate in the wireless ad-hoc subnetwork. According to the similar way as the Chapter 3 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 IEEE 802.11 links error free scenario

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 subnetwork. 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 subnetwork

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

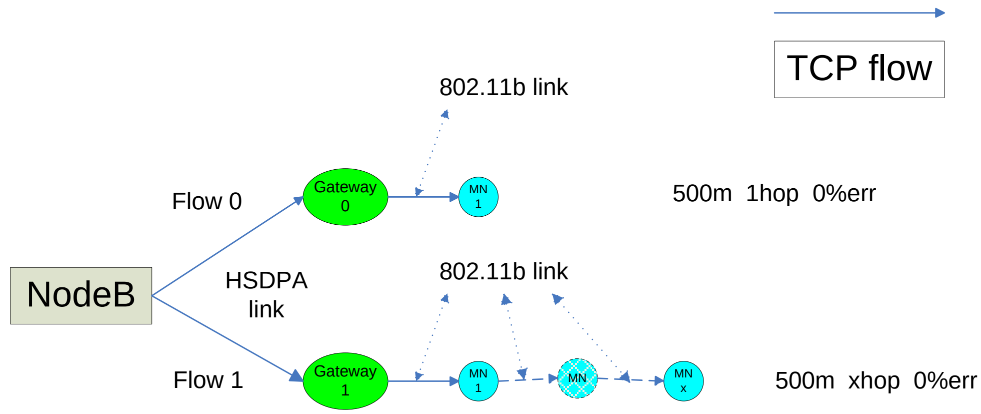

Figure 4-1 Simulation topology

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%	

Table 4-1 Round Robin V.S. FTSDS

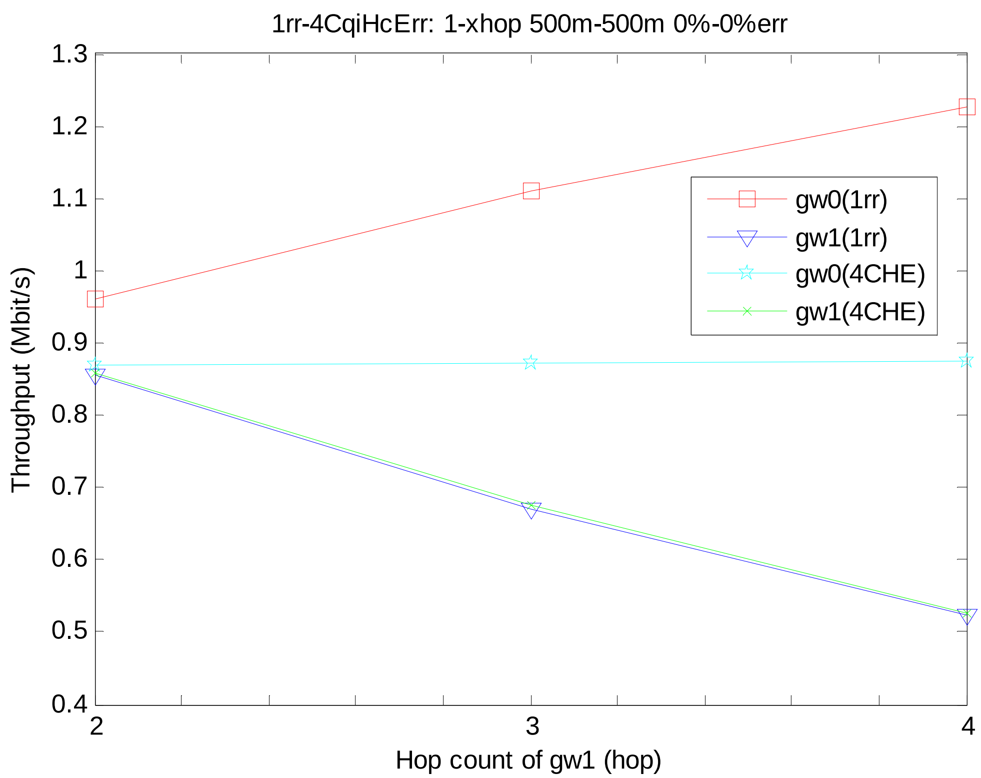

Figure 4-2 Round Robin V.S. FTSDS

We can see that for the same distance parameters of the HSDPA subnetwork between the two flows the new scheduling metric can improve the fairness obviously, however, the throughputs of the flow 1 are not increased more. They have reached the maximum values in the corresponding situations.

