WCDMA/WLAN 異質網路之利益函數式網路接取機制

A utility function-based Access Selection Method for Heterogeneous WCDMA and WLAN Networks

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摘要

Third generation (3G)無線通訊系統使用 WCDMA 技術以提供大範圍的無線通訊及高移動性的使用者，但其傳輸率卻不足以提供頻寬給需要高傳輸率的服務；另一方面，WLAN 系統雖可以支援高傳輸頻寬，但只能提供小範圍通訊且不能保證傳輸服務品質(quality of service, QoS)。為了支援高傳輸率的多媒體服務以及高移動性的使用者，一個 WCDMA/WLAN 異質網路被 third generation partnership project (3GPP)所提出。

在本篇論文中，我們針對 WCDMA/WLAN 異質網路中的網路選擇問題，提出一個利益函數式網路接取機制。這項機制可以為每一個使用者上的服務找到一個提供服務的細胞，其中使用者的服務可以分成新產生的服務(new service)及想要換手的服務(handoff service)兩種類型。每個使用者的手持裝置擁有 WCDMA 及 WLAN 兩種無線電頻率模組，因此可以同時連結兩個無線網路系統以完整利用網路資源。我們提出的方法包含了三個步驟，分別是*網路細胞分類*(cells classification)、*利益函數計算*(utility function computation)、以及*目標細胞選定*(target cell determination)。第一個步驟是負責為每個使用者過濾出可以使用的細胞，以確保服務的傳輸連續性，第二個步驟是使用我們所定義的利益函數計算每個細胞的利益值，第三個步驟是為每個服務選定提供服務的細胞，這通常是選擇利益值最大的細胞。我們所定義的利益函數中考慮了以下四個因素：頻寬(data rate)、延遲(delay)、位元錯誤率(BER)，以及移動速度(mobility)。為了要降低負載重的細胞被選到的機率，我們在利益函數中也考慮了目前系統負載狀況的參數，只有當負載狀況超過一被定義的門檻值的時候，此參數值才會有影響。

模擬結果顯示我們所提出的方法可以降低換手(handoff)產生的次數，並維持服務所要求的傳輸服務品質，同時還在系統容量和系統負載之間找到平衡點。最重要的是，根據我們所提出的方法，可以得到比傳統方法還高的總傳輸量。

A Utility Function-based Access Selection Method for Heterogenous WCDMA and WLAN Networks

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Abstract

An interworking WCDMA/WLAN networks is considered to support high-data-rate multimedia services and high mobility. In this thesis, we propose a utility function-based access selection method (UFAS) to determine a cell for serving a service request from mobile node (MN). The proposed method decides the cell selection for initial link selection and handoff decision according to the service QoS requirements while striking a balancing between system capacity and cell loading. It contains three parts, *cells classification*, *utility function computation*, and *target cell determination*. The cells classification filters feasible cells for the MN; the utility function computation calculates utility values of the feasible cells by a utility function; the target cell determination selects a best-fit cell according to the utility values. The utility function of the proposed method comprises of delay, bit error rate, data rate, and mobility evaluation functions. Moreover, in the utility function computation, a balancing index is also adopted to tighten up the QoS requirements so that the chance to select the heavily loaded cells would be reduced. The simulation results shows that the proposed method can reduce handoff occurrence rates and strike a balance between system capacity and system loading while maintaining services QoS requirements. Consequently, the total throughput of the proposed method is larger than the compared method.

誌 謝

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最後我要感謝我的家人一直默默支持著我，尤其是我的父母，謝謝你們的教育與鼓勵，還有我可愛的妹妹，你的支持是我活力的最大來源。

媛玉 謹誌

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Chapter 1

Introduction

1.1 Motivation

Multiple mobile communication systems have been developed for supporting high data rate multimedia services, for example, the enhanced data rate for GSM evolution (EDGE), third-generation (3G) mobile systems, wireless local area network (WLAN) systems and etc. However, no single system can provide full spectrum for all kinds of services. The trend of telecommunication systems is interworking between networks to build a high transmission platform for wireless multimedia services.

In the thesis, interworking between third-generation (3G) mobile systems and wireless local area network (WLAN) systems are considered. 3G systems are able to mitigate the heavy traffic load and supply the mobility issue for WLAN systems [1]; and, WLAN systems can be a complementary radio access technology to 3G systems to provide enough bandwidth and economic benefits [2]. Notably, 3G partnership project (3GPP) has organized task forces to investigate the interworking between WLAN and wideband code-division multiple access (WCDMA) networks [3]. And within the IEEE 80211 community, a task group is organized to define an amendment for IEEE 802.11 standard to support the functionality and interface between an IEEE 802.11 access network and any external network [4].

The WCDMA supports wide coverage and high mobility but only up to 2Mbps data rates. The main driver of WCDMA systems is to provide mobile nodes (MNs) a radio link access to services comparable to those currently offered by fixed networks, resulting in a seamless convergence of both fixed and mobile services. Different types of services, such as voice, data, image, and compressed video are integrated in WCDMA networks. The capacity in WCDMA systems is affected by the number of services because WCDMA networks are interference-limited. Thus, the cell loading in WCDMA networks is important to evaluate the capacity.

