Distributed Resource Allocation for Hybrid Networks

——Report 2 for project

By : **Gao Junwei** **Xu Mengran** **Hu Xiuwen** **Sara**

May 6, 2008

Contents

1 Abstract

Depending on whether or not there is a fixed infrastructure, wireless systems can be categorized as cellular systems or ad hoc *networks. A cellular system has a fixed infrastructure in the form of a base station which performs central administration for the system.* Ad hoc *networks have no fixed infrastructure and the network architecture is configurable. The next generation(4G)networks[1] will employ hybrid network architectures using both cellular and ad-hoc networking concepts. Thus, how to effectively allocate the two different communication resources is an important problem. In this paper, we will investigate the strategies existed and compare with their characteristic in theory and simulating. Then make a conclusion which is the most effective strategy or even find out our fairly new method.*

2 Introduction

In the wireless communications community we are witnessing more and more the existence of the composite radio environment (CRE) and as a consequence the need for reconfigurability concepts. The CRE assumes that different radio networks can be cooperating components in a heterogeneous wireless access infrastructure, through which network providers can more efficiently achieve the required capacity and quality of service (QoS) levels. Reconfigurability enables terminals and network elements to dynamically select and adapt to the most appropriate radio access technologies for handling conditions encountered in specific service area regions and time zones of the day. Both concepts pose new requirements on the management of wireless systems. Nowadays, a multiplicity of radio access technology (RAT) standards are used in wireless communications.

2.1 background

cellular network A cellular network consists of a collection of mobile stations served by a central coordinating entity called the base-station. In a cellular network, mobile stations communicate directly with base stations to the wired network. Cellular wireless networks have experienced tremendous growth over the last decade, and this growth continues unabated worldwide.

However, there are some disadvantages of cellular wireless network that impede the progress of cellular networks: First, it.s hard to provide full coverage and dead zones might appear. Second, the availability of network is easily downgraded in cells where there are too many mobile stations using the network and the system is overloaded.

Peer to Peer—ad hoc network To overcome the limitations of cellular wireless networks, an interesting solution proposed by some research works is to use a combination of the cellular network model with the a peer-to-peer network model called ad-hoc networks, which results in a hybrid wireless network. In hybrid wireless network, multi-hop paths between mobile nodes and base stations can extend the coverage of the network and provide alternatives to communicate via the network when the system is overloaded.

For a long time ,cellular networks and ad-hoc networks have been extensively studied individually, because of their individual characteristic.

- A cellular system has a fixed infrastructure in the form of a base station which performs central administration for the system. Cellular networks provide the information transport platform for wireless local area networks(WLANs) and wireless wide area networks(WWANs). Wireless LAN standards activities have been spearheaded by IEEE 802.11, while wireless WAN standards activities have been led by ANSI(American National Standards Institute) and ITU(International Telecommunications Union).
- *Ad hoc* networks have no fixed infrastructure and the network architecture is configurable. Every node(mobile) in the *ad hoc* network can set up as, and play the role of, a base station in that it can directly transmit to and receive from other nodes in the network.
- The cellular network is more reliable and has better performance. It include second-generation (2G) mobile systems, such as Global System for Mobile Communications (GSM), and their evolutions, often called 2.5G systems, such as enhanced digital GSM evolution(EDGE), General Packet Radio Service (GPRS) and IS–136 in the USA. However, the ad hoc network topology is more desirable because of its low cost, plug-and-play property, flexibility, minimal human interaction requirements, and especially battery power efficiency. It is suitable for communication in a closed area - for example, on a campus or in a building.

2.2 Hybrid network

Cellular wireless networks have experienced tremendous growth over the last decade, and this growth continues unabated worldwide. So the cellular wireless network has made a success, however, there is some limitations in itself obstructing its progress: First, it's hard to provide full coverage and dead zones might appear. Second, the availability of network is easily downgraded in cells where there are too many MSs using the network and the system is overloaded.

Future generation[1] wireless systems are expected to provide ease of deployment, spectral efficiency, dynamic adaptation to the working condition and QoS mechanism support. The embedding of all such requirements inside innovative systems needs a careful and joint design of different layers. With the rapid development of wireless communication technology, such a single cellular system can't perform our aim, unless the limitations disappear.