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

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

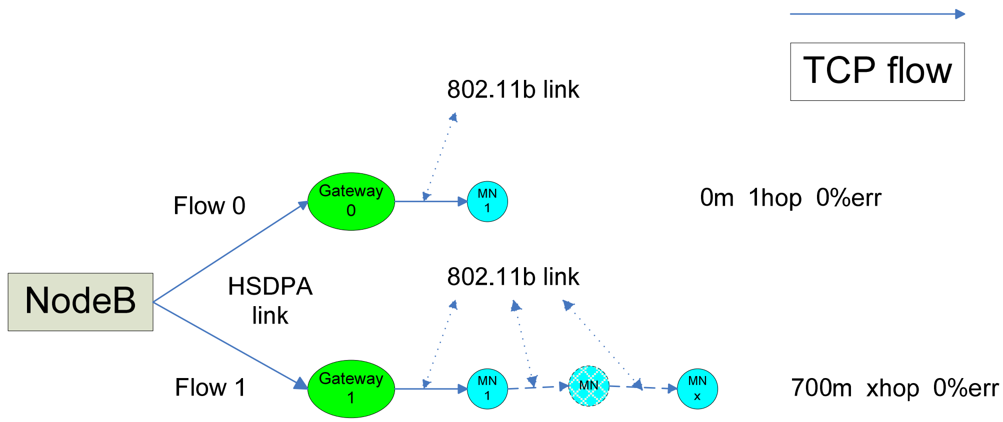

Figure 4-3 Simulation topology

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%	

Table 4-2 Round Robin V.S. FTSDS

Compared with the Table 4-1, due to adopting the new FTSDS scheduling mechanism not only can the unfairness be relieved between the two flows, but the improved ratios of the throughput are also much larger than that of the previous scenario 1. All the improved ratios in terms of different hop count can reach more than 10%.

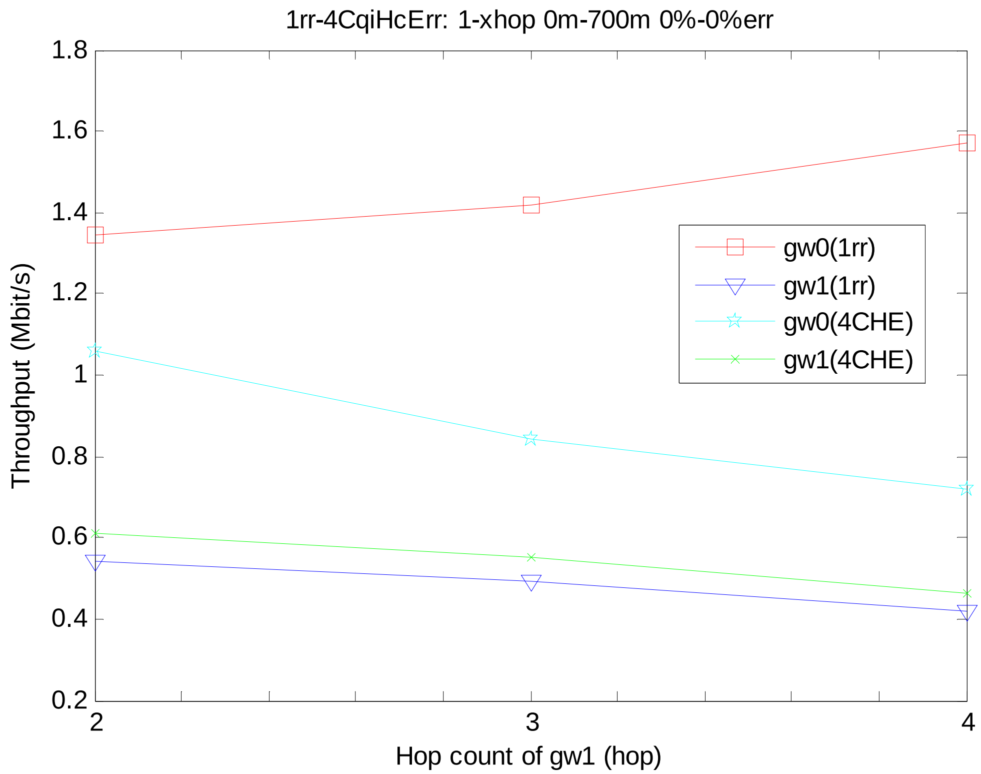

Figure 4-4 Round Robin V.S. FTSDS

From Figure 4-4, it is manifest that owing to utilizing the new scheduling method, when the throughput of the flow 0 decreases, the flow 1 throughput increases at the same time. Besides, there is the better fairness between the two flows compared with the Round Robin scheduling scheme.

Discussion: Based on the result above, we can see that the unfairness can be dealt with better under the FTSDS scheduling, we can achieve more than 10% throughput improvement with our new scheduling mechanism.