On the other hand, the IEEE 802.11 WLAN technology [5] operates on 2.4GHZ or 5GHZ uncoordinated industrial, scientific, and medical (ISM) bands, and hence the charge for using is free except the network infrastructures. WLAN systems provides capacity up to 54Mbps data rates with a radio coverage of 100m or 30m radius in outdoor or indoor environments, respectively. It adopts frequency hopping (FHSS) or direct sequence (DSSS) spread spectrum modulation [6], [7], [8]. Until now, WLAN systems are widely applicable to all business on the spots, such as home, small office, warehousing and hospital.

From the benefits of WCDMA and WLAN systems, 3GPP develops a cellular-WLAN interworking architecture as an add-on to the existing 3G systems and defines it in the 3GPP Release 6 specification [3]. The main objective is to enable 3GPP system operators to provide public WLAN access as an integral component to their subscribers. Thus, in case of 3G system functionalities located behind WLAN, the specification enables the usage of 3GPP system functionalities between subscribers and 3G systems via the WLAN systems, and utilizes 3G system functionalities to complement the functionalities available in the WLAN, such as providing charging means, authentication, authorization, and etc. And another case of when WLAN is seen as a parallel system to the 3G systems, the specification defines the creation of mechanisms for selecting and switching between the WLAN and 3G systems. On the other hand, the task group u in the IEEE 802.11 allows a common approach to interwork IEEE 802.11 access networks to external networks in a generic and standardized manner. And it also indicates what services a network offers for users, authenticates from a cellular network to establish the access link to use a network, presents restricted services (for emergency calls), or simply indicates that it's possible to access a network.

In the 3GPP specification, the process and signaling are defined in details but how to make the access selection is an open issue. The access selection is to decide which network is better for an MN to access networks and transmit data. On the other hand, the main issue in IEEE 802.11u [4] is also the access selection but the solving method is not published yet. In this thesis, we proposed a novel method to make a access selection decision for MNs.

1.2 Paper Survey

The access selection is required to ensure services consistency and continuity to achieve the interworking between WCDMA and WLAN networks. Here, two situations are taken into account, involving initial link selection and handoff decision. The initial link selection is the method of network selection for new services. And the handoff decision is to support service transmission consistency among cells. When the MN roams between WCDMA and WLAN, called vertical handoff [9], the handoff decision needs to consider inter-operability between WCDMA and WLAN.

Apparently, the objective of access selection is to support an MN mobility while supporting MN's minimum quality of service (QoS) requirements are maintained. Both the initial link selection and handoff decision are about the resource allocating utilization, but the ongoing call has higher priority than the new call. The survey of this issue can be focused on handoff decision simply. The generally handoff decision solving method are parted into three types: geographical-based method [1], [10], signal strength hysteresis-based method

[11], [12], and parameter-based method [13], [14], [15], [16].

The geographical-based method is to use the WLAN cell in interworking networks as soon as it is available, which can reduce the monetary cost [1], [10]. The MN will be handed over WLAN networks when the beacon signal is larger than a predefined minimum signal to noise ratio (SNR) threshold. The benefits come from simplicity and low operating cost of WLAN, but the handoff frequency might increase when the MN is at a high speed or roaming in the cell boundary. Thus, the method is usually considered with other issues, for instance, transmission quality. And the threshold is changed dynamically, depending on signal quality and cell loading factors [10].

The signal strength hysteresis-based method is to measure the signal strengths of WCDMA and WLAN networks for a period of time [11], [12]. The handoff decision was based on the measurement of received signal strength from IEEE 802.11 and CDMA systems. It is performed when the amount of continuous received signals reaches to a predefined value. The predefined value is different for real-time and non real-time services since real-time services take handoff delay constraint into account while non real-time services take throughput into account.

The parameter-based method embeds parameters into an evaluation function to determine the target network. The parameters includes the QoS requirements of services, cost, power consumption, and etc. In [13], [14] and [16], a cost function comprising lots of policy parameters to make handoff decisions is proposed, and the network with the lowest cost is selected. The cost function involves weights to indicate the preference of MNs. The handoff is performed while the cost of a cell is the lowest which means that the resource of the cell is the largest in the considered parameters. Balasubramaniam [15] proposed a rule-based vertical handoff process, which also involves the initial link decision. The process adopts four rules to decide whether handoff is necessary. It uses lots of context information to decide handoff requests, and selects a cell according to a locality based network selection process. The method selects other network if its value is larger than the current one. All papers belong to parameter-based methods [13], [14], [15] and [16] defined a method with an attempt to select a network having the most available resources to an MN. Consequently, the remaining resources in the cell may not be enough to supply other MNs and jeopardize other MNs without QoS requirements guarantee. Then, the remaining resources may be wasted and may not be fully utilized. The same consideration is also in service point of view. The defined cost function may not find a network for all services on an MN if the QoS requirements of all services are hard to achieve. But if the access selection selects a network for one service each time until all services on an MN are served, then some services are able to continue the transmission and not be sacrificed.

1.3 Dissertation Organization

In this thesis, we propose a novel utility function-based method (UFAS) for both initial link selection and handoff decision to determine a cell at the basis of a service on an MN. The design strikes a balance between system capacity and cell loading, and also maintains MNs' minimum QoS requirements, even in high mobility. The UFAS method involves three procedures for reducing handoff occurrence rates and maintaining MNs' QoS requirements. It is operated within radio network controller (RNC). The first procedure is the *cells classification* based on the power received at MN to filter the feasible cells into a candidate cell group. The second procedure is the *utility function computation*, which calculates utility values of all cells in the candidate cell group. The final procedure is the *target cell determination* which selects the cell with the largest utility value from the result of the second procedure.