To overcome the limitations of cellular wireless networks, an interesting solution proposed by some research works is to use a combination of the cellular network model with the a peer-to-peer network model called ad-hoc networks, which results in a hybrid wireless network. In hybrid wireless network, multi-hop paths between mobile nodes and base stations can extend the coverage of the network and provide alternatives to communicate via the network when the system is overloaded.

While cellular networks and ad-hoc networks have been extensively studied individually, hybrid wireless networks bring new challenges in traffic modeling and performance evaluation. Traffic in hybrid networks can be both within the *ad hoc* network, and to or from nodes in the cellular network. Similar to cellular network, several parties and applications such as conferencing, web browsing and email checking are supposed to share the network. Different applications have different configuration and performance requirements, so resource allocation is an important component of such networks, and proper simulation tools are needed to test and find appropriate resource allocation schemes.

In hybrid networks the concepts of cellular networks and mobile ad-hoc networks are mixed. On one side we have a cellular network, on the other side there are mobile nodes with routing facilities. Since UMTS/802.11 *ad hoc* network is a typical representative of hybrid wireless networks, this combination will also be adopted in this thesis to implement the simulator for hybrid networks. Therefore, we present the technologies of UMTS network and 802.11 ad-hoc network in the following sections to give readers a basic understanding of hybrid network.

2.3 Challenge to face

In Future Generation wireless networks, diverse wireless technologies such as Cellular, WLAN, and Bluetooth will proliferate in different edges of the Internet and complement each other to provide untethered multimedia services and seamless visits to the IP-core network. Most wireless access technologies are deployed in either infrastructure based cellular mode or infrastructure-less ad hoc mode. While each access mode was initially designed with distinct characteristics, many recent efforts are underway to define hybrid networks, that combine the advantages of both access modes [1, 21, 2, 9]. These approaches to hybrid networks can be classified as either "ad hoc over cellular" or "cellular over ad hoc" . In our work, we focus on "ad hoc over cellular" approach that aims to "stretch" the reach of cellular networks, and integrate high speed access, global coverage and roaming support into a single seamless system. These concepts motivate the ODMA option in 3GPP (Opportunity driven multiple access). Among the challenges in the hybrid wireless networks, is optimal resource management of diverse radio resources, from the perspectives of both the users and the service provider. Hybrid network radio resources often include "cellular" capacity (licensed frequency spectrum centered around fixed base stations) in addition to "ad hoc" capacity (unlicensed frequency spectrum limited by interference local to each mobile). Furthermore, hybrid network models, that employ user equipment to serve as mobile relays, must include resulting usage costs into resource management. In earlier work, resource-utility (R-U) functions were employed and a Time-Aware Resource Allocation (TARA) scheme was proposed for Quality of Service (QoS) resource allocation in cellular networks. TARA maximizes the accumulated utility of the whole cell (over time) in an adaptive way. In this paper, we continue to use utility functions to characterise the bandwidth of the cellular link (as the bottleneck resource). Moreover, we extend the approach to model additional resources at the ad hoc nodes. That is, we consider non-critical resource usage (such as power usage, processing capacity and bandwidth of the ad hoc link) at the relaying user equipment and model it as a cost function. Two resource allocation algorithms result from this study. First, a centralized optimal allocation algorithm based on linear programming is formulated. Second, a distributed heuristic algorithm is formulated that attempts to perform close to the optimal solution with considerably lower runtime complexity. The simulation analysis, using the J-Sim simulator, illustrates the performance gains in "ad hoc over cellular" hybrid networks. It demonstrates the capability of the proposed heuristic algorithm to efficiently utilize resources in the hybrid radio context and provide benefits such as load-balancing and fault tolerance.