4.1.2 IEEE 802.11 error channel scenario

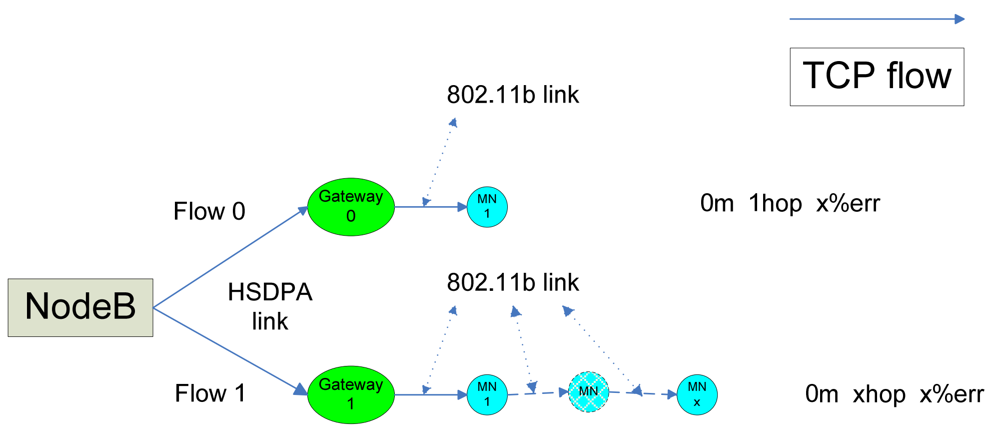

Figure 4-5 Simulation topology

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

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%	

Table 4-3 Round Robin V.S. FTSDS

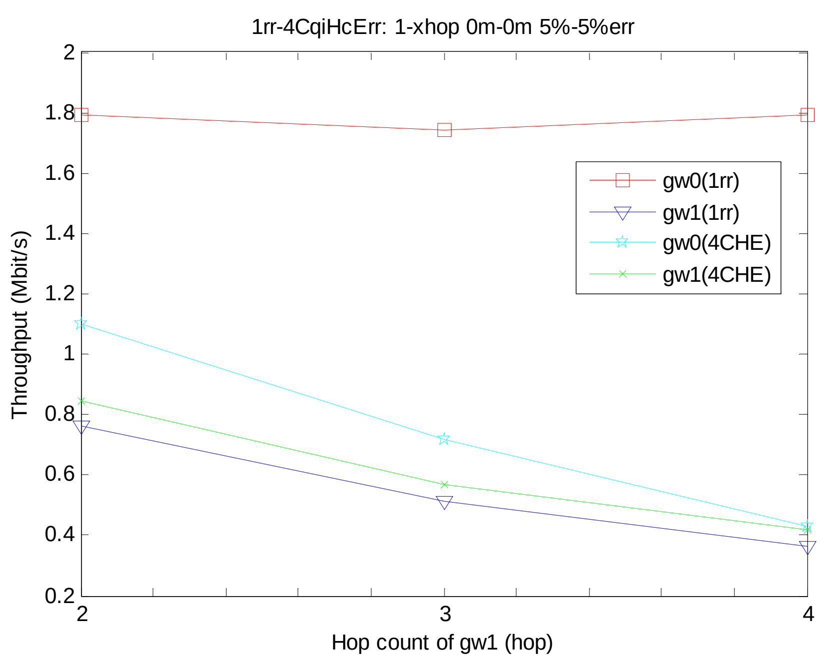

Figure 4-6 Round Robin V.S. FTSDS

Based on the result, we can see that when in the wireless ad-hoc subnetwork the error rate is set as 5%, our new FTSDS scheduling metric can still resolve the unfairness between the two flows and enable the throughput of the flow 1 increases to more than 10%. However, there is a disadvantage that in order to improve the flow 1 throughput, the throughput of the flow 0 is decreased too much in some situations so as to degrade the performance of the whole integrated networks system. But in several scenes the fairness between different flows is more important than the total high throughput of the whole system, thus, it is worthy of developing the novel FTSDS scheduling algorithm.

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

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%	

Table 4-4 Round Robin V.S. FTSDS

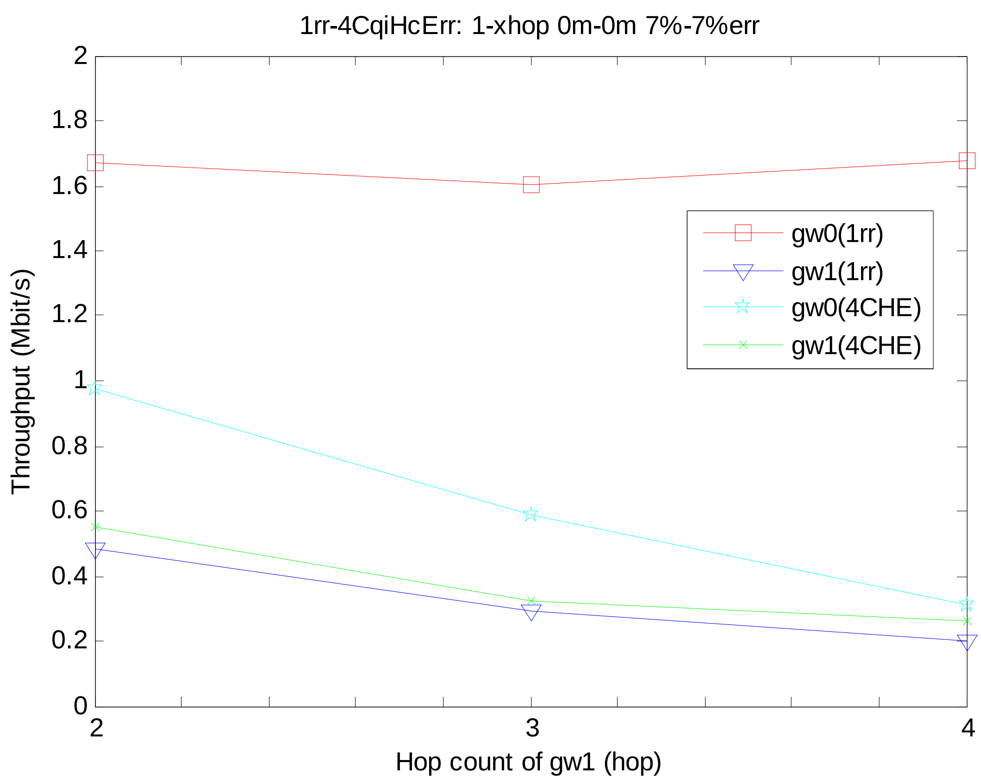

Figure 4-7 Round Robin V.S. FTSDS

Based on the result, we can see that there is the similar trend to the previous scenario. The FTSDS scheduling can bring the same pros and cons. According to the Table 4-4, for 7% error rate our new scheduling can improve the unfairness and the flow 1 throughput better than for 5% error rate, however, it costs a large the performance of the total system, especially, for 4 hops, the throughput of the flow 0 is decreased from 1.657546Mbit/s to 0.309149Mbit/s eventually to make the total throughput of the whole system degrade. But we gain the fairness between the two flows and the growth of the flow 1 throughput.