A cell is more likely to be chosen when the provided resources in the cell closes to the required resources of services and is larger than the required resources to fully utilize the network resource an maintain the minimum service requirements. User mobility and QoS requirements including delay, bit error rate (BER), and data rate, are adopted to determine the target cell from candidate cells. Moreover, a balancing index is adopted to reduce the selected probability of heavily-loaded cells, and then the cell loading among cells can be balanced.

The structure of the thesis is as follows. Chapter 2 describes the system architecture, including WCDMA and WLAN systems. It also describes the characteristics of MNs and the source model. Then, chapter 3 describes the utility function-based access selection (UFAS) method which has three steps. The three steps are cell classification, utility function computation and target cell determination. In chapter 4, simulation results are presented and discussed. Finally, concluding remarks and future works are given in chapter 5.

Chapter 2

System Architecture

2.1 WCDMA/WLAN Interworking Architecture

Fig. 2.1 shows a network topology of IEEE 802.11g WCDMA and WLAN interworking systems. The basic service sets (BSSs) in the WLAN networks are called as WLAN cells, and similarly, the cells in the WCDMA networks are WCDMA cells. Obviously, the WLAN networks with small coverage underly the fully-deployed multi-cell WCDMA networks. The WLAN networks act as relay networks of WCDMA networks to support the vacant spaces between the WCDMA service coverage. Moreover, WLAN is specified to serve as a complementary technology to WCDMA in an urban area where the WLAN cells deploy intensively. This is because people move faster in the urban then in the suburban area. In the urban area, the WLAN cells may be built for serving users requiring large bit rates. For this scenario, the WLAN complements the WCDMA networks and alleviates the load congestion so that the system resources are fully utilized and the handoff occurrence rate reduces. For instance, the two WCDMA cells in the right of Fig. 2.1 is the urban area, and the WLAN cells are grouped as a hotspot zone. In the hotspot zone, only pedestrian or slow-moving users subscribe the mobile services requiring high data rates. On the other hand, the left two WCDMA cells in Fig. 2.1 are regarded as the suburban zone, and the WLAN networks are built as hotspots with less chances since only few users subscribe services there.

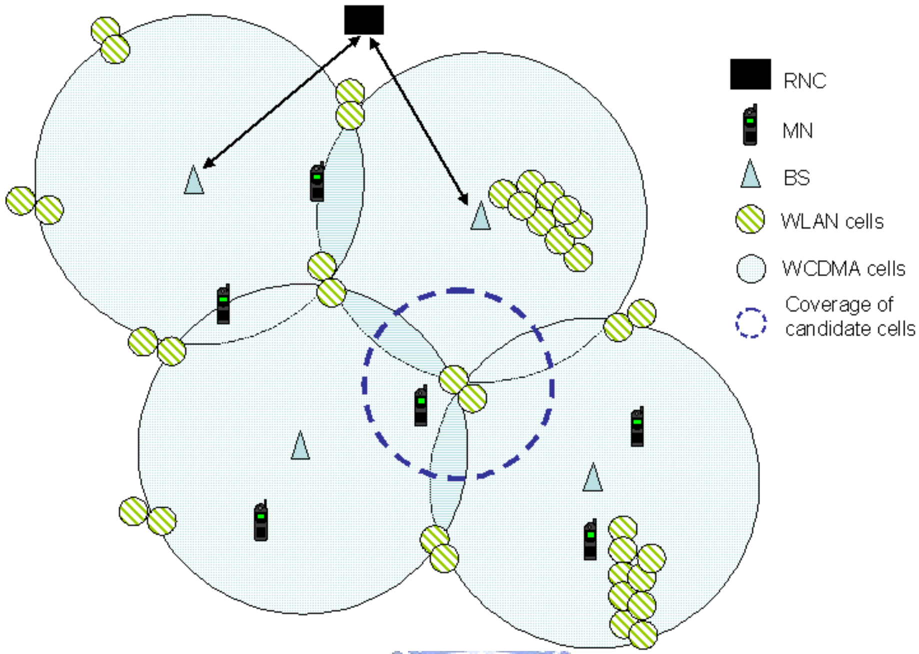


Figure 2.1: The WCDMA and WLAN systems topology.

In the network topology shown in Fig. 2.1, a base station (BS) in each WCDMA cell takes responsibility for communicating with the MNs. In the transmission, excepts receiving/transmitting the data from/to MNs, the BS collects information of MNs, involving MNs' channel quality, MNs' position, MNs' velocity, MNs' services status, and etc. The information are reported to radio network controller (RNC). Thus, the BS and RNC keeps the continuity of the call connection when the MN moves from WCDMA cell to WCDMA cell. The BS also shares its cell loading information to RNC, and then RNC uses its and other neighboring cells's loading information for capacity reservation estimation. For the interference-limited WDCMA networks, the BS needs to control the number of interference in the cell. That is to control the capacity in the WCDMA cell. In the downlink transmission, which is that the BS transmits data to MNs, the interference can be controlled because the number of MNs and the transmission rate are fixed, and the channel condition is estimated. However, in the uplink transmission, which is that MNs transmits data to the BS, the interference is hard to be limited. The interference is called as multiple access interference (MAI) that is generated at the BS by all the uplink signals transmitted by MNs, in either the same or other cells. The interference from other cells is because the MN's position may close to the cell boundary. The signal from the MN may be higher or lead to outage conditions for some of the existing conditions in adjacent cells. An action of call admission control (CAC) scheme is to control the MAI. The CAC scheme regulates the operation of the network so as to ensure the existed service provision to be uninterrupted and accommodate new connections if possible. In our thesis, the CAC scheme is performed by ensuring the total interference is a predefined value higher than the background noise. The predefined value is a threshold load ρ_{th} to limit the WCDMA capacity.