2.4 Future strategy

To combine their strength, possible 4G concepts might prefer to add BSs to an *ad hoc* network. To save access bandwidth and battery power and have fast connection, the MHs could use an *ad hoc* wireless network when communicating with each other in a small area. When the MHs move out of the transmitting range, the BS could participate at this time and serve as an intermediate node. The proposed method also solves some problems, such as a BS failure or weak connection under *ad hoc* networks. The MHs can communicate with one another in a flexible way and freely move anywhere with seamless handoff. There have been many techniques or concepts proposed for supporting a WLAN with and without infrastructure, such as IEEE 802.11 [14], HIPERLAN , and *ad hoc* WATM LAN . The standardization activities in IEEE 802.11 and HIPERLAN have recognized the usefulness of the *ad hoc* networking mode. IEEE 802.11 enhances the *ad hoc* function to the MH. HIPERLAN combines the functions of two infrastructures into the MH. Contrary to IEEE 802.11 and HIPERLAN, the *ad hoc* WATM LAN concept is based on the same centralized wireless control framework as the BS-oriented system, but insures that MH designed for the BS-oriented system can also participate in *ad hoc* networking. Both the BS oriented and *ad hoc* networks have some drawbacks. In the BS-oriented networks, BS manages all the MHs within the cell area and controls handoff procedures. It plays a very important role for WLAN. If it does not work, the communication of MHs in this area will be disrupted. Under this situation, some MHs could still transmit messages to each other without BS. Therefore, to increase the reliability and efficiency of the BS-oriented network, MH-to-MH direct transmission capability can be added. However, this is restricted to at most two hops such that this new enhancement will not increase the protocol complexity too much. In the *ad hoc* networks, it is not easy to rebuild or maintain a connection. When the connection is built, it will be disrupted any time one MH moves out of the connection range. So, as a compromise, the MHs could communicate with each other over the wireless media, without any support from the infrastructure network components within the signal transmission range. Yet when the transmission range is less than the distance between the two MHs, the MHs could change back to the BS-oriented systems. MH would be able to operate in both *ad hoc* and BS-oriented WLAN environments. Two different methods C one-hop and two-hop direct transmission within the BS-oriented concept C will be considered. The first method is simple and controlled by the signal strength. The second method should include the data forwarding and implementation of routing tables.

3 Related Works

The idea of hybrid networks has been studied for many years. In May 2003, during the celebrated meeting—*Next Generation Internet Symposium*, many scientists brought forward their research on hybrid networks. Such as "Application-Oriented Routing in Hybrid Wireless Networks"(Yuan Sun et al.). Besides, R.Sivakumar et al.,has worked on using the ad hoc network model in cellular packet data networks. Robert Jonasson, was committing himself to the simulating for resource allocation in future mobile networks.

Several "ad hoc over cellular" approaches such as MCN and iCAR use relays to overcome cellular shortcomings, such as limited spatial coverage, low bit rates, and a high bit cost for data services. Relays, being either static infrastructure or other mobile stations (MS), form a virtual overlay for congestion mitigation and alternate routing to extend and improve coverage of the cellular base stations (BS) . In these hybrid networks, admission control (AC) and bandwidth allocation (BA) schemes for resource management are necessary to ensure QoS guarantees.

Work on resource management for cellular networks often focuses on management of licensed frequency spectrum local to each base station. The work in employs bandwidth borrowing and degradation as part of AC with each connection request submitting acceptable max and min resource requirement. In an AC algorithm is proposed that uses controlled QoS degradation of on-going calls to manages a tradeoff between resource allocation of on-going calls and new calls. A similar tradeoff is managed by an AC algorithm proposed in using Guard Channel policies. AC schemes proposed in consider both "non-prioritized" schemes in which the BS made no distinction between new and HO calls, and two "priority oriented" schemes that allow queuing of handover calls.

Work on resource management for ad hoc networks often focuses on managing the interference, generated by consumption of unlicensed frequencies, local to each MS involved in an ad hoc path between a source and destination node. For example, in a contention-aware AC is proposed which attempts to support QoS guarantees by limiting the number of connections allowed within a neighborhood of nodes. A distributed AC algorithm is introduced in that is based on the concept of a "service curve" to reflect the status of the network (number of active nodes, activity index and contention status). An ad hoc node wanting to establish a new connection must compare the "service curve" with a predefined universal performance threshold curve for QoS purpose.

Variable resource needs and differentiated importance levels of most of the new services decrease the relevance of traditional performance metrics such as blocking/dropping probabilities. Thus, the user-perceived utility might be more suited as performance criterion. As opposed to maximizing the total utility of the system, Rui-Feng Liao et al.[15] provide "utility fair allocation". Their algorithm extends "max-min fair allocation", with utility replacing bandwidth as the fairness criterion.