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

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%	

Table 4-5 Round Robin V.S. FTSDS

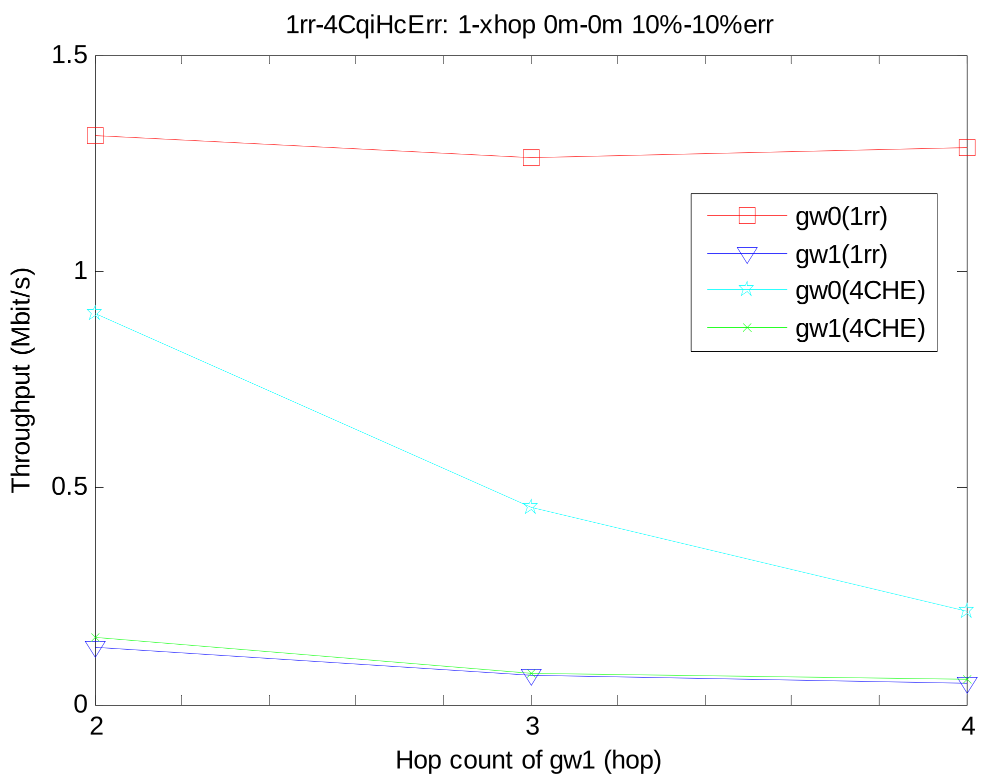

Figure 4-8 Round Robin V.S. FTSDS

As can be seen from the Table 4-5 and Figure 4-8, there is the similar trend to the previous two scenarios. Our new FTSDS scheduling mechanism can bring the advantage and disadvantage the same as those of the previous scenarios. In spite of at cost of the total system performance degradation, the fairness and the throughput of the flow 1 can be enhanced.

4.2 More than two gateways scenario

4.2.1 Integrated networks with three ad-hoc gateways

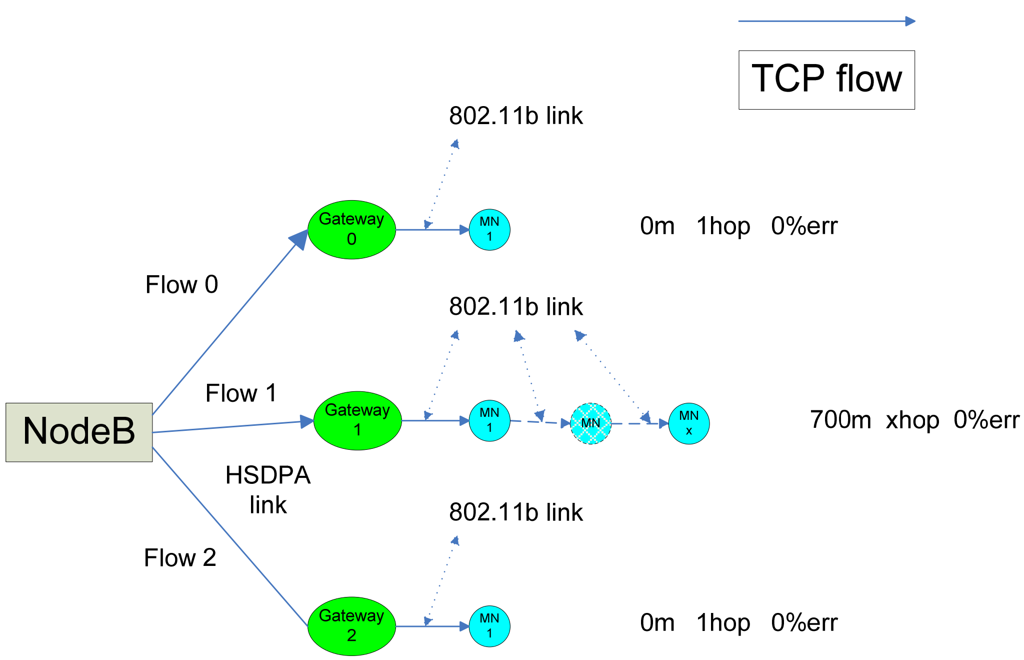

Figure 4-9 Simulation topology

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%	

Table 4-6 Round Robin V.S. FTSDS

Based on the result, we can see that for the three gateways scenario, the performance of our new FTSDS scheduling scheme is better than that for the two gateways scenarios. It can gain the larger improvement in the fairness and the flow 1 throughput at the expense of a small total system throughput decrease.