The WLAN access point (AP) acts as the BS in WCDMA networks, providing a simply transmission relay. The MN's information are collected and recorded by the WLAN AP. Behind the AP, a wired core network is used to connect all APs to provide authentication, authorization, accounting, and transmission. This core network may attach to RNC via IP network so that the RNC can collect information in WLAN networks. Two choices to access channel in WLAN networks are distributed coordinator function (DCF) and point coordinator function (PCF). DCF is a slotted binary exponential backoff scheme based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. PCF is an optional mode that is centralized polling protocol controlled by the WLAN AP. To support services with quality requirements, IEEE 802.11e [17] amendments DCF to enhanced DCF (EDCF) and PCF to hybrid coordination function (HCF), respectively. EDCF is also based on CSMA/CA protocol but provides four differentiated priorities for MNs to access. On the other hand, HCF is also adopted the original polling mechanism but more flexible. In this thesis, we assume that MNs uses EDCF mode to transmit data.

An interworking layer is worked in RNC, which has context manager and access selection modules, to collect and exchange the information among all MNs, WLAN cells and WCDMA cells. And two types of service requests, new service request and handoff request, are processed in the interworking layer according to service characteristic. In the interworking layer, the context manager module gathers and manages the information, including the cell capability for QoS requirements, the MNs location, MNs velocity, QoS requirements of services, cells location, cells coverage, and etc. Also it handles the access selection requests invoked by new service and handoff service. The context manager invokes the new service request because the request is originated by the MNs and processed by RNC. It evaluates transmission status from the collected information and invokes handoff request while it is necessary.

When the context manager module invokes requests, the access selection module which also operates within RNC makes decisions by utility function-based access selection (UFAS) method. The decision is not made upon the transmission capability of networks but the utility function which is described in the next section. Notably, the method is not necessary to be performed on all cells in both two networks. For examples, the dash ring in Fig. 2.1 express the candidate cells including two WLAN and three WCDMA cells. The determination of candidate cells are determined by RNC, which is described in the next section.

From the RNC point of view, services are classified by new service request and handoff request. The new service request initiates when the MN asks for service and then a new link connection is required. The handoff request occurs when the MN moves from one cell to another one. Here, the handoff type is the hard handoff but not the soft handoff. Therefore, the case of connecting with more than one BS is not considered in this thesis. Due to the terminal capability, more than one handoff services may be included in the handoff request, named bundle handoff request. It is called single handoff request if the handoff request has only one handoff service. The bundle handoff request happens if only one network can provide services and the MN requires two or more services. The main difference between two types of requests is the content of QoS requirement. The content of single handoff request is the QoS requirement of new service, while the content of bundle handoff request is the union of the QoS requirements of all services in the handoff request

2.2 Mobile Nodes (MNs)

The mobile nodes (MNs) roam around the WCDMA/WLAN interworking networks at any place, any time by two different radio frequency (RF) modules for two radio interfaces. Thus, the dual-mode mobile device with two radio interfaces is able to connect with WCDMA and WLAN networks simultaneously. Moreover, each MN has an MAC layer to combine multiple services into a single data stream so that they can transmit over a single radio interface. When an MN requests a service, the service can choose its target network according to the result by the proposed method as long as the radio modules are available. During the transmitting, the service can be configured to attach to another network for transmission quality consideration. On the contrary, the handoff decision is a totally different situation, which depends on the availability of radio modules. The re-configuration is not allowed because selecting the occupied radio module may degrade the transmission quality of the existed services.

2.2.1 *Mobility model*

Here, the mobility pattern is characterized by the velocity and moving direction of MN. Assume the current position of MN is $\overrightarrow{(x_{(t_a)}, y_{(t_a)})}$ in the observation point t_a, and after a period of observation time T, the MN will be in $\overrightarrow{(x_{(t_b)}, y_{(t_b)})}$ where $t_b = t_a + T$ is the next observation point. It is formulated as,

$$\overrightarrow{(x_{(t_b)}, y_{(t_b)})} = \overrightarrow{(x_{(t_a)}, y_{(t_a)})} + \nu T \cdot d, \tag{2.1}$$

where d is the unit vector of the MN's moving direction, and ν is the velocity of the MN. The vector d of the MN in the urban area is different to in the suburban area because the streets in the urban area are often in a planning chart. Thus, d in the urban area is $(1, 0), (0, 1), (0, -1)$ with $\frac{1}{3}$ probability on each while in the suburban area is $(1, 1), (1, -1), (-1, 1), (-1, -1)$ with $\frac{1}{4}$ probability on each as shown in Fig. 2.2. The reason of the given value is that the MNs move either in going straight or in turning 90 degrees around the corner following the street deploying in the urban area; and on the contrary, the MNs in the suburban area moves randomly. Three velocities are adopted: 3 kilometers maximum per hour for pedestrians, and 40 kilometers and 80 kilometers maximum per hour for vehicles. When the MN hits the boundary of system coverage, the MN's position will be reset to a randomly given position where is not alike the original home cell.