QoS-aware Distributed Resource Allocation for Hybrid FDMA/TDMA Multicellular Networks[13]. This paper chooses another hybrid aspect. It focus on MAC level. It considers a multicellular network using a hybrid FDMA/TDMA medium access with a complete reuse of the resources among neighboring cells. The resource allocation mechanism runs in a completely distributed way, tracking the traffic dynamics, adapting itself to the channel and interference condition and providing QoS differentiation among different traffic classes. The proposed algorithm performs both spectral efficiency optimization, by exploiting information on channel and interference, and traffic differentiation at MAC level, by means of a weighted share of the bandwidth among different priority traffic flows. The traffic differentiation mechanism, which is the original contribution presented in this paper, works locally on each cell but exploits values of interference measurements in order to acquire information on the neighboring cells load, with the goal of implementing a collaborative algorithm. Interference measurement is the only form of communication among cells and no explicit signalling is assumed. The aim of the proposed algorithm is to provide traffic differentiation at the MAC level in a global perspective, where the share of the bandwidth inside a cell depends also on the priority of the traffic in the surrounding cells. Finally, the algorithm is tested and validate on a multicellular network with a static and a timeCvariant channel, thus confirming its behavior.

4 Hybrid wireless Network

In hybrid networks the concepts of cellular networks and mobile ad-hoc networks are mixed. UMTS/802.11 ad hoc network is a typical representative of hybrid wireless networks.

4.1 UMTS Network

UMTS is the abbreviation for Universal Mobile Telecommunications System. It is one of the third generation (3G) digital cellular networks. A UMTS network consists of three interacting domains: Core Network (CN), UMTS Terrestrial Radio Access Network (UTRAN) and User Equipment (UE). The main function of the core network is to provide switching, routing and transmission for user traffic. UTRAN provides the air interface access method for User Equipment. Two new network elements are introduced in UTRAN: Node B and RNC. Base Station is referred as Node- B and control equipment for Node-Bs is called Radio Network Controller (RNC). UTRAN is subdivided into individual radio network systems (RNSs), where each RNS is controlled by an RNC. The RNC is connected to a set of Node B elements, each of which can serve one or several cells.

Node B is the physical unit for radio transmission/reception with cells. Depending on sectoring, one or more cells may be served by a Node B. Node B connects with the UE via the Uu radio interface and with the RNC via the Iub interface. 7 The main task of Node B is the conversion of data to and from the Uu radio interface. It also measures quality and strength of the connection, transmitting these data to the RNC as a measurement report for handover and macro diversity combining.

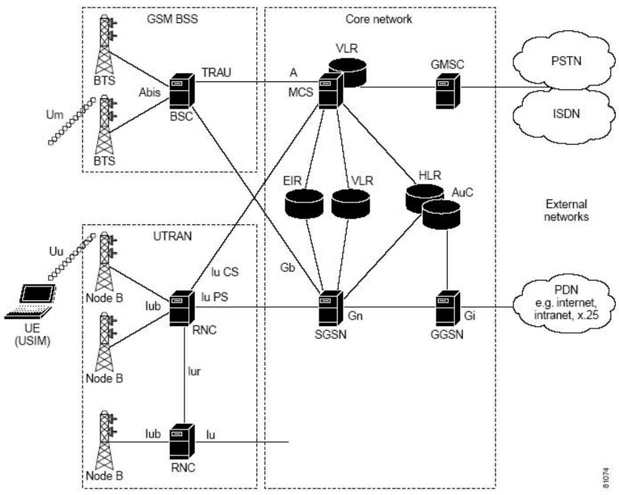

Figure 1: UMTS Architecture

RNC , its main mission is to manage and optimize the radio network resources and to control mobility. It is the equivalent of the base station controller (BSC) in GSM networks. To this thesis radio resource management is the most interesting task of the RNC. In our simulator, the RNC contains the resource allocation algorithm as its child component that actually implements the resource management functions including Admission Control, Channel Switching, RRC Connection Setup and Release, Handover.