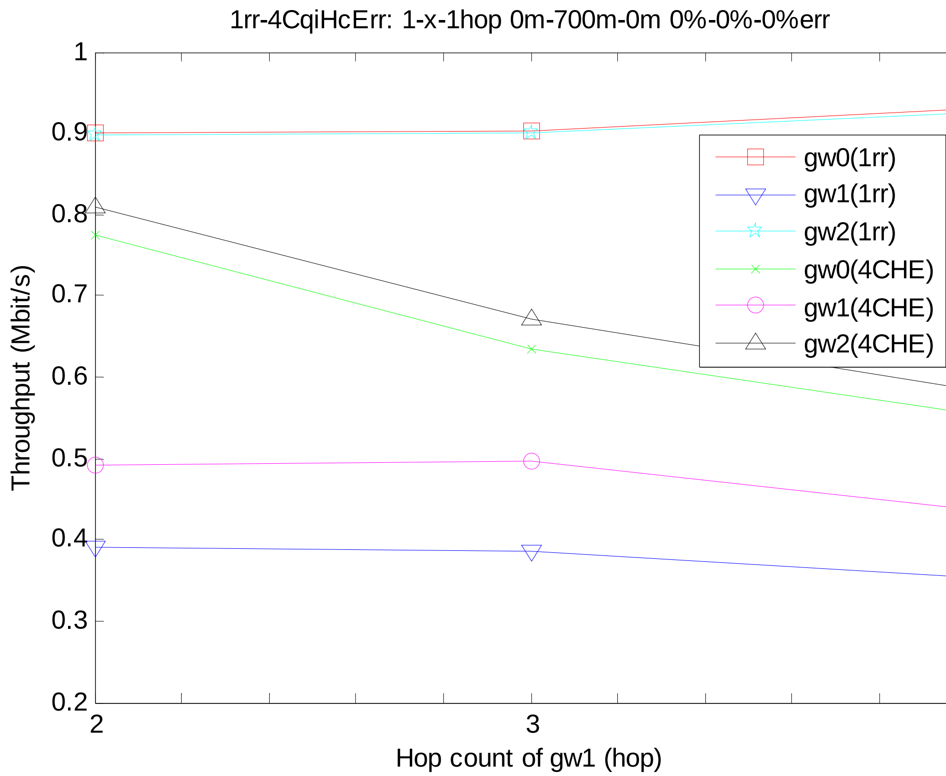

Figure 4-10 Round Robin V.S. FTSDS

From Figure 4-10, it is also shown that when the throughputs of the flow 0 and flow 2 drop, the flow 1 throughput rises and the growth is very obvious. Meanwhile, the pink line (the throughput of the flow 1) is closer to the green (the throughput of the flow 0) and the black line (the throughput of the flow 2), which represents the better fairness between the different flows.