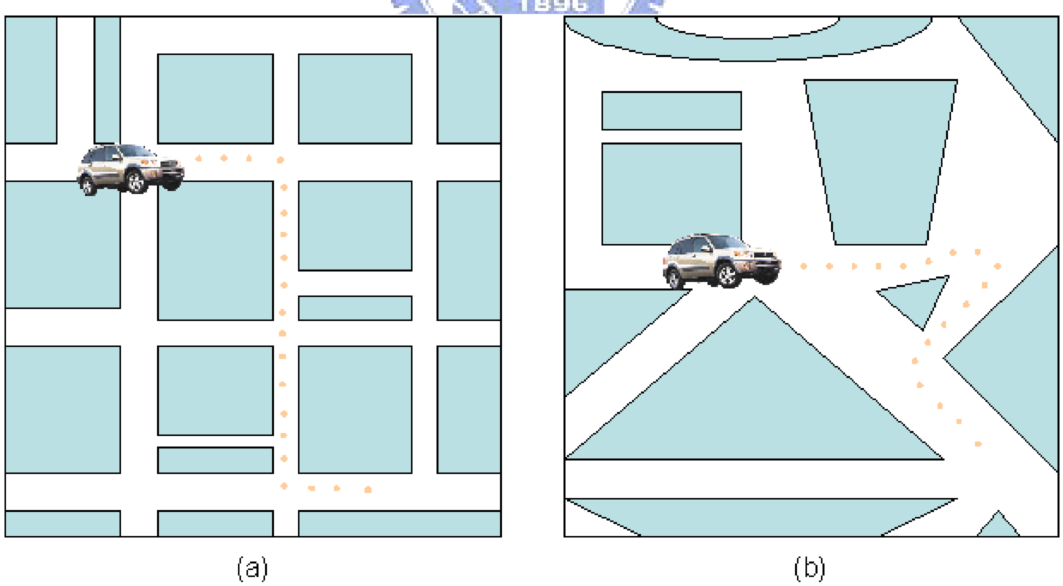


Figure 2.2: (a) Mobility scenario in the urban area, and (b) Mobility scenario in the suburban area.

2.2.2 *Service classes*

3GPP [18] defines four traffic classes, which involves conversational class, streaming class, interactive class and background class. The conversational class represents real-time multimedia applications such as telephony and video. The steaming class is for streaming type of applications, like video on demand (VOD). The interactive class includes applications for Web-browsing, chat room, etc. The background class involves others services that uses best effort transmission. In the thesis, four traffic classes are clustered into two groups, real-time group and delay-tolerant group. As implied by the name, the real-time group includes most delay sensitive applications which involves conversational and streaming class. Compared to the real-time group, the delay-tolerant group cares data error rate more, which includes interactive and background class.

According to the service requirement in real-time group, the QoS constraints contain low delay, low bandwidth variation, handoff frequency and low jitter. Also the real-time group is able to tolerant to a certain level of packet loss. On the other hand, the QoS constraints of delay-tolerant group include data integrity, high bandwidth and packet loss to have a reliable transmission. The transmission rate variations are allowed in delay-tolerant group. Here, we consider voice service and Web-browsing as representative services of real-time group and delay-tolerant group, respectively. We adopt user mobility and QoS requirements, involving delay, bit error rate and data rate, for the utility function.

2.3 Source Model

As mentioned before, voice and Web-browsing services are considered in the thesis. The source models of these services are shown below.

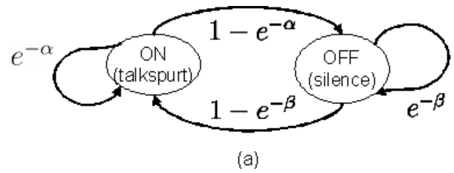


Figure 2.3: A pattern of on-off voice model.

2.3.1 *Voice service*

Packet voice streams are based on the classic on-off model as shown in Fig. 2.3. This assumption is based on the observation that the human speech is decomposable in talkspurt (ON) and silence (OFF) period, where α and β are the mean of talkspurt and silence periods, respectively. The two periods are assumed to be exponentially distributed.

2.3.2 *Web-browsing service*

A Web-browsing session model is shown in Fig. 2.4 [19]. The session is composed by

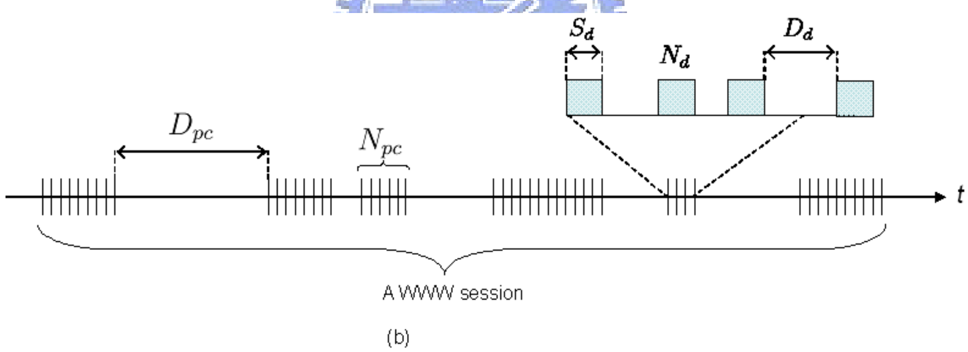


Figure 2.4: A pattern of Web-browsing session model.

number of packet calls and the reading time for simulating the behavior of Internet surfing. When the MN clicks a link on Internet, a packet call including a number of datagrams is transmitted to the MN via the wireless medium. After the MN downloads the information, a period of reading time is needed to digest the information. The length of packet call N_{pc} is generated by geometrical distribution with mean $\kappa_{N_{pc}}$. The packet calls are separated by reading times D_{pc} which simulates the user's studying the information and are also exponentially distributed in mean time $\kappa_{D_{pc}}$. During a packet call, the number of datagrams N_d is geometrical distributed, whose mean is κ_{N_d}. The size S_d of a datagram is Pareto distributed, and is generated with mean κ_{S_d}. The datagrams are parted by inter-arrival times D_d which is also in geometrical distribution with mean κ_{D_d}. In the simulations, we assume that the dwell time of a WWW session is exponentially distributed and the Web session arrivals is based on Poisson distribution.