4.2 Mobile Ad hoc Network

A mobile ad-hoc network (MANET) is a system of wireless mobile nodes dynamically self-organizing in arbitrary and temporary network topologies. People and vehicles can thus be internetworked in areas without a preexisting communication infrastructure, or when the use of such infrastructure requires wireless extension. In a MANET, mobile nodes can talk to each other directly via peer-to-peer wireless communication when they are within each other's transmission range. When direct communication is not possible between sender and receiver, their packets can be forwarded by the intermediate nodes along a multi-hop path. As a result, each node in a MANET behaves not only as an end system to the users, but also as a router to forward packets for other nodes. There are neither fixed routers nor fixed locations for the routers as in cellular networks - also known as infrastructure networks. Cellular networks consist of a wired backbone that connects the base-stations. The mobile nodes can only communicate over a one-hop wireless link to the base-station, multihop wireless links are not possible. By contrast, a MANET has no permanent infrastructure at all. All mobile nodes act as mobile routers. A MANET is highly dynamic. Links and participants are often changing and the quality of the links as well .

4.3 Hybrid Wireless Network Architecture

A hybrid network is formed by placing a sparse network of base stations in an ad hoc network. These base stations are assumed to be connected by a high-bandwidth wired network and act as relays for wireless nodes. They are not data sources or data receivers. Hybrid networks present a tradeoff between traditional cellular networks and pure ad hoc networks in which data may be forwarded in a multi-hop fashion or through the infrastructure.

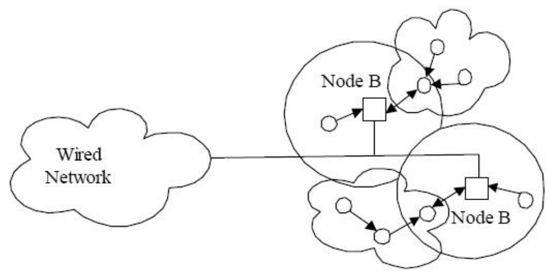

Figure 2: A Hybrid Wireless Network

In a hybrid wireless network, a UE contains two primary interfaces: one is the UMTS interface that communicates with base stations via the Uu interface, the other is the wireless interface that enables it to exchange messages with other user equipments by the IEEE 802.11 standards.

4.4 Resource Allocation

Resource allocation is done to ensure an efficient use of resources in the network. In a 3G network the resources include transmitting power, frequency channels and so on. This thesis addresses bandwidth allocation only. The simulator could in principle be expanded to include allocation schemes that deal with other resources as well. Bandwidth for a connection is allocated at connection setup and kept through the duration of the connection. Bandwidth is possibly changed when the connection is handovered from one cell to another cell, since available bandwidth in the new cell might be different from that in the original cell. In this thesis, connections are categorized into several types of service or application. Different types of service or application have different bandwidth requirements. In the existing wireless simulator for cellular networks, bandwidth is reserved for a connection by the RNC over the cellular link between UE and Node-B. The amount of the reservation is determined by the resource allocation algorithm in RNC according to the service type of the connection. Resoruce allocation is implemented the same way in the new simulator. In other words, bandwidth for a connection is only reserved over cellular link, 15 which may be counter intuitive. After all, due to the existence of multi-hop connection in hybrid networks, it seems that the bandwidth management in the new simulator should be applied not only to cellular links but also to ad hoc links. However, in the new simulator, it is assumed that bandwidth of ad-hoc links is always much larger than that of cellular links. Thus the cellular link becomes the bottleneck of bandwidth management for a multihop connection. As a result, bandwidth management in the new simulator is limited to cellular links, just as the existing simulator.

5 Resource Allocate

5.1 RESOURCE MANAGEMENT IN 4G

An integrated bandwidth management approach is nowpresented that can be implemented in next generation wireless networks that support multimedia services (data, voice, video, etc.). The main principles of the approach are summarized as follows:

1. The system supports multiple classes of service that require various levels of quality that may range from strict to flexible and soft QoS requirements.

2. Advanced bandwidth reservation is performed to the cell a mobile user is moving towards in order to assist and support a seamless handoff process.

3. User mobility is introduced into the reservation scheme and process in order to optimize the efficiency of handoff mechanisms and minimize, if not eliminate, the unnecessary reservation of resources and, therefore, improve the system capacity and throughput.

4. Bandwidth reconfiguration processes are used that may allow the efficient resource redistribution in a cell to satisfy the QoS requirements of all the mobile users in the cell, especially when users with flexible QoS requirements are supported in the system.