4.2.2 Integrated networks with four ad-hoc gateway nodes

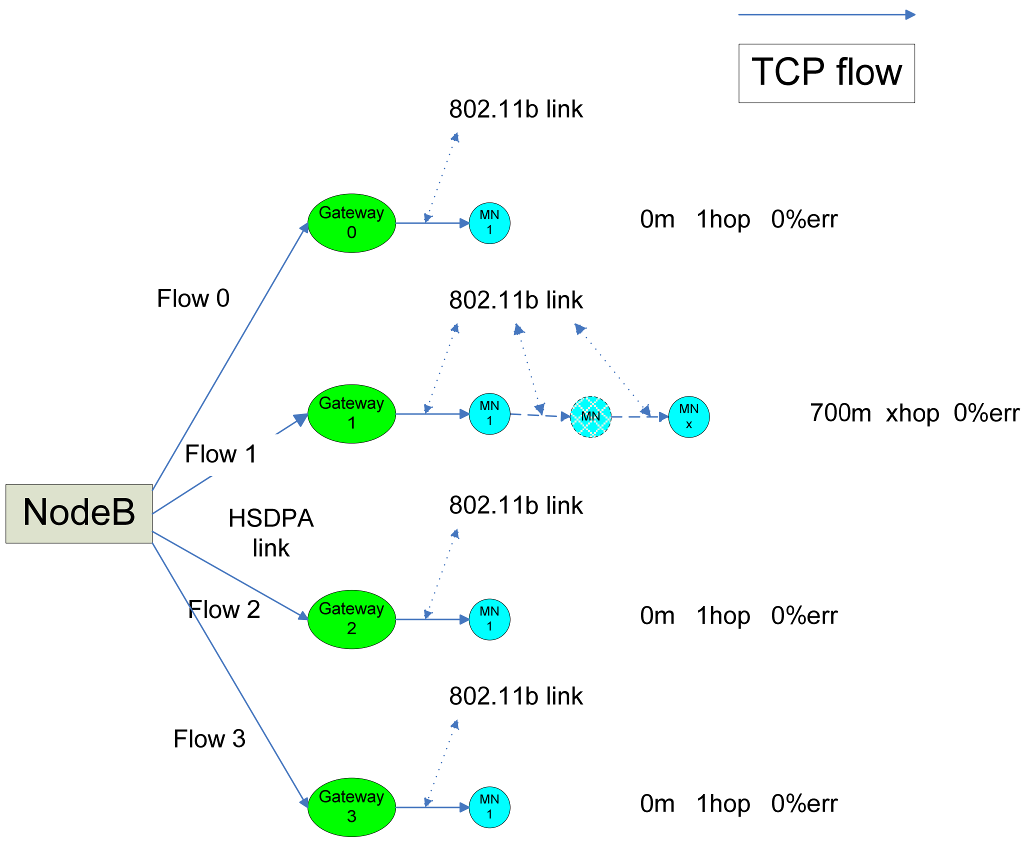

Figure 4-11 Simulation topology

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%	

Table 4-7 Round Robin V.S. FTSDS

As shown in the Table 4-7, for the four gateways the new FTSDS scheduling metric can improve the unfairness and the throughput of the flow 1 the best in all the scenarios mentioned above. In other words, the more the number of the flows is, the better the performance of our FTSDS scheduling is. For example, for 1-3-1-1 hop scenario, the improved ratio of the available throughput of the flow 1 can even arrive at more than 50%.

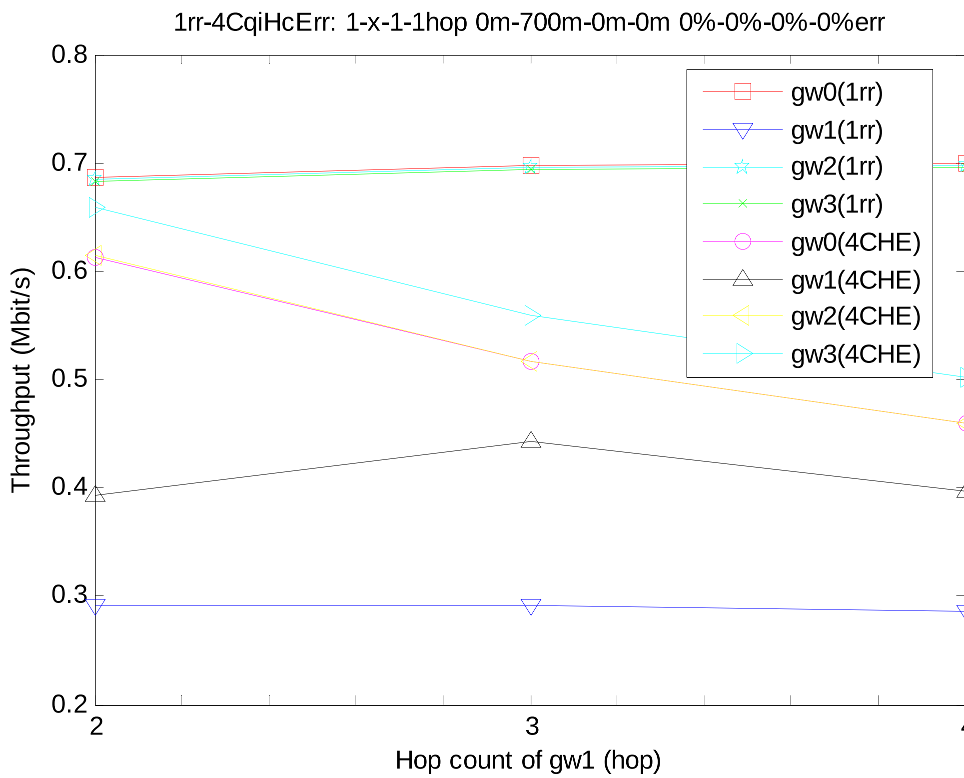

Figure 4-12 Round Robin V.S. FTSDS

Based on the result, we can see that for the four gateways there is the similar trend to the previous three gateways scenario. Due to reschedule all the flows utilizing our new FTSDS scheduling algorithm and all the flows are reselected in accordance with their own weights (here the flow 1 should be rescheduled at the larger ratio while the other three flows are reselected at the smaller percentage), the throughputs of the flows 0, 2 and 3 decline and the flow 1 throughput goes up. Meanwhile, we also attain the better fairness among all the four flows, which can be seen from Figure 4-12. The black line (the throughput of the flow 1) gets closer to the other three pink, yellow and light blue lines (the throughputs of the flow 0, 2 and 3) compared with the Round Robin scheduling method.

4.3 Performance validation in terms of the fairness index

In this Section, the optimal index α and β set for each group obtained in Section 3.5.4 of the Chapter 3 is used to investigate the performance of the new FTSDS scheduling in terms of the fairness index.

In order to gain the unfairness more clearly, the fairness index formula is introduced as follow:

$$f = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2}$$

Where n is referring to the number of concurrent FTP flows and x_i indicates the throughput achieved by the I th flow. The result is: 1/n <= f <= 1, where 1/n (worst case) and 1 (best case).