Chapter 3

Utility Function-based Access Selection (UFAS) Method

3.1 Introduction

The utility function-based access selection (UFAS) method contains three parts, *cells classification*, *utility function (UF) computation*, and *target cell determination*. As shown in Fig. 3.1, for a request from the context manager module within RNC, the *cells classification* is to filter out unfeasible cells for the MN. Every cell in the candidate cell group comes through the *UF computation* to get its utility value. Based on the utility values, the *target cell determination* selects a best-fit cell for the service on an MN. In the following subsections, each part is described in details.

3.2 Cells Classification

RNC classifies the cells before the UF computation for services and forms a group of candidate cells. This classification can speed up the cell selection and provides a suitable and reasonable access decision. Three constraints are adopted to select cells into the candidate cell group, including signal strength constraint, cell admission constraint and terminal capability constraint. Define n as the cell index, which is jointed into the candidate cell group N

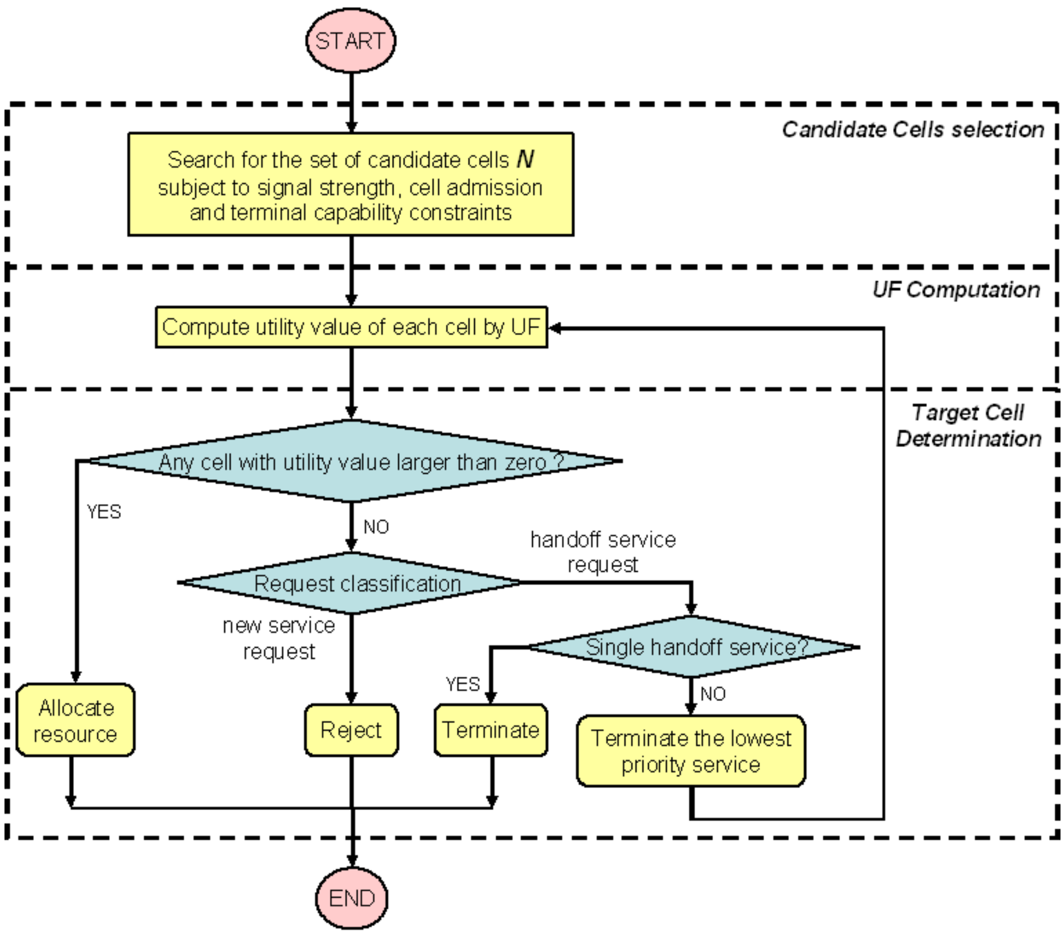


Figure 3.1: The UFAS method procedure

when cell n passes the three constraints according to service characteristics.

3.2.1 *Signal strength constraint*

For an MN, if the strength of pilot or beacon signal from the BS is too small or the distance between the MN and the BS is too far, the cell associated with the BS is not useable. The MN measures the signal strength around in order to filter the cells with enough power out, that is, to eliminate the cell on the far side or the cell with deficient signal strength. If the received signal strength from cell n, denoted by PW_n, exceeds a given power threshold, the cell is classified as feasible. Since WLAN networks differ from WCDMA networks, the predefined signal strength threshold would be different.