5. A mobile agent based framework is used to facilitate the efficient implementation of the above integrated approach.

One of the elements in future resource management is mobile locationing and tracking. Position location technology can be loosely classified into two major categories: mobile-based solution and network-based solution. The global positioning system (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. As an alternative to mobile-based approaches, cellular networks can be used as the sole means of providing location services, where the MSs are located by measuring the signals traveling to and from a set of fixed cellular BSs. The signal measurements are used, for example, to determine the length and/or direction of the individual radio paths, and then the MS position is computed from geometric relationships. Basically, radiolocation systems can be implemented based on either signal strength, angle of arrival (AOA), or time of arrival (TOA) measurements or their combinations . However, there are several problems associated with the existing network-based geolocation systems which limit and prevent the use of location information of mobile users for network management purposes.

- The triangulation measurement data collecting procedure is quite complicated. At least two or three BSs should be involved in locating the position of a mobile user. Each BS will perform some triangulation measurement.

- All this data has to be sent to some device to carry out the calculation. This procedure requires some specialized protocol to support the information exchange. This also would waste some bandwidth in data transmission and introduce some delay to the overall location algorithm. Nowadays, for some practical systems, it may take several seconds to locate a mobile user. So, if the user moves with high speed, we cannot obtain an accurate position information, in real time. Furthermore, performing the calculation at BS instead of MS raises some difficulties in obtaining accurate radio parameters of an MS that may vary with time and position.

- If all the mobile users in the network need geolocation information, the computational load at one BS becomes very heavy. Such an overload condition may lead to high processing delays or failures of the location module in the BSs. By moving the measurement and calculation function to the mobile station, all the information needed for the geolocation can be gathered almost at one time and then be treated locally.

In order to allow the geolocation system to have more flexibility so that the MS can smoothly roam among different networks with different geolocation approaches, a mobile agent-based system framework can be used. The use of an approach based on code-on-demand increases the flexibility of the system and maintains agents simple and small at the same time. In this section, one of the basic ideas introduced is that, when the MS is turned on or roaming into a network with different geolocation approach, it sends a message agent (MA) to the BS. Then, the BS will generate a geolocation agent (GA) and send it to the mobile station. The GA should contain the signal processing algorithm for signal measurement and the triangulation algorithm. By using this framework, mobile stations can obtain all the data for triangulation calculation almost at the same time and carry out the geolocation calculation locally.

5.2 Bandwidth allocation in hybrid networks

In this section we explain the system model used for our utility maximization scheme. We start from a classic cellular network model, where in each cell a base station (BS) serves the mobile stations (MSs) inside the covered area. MSs can connect to the BS using the direct cellular wireless link. In addition, we assume each MS is equipped with a second wireless interface that can be used to connect to other MSs in an ad hoc manner. We consider the two spectra (cellular vs. ad hoc) to be in different bands, the cellular using a narrower, highly regulated band while the ad hoc belongs to a broader, reusable, unregulated band. Thus, there is no interconnection/interference between the two bands. At a certain point in time, a MS can connect to a BS directly through the cellular link, or relay via ad hoc paths using other MSs, and further through the cellular interface of the last MS in the path. Figure 1 presents an example. The ad hoc network serves only as an extension for the cellular network, with most of the function (allocation, security, billing, etc.) located in the nodes of the cellular network. Regarding the bandwidth allocation problem, we make the following observation: The bandwidth of the ad hoc network is usually more than one order of magnitude greater than the bandwidth of the cellular network. E.g. today the bandwidth of a 3G base station is 2 Mb/s while the bandwidth of 802.11g is 40Mb/s. Therefore we consider, the cellular link bandwidth as the bottleneck resource of the hybrid system, which makes the ad hoc links' bandwidth virtually unrestricted in comparison. Though we consider the bandwidth of the BS as bottleneck, in an optimized allocation we have to consider the effects of using the ad hoc paths. First, there is increased resource consumption on the relaying MS such as battery energy and processing power. We assume that users would appreciate some incentive for letting other connections use their MS. Second, there is the problem of the weaker QoS offered by the ad hoc route. Delay increases with hop count. Moreover, an ad hoc path might get disconnected due to mobility. We model these relay costs and QoS losses with the help of a path dependent cost that is proportional to the number of ad hoc hops and the amount of traffic sent on that path. From a pricing viewpoint, we can regard the utility functions as proportional to the rates the user is willing to pay for a certain connection. In the same manner, incentives proportional to the per hop costs could be regarded as reimbursements to the owner of the MS used as relay.