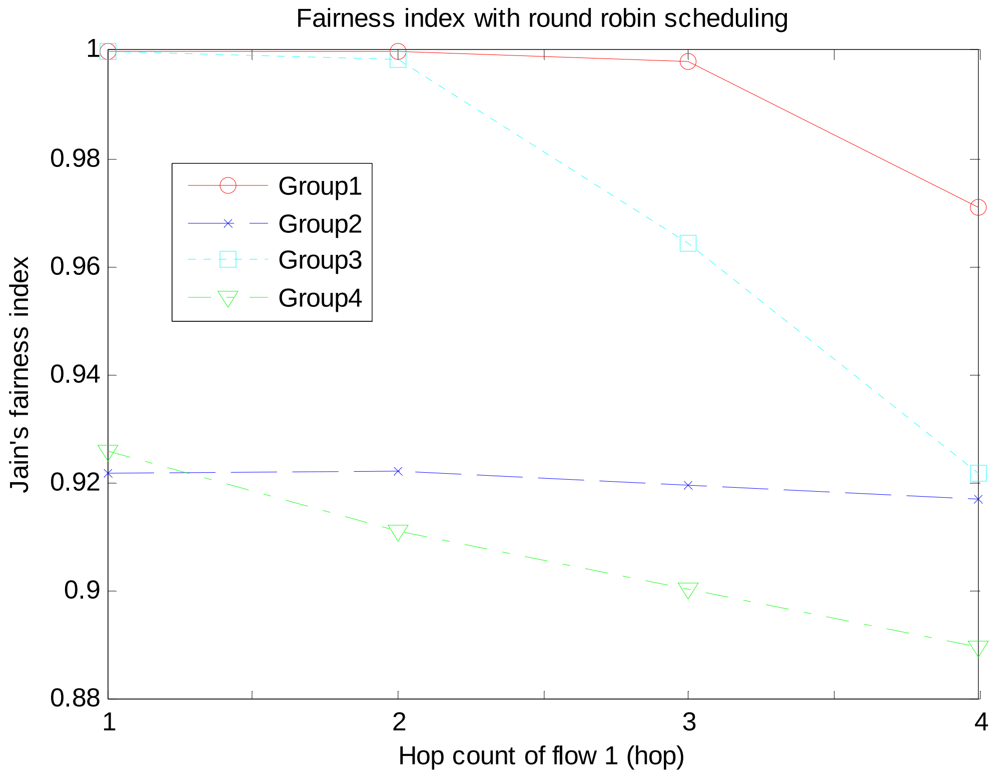

Figure 4-13 Fairness index with Round Robin scheduling

As shown in Figure 4-13, the fairness index declines in all the simulation scenario groups with the hop count rising for the flow 1. The fairness index of the flow 1 drops the most for the Group4 when both the HSDPA and IEEE 802.11 ad-hoc link qualities are the worst of all the four groups.

Group4 (RR)	1-1-1-1	1-2-1-1	1-3-1-1	1-4-1-1
Flow 0 (Mbit/s)	0.691216	0.689961	0.713423	0.732889
Flow 1 (Mbit/s)	0.302254	0.267396	0.258655	0.236356
Flow 2 (Mbit/s)	0.689207	0.687961	0.733722	0.724923
Flow 3 (Mbit/s)	0.687228	0.686334	0.730843	0.725637
Fairness Index	0.925935	0.911025	0.900478	0.889858

Table 4-8 Group4 with Round Robin scheduling

From the Table 4-8, the throughput the flow 1 can get decreases with the hop count increasing the flow 1 travel through. In the most severe situation (i.e. 4 hops), the flow 1 can only get 0.236356Mbit/s data rate. It drops 28% compared with the best situation (i.e. 1 hop) throughput 0.302254Mbit/s.

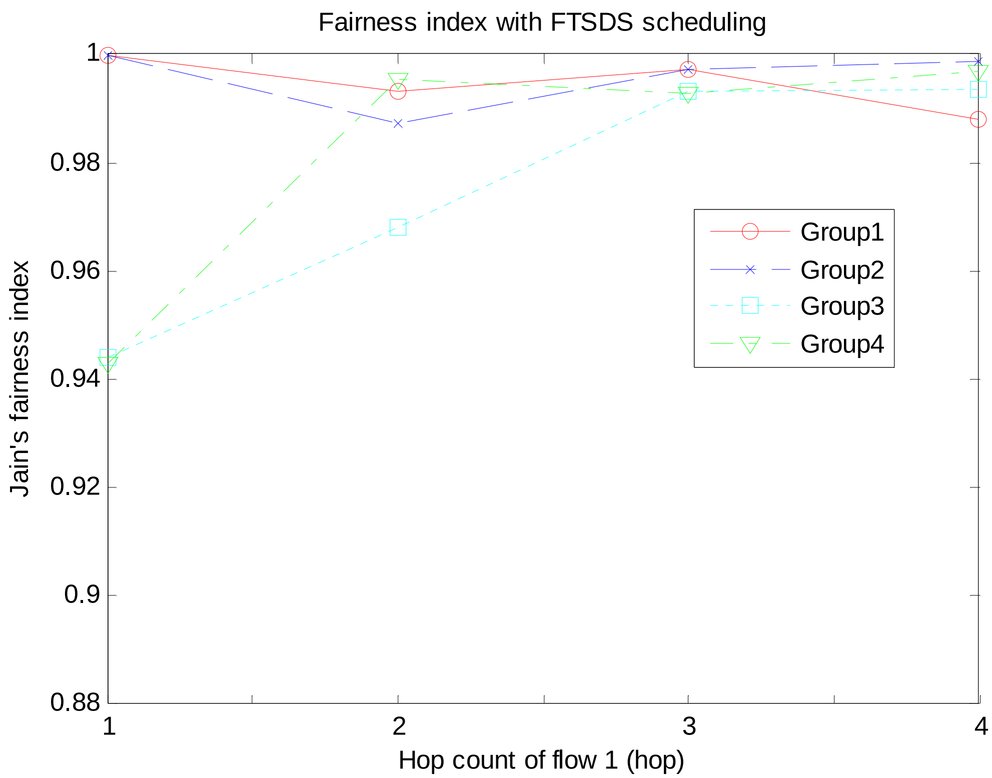

Figure 4-14 Fairness index with FTSDS scheduling

According to Figure 4-14, the new FTSDS scheduling enables the fairness index for every simulation group to increase though the hop count also rises at the same time. Especially for the Group4 in which both links conditions are the worst, the growth of the fairness index is very clear.