3.2.2 *Cell admission constraint*

This constraint is used to check that the admittance does not sacrifice the quality of the existing connection. The admission control functionality is located in RNC. The cell loading of the WCDMA cell n, ρ_n, is derived in the Appendix A. Similarly, ρ_n for WLAN cell n is derived in the Appendix B. The constraint is designed to hold the cell loading to be under a predefined threshold load ρ_{th} to ensure the request can be accepted by the CAC scheme.

In WCDMA networks, the threshold load ρ_{th} is related to the radio network planning, cell capacity and coverage [20]. For instance, the operator sets the cell loading ρ_{th} to be 0.6 in average. When a new service comes and wants to enter the cell, the admission control calculates the effect of this service on the cell loading to ensure the loading of cell n ρ_n will not over ρ_{th}. The increasing load ΔL of the service is denoted by,

$$\Delta L = \frac{1}{1 + \frac{W}{(E_b/N_0)\cdot R\cdot \upsilon}}, \tag{3.1}$$

where W is the chip rate, (E_b/N_0) is the required spectral efficiency of the service, υ is the assumed voice activity factor of the service, and R is required bit rate of the service.

Notably, the value of R for new service request is the bit rate of the new service, and for handoff request, it is the total bit rates of the handoff service.

In WLAN networks, the increasing load ΔL is the required data rate of service s. The current load is derived in the Appendix B. Notably, the threshold load ρ_{th} is 1.0 so that the current load is the upper bound for the next time since WLAN networks do not have capacity limitation.

By allowing the service into the cell, the RNC does remove the cell from the candidate cells if the load is larger than ρ_{th},

$$N_{WCDMA} = N_{WCDMA} \setminus \{n\}, \text{ if } \rho_n + \Delta L >= \rho_{th}. \tag{3.2}$$

Usually, the call admission control strategy has two different thresholds according to two service request types, ongoing call (handoff request) and new call (new service request). Notably, the ρ_{th} for the handoff request will plus a reservation margin since blocking of new call attempts is more tolerable than forced termination of ongoing calls. The margin is also set by radio network planning [20].

3.2.3 *Terminal capability constraint*

The final constraint reflects the radio module capability and also has different determination on two service request types. By this constraint, the candidate cell group N for the service on an MN is determined. Due to the terminal capability, the candidate cell group is determined based on the condition of radio module occupancy. The determination of N for these cases is described as follows.

The handoff service can hand off any cell of the current network. The cell that uses the free radio module is also considered since it can support the handoff service. Contrarily, for the new service, the selection of candidate cells depends on the free radio modules. When MN opens his first connection, the new service can select any cell from WCDMA and WLAN networks. If the MN has already used services and then invokes an new one, the cell that currently in use can not be changed or the existed services may be blocked. Hence, the cell that currently in use is a choice and other choice depends on the free radio module. Moreover, if both radio modules are occupied, then the new service needs to join into the existed connection to avoid other existed services' blocking.

3.2.4 *Illustration of Cell classification*

In the following, we listed three cases to depict the work of cell classification. The first two cases are about the handoff request because the handoff services may be linked with WLAN or WCDMA networks originally. And this will affect the consideration of available RF modules. The first case is shown as,

For handoff request which uses WCDMA RF module,

For cell n is a WCDMA cell,

$$N = N \cup \{n\} \text{ , if } PW_n > PW(WCDMA), \text{and } \rho_n + \Delta L < \rho_{th}. \tag{3.3}$$

For cell n is a WLAN cell,

$$N = N \cup \{n\} \text{ , if } PW_n > PW(WLAN) \text{ , } \rho_n + \Delta L < \rho_{th} \text{ , and}$$
$$\text{cell } n \text{ is currently used or WLAN RF module is available.} \tag{3.4}$$

The second case is about the handoff request which uses the WLAN RF module, and the consideration is given by,

For handoff request which uses WLAN RF module,

For cell n is a WLAN cell,

$$N = N \cup \{n\}, \text{ if } PW_n > PW(WLAN), \text{and } \rho_n + \Delta L < \rho_{th}. \tag{3.5}$$

For cell n is a WCDMA cell,

$$N = N \cup \{n\},\ \text{if} \quad PW_n > PW(WCDMA)\ , \quad \rho_n + \Delta L < \rho_{th}\ \text{, and}$$
$$\text{cell } n \text{ is currently used or} \quad \text{WCDMA RF module is available.} \qquad (3.6)$$

The last case is the consideration of new service request, which is shown as,

For new service request,

For cell n is a WCDMA cell,

$$N = N \cup \{n\},\ \text{if} \quad PW_n > PW(WCDMA)\ , \quad \rho_n + \Delta L < \rho_{th}\ \text{, and}$$
$$\text{cell } n \text{ is currently used or} \quad \text{WCDMA RF module is available.} \qquad (3.7)$$

For cell n is a WLAN cell,

$$N = N \cup \{n\},\ \text{if} \quad PW_n > PW(WLAN)\ , \quad \rho_n + \Delta L < \rho_{th}\ \text{, and}$$
$$\text{cell } n \text{ is currently used or} \quad \text{WLAN RF module is available.} \qquad (3.8)$$

In each case, the cell n is grouped into the candidate cell group N when it complies with the signal strength constraint, cell admission constraint, and terminal capability constraint.