In order to establish an end-to-end connection the algorithm must choose among a set of reachable BSs, and for each BS there might be several ad hoc paths available. Taking into account the above cost model, it is obvious that the shortest (in the number of hops) ad hoc route to a BS has also the lowest costs. Thus, the path choice in our scheme consists of two phases. First, a shortest path first routing algorithm is employed to find the best paths from an MS to a set of near BSs. A BS is considered near if a shortest path exists, given that the hop-count does not exceed a certain threshold value. Second, the allocation algorithm will use this set of paths in the optimized allocation.

5.3 Hybrid algorithm

For this part, we have read many references, but the kinds of algorithm are so large and difficult for us that it still need a long time. Nowadays, we focus on *Hybrid-heuristic Algorithm*[16].

6 Simulated and Experimental Result

7 Conclution

8 References

1. Savo G. Glisic University of Oulu, Finland. *Advanced Wireless Networks 4G Technologies.* John Wiley Sons, Ltd.

2. Chuan Heng Foh, Moshe Zukerman and Juki Wirawan Tantra. "A Markovian Framework for Performance Evaluation of IEEE 802.11," in *Proc. IEEE Transactions On Wireless Communications, vol.* 6, NO. 4, APRIL 2007.

3. C. H. Foh and M. Zukerman, "Performance evaluation of IEEE 802.11," in *Proc. IEEE VTC Fall*, May 2001.

4. A. Grilo, M. Macedo, and M. Nunes, "A scheduling algorithm for Qos support in IEEE 802.11 networks," *IEEE Wireless Commun., vol.* 10, no. 3, pp. 36-43, June 2003.

5. Sri Harsha, Anurag Kumar, and Vinod Sharma, "An Analytical Model for the Capacity Estimation of Combined VoIP and TCP File Transfers over EDCA in an IEEE 802.11e WLAN".

6. Tao Li, Dimitris Logothetis, and Malathi Veeraraghavan, “Analysis of a Polling System for Telephony Traffic with Application to Wireless LANs” *IEEE Transactions On Wireless Communications, vol.* 5, NO. 6.

7. Mustafa Ergen and Pravin Varaiya, “Formulation of Distributed Coordination Function of IEEE 802.11 for Asynchronous Networks: Mixed Data Rate and Packet Size” in *IEEE Transactions On Vehicular Technology, vol.* 57, NO. 1.

8. Deyun Gao, Jianfei Cai, Chuan Heng Foh, Chiew-Tong Lau, and King Ngi Ngan, “Improving WLAN VoIP Capacity Through Service Differentiation” in *IEEE Transactions On Vehicular Technology, vol.* 57, NO. 1,

9. Zhigang Wang, Lichuan Liu and MengChu Zhou, “Space and Network Diversity Combination for Masked Node Collision Resolution in Wireless Ad Hoc Network” in *IEEE Transactions On Wireless Communications, vol.* 6, NO. 2,

10. H. Zhai, J. Wang, X. Chen, and Y. Fang, “Medium access control in mobile ad hoc networks: challenges and solutions,” J. Wireless Commun. and Mobile Comput., special issue on ad hoc wireless networks, accepted for publication.

11. K. Kwon, Y. Fang, and H. Latchman, “Design of MAC protocols with fast collision resolution for wireless local area networks,” *IEEE Trans. Wireless Commun., vol.* 3.

12. Yu Cheng, Xinhua Ling, Wei Song, Lin X. Cai, Weihua Zhuang, and Xuemin Shen,“A Cross-Layer Approach for WLAN Voice Capacity Planning” in *IEEE journal on selected areas in communications, vol.* 25, NO. 4

13. Simone Merlin, Luca Begnini, Andrea Zanella, Leonardo Badia and Michele Zorzi, “QoS-aware Distributed Resource Allocation for Hybrid FDMA/TDMA Multicellular Networks”

14. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Std. 802.11, Aug. 1999.

15. R. R.-F. Liao and A. T. Campbell. *A utility-based approach for quantitative adaptation in wireless packet networks.* Wireless Networks, Sept. 2001.

16. Calin Curescu, Simin Nadjm-Tehrani, Bing Cao and Teresa A. Dahlberg. “Utility-based Adaptive Resource Allocation in Hybrid Wireless Networks”. Computer society.