Group4(FTSDS)	1-1-1-1	1-2-1-1	1-3-1-1	1-4-1-1
Flow 0 (Mbit/s)	0.795520	0.655644	0.546789	0.431752
Flow 1 (Mbit/s)	0.412079	0.589823	0.481410	0.455753
Flow 2 (Mbit/s)	0.794990	0.659287	0.550830	0.428043
Flow 3 (Mbit/s)	0.849219	0.717423	0.614155	0.491479
Fairness Index	0.943112	0.995274	0.992719	0.996878

Table 4-9 Group4 with FTSDS scheduling

Compared between the Table 4-8 and Table 4-9, there is an obvious rise in the fairness index due to adopting the new FTSDS scheduling mechanism. And the throughputs the flow 1 can get utilizing the FTSDS scheduling increase for all the hop count scenarios in Group4 compared with those of the Round Robin scheduling. For instance, for the worst 4 hops scenario, the throughput the flow 1 can get reaches 0.455753Mbit/s owing to using the new FTSDS scheduling, which grows almost 2 times as much as that of the Round Robin scheduling (0.236356Mbit/s).

5 Conclusions and future work

5.1 Conclusions

The work in this thesis has simulated an integrated network with multiple gateways, multiple TCP flows, different HSDPA, IEEE 802.11 number of hops and 802.11 link qualities with different scenarios. 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 rates 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 additional 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 let the different flows share the resources more fairly and let all the nodes be able to access the Internet with enough bandwidth. Extensive simulations were done to validate our proposal and simulation results indicate that better fairness is achieved among different flows.

Initially, we have simulated the integrated networks with multiple gateway nodes and TCP flows in NS-2. Although there are several configuration modifications in NS-2 codes needed to be done (the distance between each GW needs ensuring more than 250m), the achievement is significant for our new integrated networks study. Because the [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 and traffic flows are investigated in this thesis. Simulations were done to gain the performance knowledge of the integrated networks with multiple gateways. Besides, due to adopting the beyond 3G cellular mobile networks (i.e. HSDPA) technology, the integrated networks with multiple gateways are researched in case of different scheduler type of the Node B.

Next, as the simulations of the multiple gateways integrated networks have been accomplished, simulations show that the TCP throughput of terminal nodes is influenced by two networks. The two subnetworks: the HSDPA cellular subnetwork and the wireless ad-hoc subnetwork all impact on the performance of the integrated networks, however, the original existed scheduling mechanisms of the Node B schedule only consider the HSDPA subnetwork but not the ad-hoc subnetwork at all. Thus, we propose a new scheduling scheme that not only considers the HSDPA subnetwork, but also the ad-hoc subnetwork is considered in scheduling factor selection. As long as the GWs are scheduled also according to the ad-hoc subnetwork, the first task is that how to gain the hop count and the error rate in each wireless ad-hoc subnetwork. We modify the physical layer of the GW node so as that it can directly get the ad-hoc subnetwork information and transmit back to the Node B to reschedule each GW in terms of the two subnetworks.

Further, since the information about the wireless ad-hoc networks subnetwork 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 this information on the ad-hoc subnetwork compared to the original ones that only consider about the HSDPA subnetwork as the referring factor of scheduling all the UEs. This new scheduling mechanism adjusts the selection probability (scheduling ratio) of each GW based on the three information sources: the channel condition in HSDPA subnetwork, the hop count and the error rate in ad-hoc subnetwork 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, based on simulation results, we investigated to what extend our proposed mechanism can improve the system performance. Several simulation scenarios are designed to check if the new scheduling scheme reaches the design goal to achieve fairness in TCP throughput. Through our investigation work, the new scheduling mechanism has made the improvement as much as 12% in certain scenarios in the term of Jain's fairness index.

5.2 Future work

Future work on the integrated networks includes multiple gateway nodes and multiple flows. Because only one TCP version has been investigated in this thesis, other TCP versions and UDP can be studied. In order to make the result representative, we set the MAC mode of the ad-hoc subnetwork as CSMA/CA. The RTS/CTS mode can be configured as the MAC of the ad-hoc subnetwork to research on the integrated networks with multiple gateways. Besides, we will investigate Round Trip Time. However, the delay metric for this network is also important, so the Round Trip Time can be done to gain the further information on the integrated networks with multiple gateways.

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. In the new scenarios, not only the hybrid UEs (i.e. GW) can move freely, but the other general Mobile Node (MN) should be able to move freely. 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 subnetwork. 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 subnetwork. At that time, the dynamic topology will be closer 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
I	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-Subnetworks-Dependent Scheduling
GW	Gateway
HSDPA	High Speed Data Packet Access
HS-DSCH	High Speed Downlink Shared Channel
IEEE	Institute of Electrical and Electronic 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 rea 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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