3.3 Utility Function (UF) Computation

The main concept underlying the proposed method is to strike a balance between system capacity and cell loading while maintaining the service QoS requirements by a utility function (UF) for two service request types. The UF computation calculates the utility values of all candidate cells in N.

If a cell with the most available resources is assigned to an MN to provide services, the MN can obtain the largest bandwidth and enjoy the best transmission quality. However, this allocation only works on few MNs in networks, more MNs contributes the bandwidth fluctuation and the service quality may not be maintained. As the result, handoff occurs frequently and network operates unstably. Therefore, the UFAS selects a cell with resources close to the service requirements so that the system capacity can be maximized. Furthermore, a balancing index η is adopted to prevent a highly loaded cell to be firstly chosen. Moreover, the balancing index is also able to help the WLAN networks to provide call admission control so that the service quality can be guaranteed.

3.3.1 *Utility function*

For an MN's service s, the utility function $U_n^{(s)}$ is expressed as a product of four *evaluation functions*, where n is the cell index of the element in the candidate cell group N. The UF is formulated by,

$$U_n^{(s)} = f_{R,n}^{(s)} \times f_{D,n}^{(s)} \times f_{B,n}^{(s)} \times f_{\nu,n}^{(s)}, \tag{3.9}$$

where $f_{a,n}^{(s)}$, $a = R, D, B$,and ν is the evaluation function of data rate, delay, BER, and mobility, respectively. The evaluation function of MN mobility is adopted to present MN mobility in cell n, $n \in N$, by considering the MN current velocity ν. Notably, the evaluation functions ($f_{a,n}^{(s)}$, $a = D, B, R$) of QoS provisioning are designed to be nonlinear so as to discriminate the preference of each cell. The evaluation function of data rate is given by

$$f_{R,n}^{(s)} = \begin{cases} 0, & \text{if } R_n^{(s)} < R^{*(s)} \\ G((1+\eta)R_n^{(s)}; R^{*(s)}), & \text{otherwise} \end{cases}, \tag{3.10}$$

where $G(\cdot)$ is a bell-shape function to express nonlinear characteristic in evaluation functions. and η is the balancing index. The function $G(\cdot)$ is defined as

$$G(x;\mu) = \exp[-(x-\mu)^2/(2\mu^2)], \tag{3.11}$$

where x is the measurement value in cell n and μ is a constant used to present the service requirements required by service s. In the $G(x;\mu)$ for $f_{R,n}^{(s)}$, x is the measurement value of data rate $R_n^{(s)}$, and μ is the required data rate ($R^{*(s)}$). The $R_n^{(s)}$ in WCDMA cells is not measured as in WLAN cells, but measured by the cell loading because the system capacity in WCDMA networks is based on the interference. According to the required data rate $R^{*(s)}$, the load factor ΔL is derived from Eq. (3.1). Then the new cell loading in cell n can be estimated by summing current cell loading ρ_n and ΔL. The new cell loading and the threshold ρ_{th} are the inputs of Eq. (3.10) so that the cell, which can maximize the system capacity, will be chosen for WCDMA cells cases.

Similarly, the evaluation functions of delay and BER are formulated by,

$$f_{D,n}^{(s)} = \begin{cases} G((1+\eta)D_n^{(s)}; D^{*(s)}), & \text{if } D_n^{(s)} \leq D^{*(s)} \\ 0, & \text{otherwise} \end{cases}, \tag{3.12}$$

$$f_{B,n}^{(s)} = \begin{cases} G((1+\eta)B_n^{(s)}; B^{*(s)}), & \text{if } B_n^{(s)} \leq B^{*(s)} \\ 0, & \text{otherwise} \end{cases}, \tag{3.13}$$

where $D_n^{(s)}$ and $B_n^{(s)}$ are the measurement value of delay and BER, respectively, and $D^{*(s)}$ and $B^{*(s)}$ are the required delay and BER, respectively.

This implies that the output of evaluation functions ranges between zero and one, and so as the UF. The value of evaluation functions is one when the QoS provisioning within a cell is equal to the QoS requirements of services. Contrarily, the values of evaluation functions roll off gradually when the difference between the QoS provisioning and the service requirements increases, and descend sheerly when the difference decreases.

Additionally, the evaluation function of MN mobility favors large coverage cell when the MN is in high mobility. Assume ℓ_n is the physical radius of cell n and ν is the MN current velocity. Then, $2\ell_n/\nu$ is the upper bound period that the MN will stay in that cell. The $f_{\nu,n}^{(s)}$ is given by,

$$f_{\nu,n}^{(s)} = \frac{(2\ell_n/\nu)}{\sum_n^N (2\ell_n/\nu)} = \frac{\ell_n}{\sum_n^N \ell_n}. \tag{3.14}$$

According to Eq. (3.14), cells that incurs the handoff frequently have less chances to be selected, especially the WLAN networks.

For a heavy loading cell with high loading index, the outputs of its evaluation functions are small and its utility value is small. In this case, the cell with heavy loading has less chances to be selected. Contrarily, the cell with light loading should not incur this constraint. Hence, η is considered only when ρ_n is larger than a predefined level ρ_0. Notably, ρ_n is the cell loading of cell n in WCDMA/WLAN interworking networks which is described in the Appendix. The formulation of η is defined as,

$$\eta = \max\{0, (\rho_n - \rho_0)\}. \tag{3.15}$$

3.4 Target Cell Determination

The utility values of WCDMA and WLAN networks are derived from the UF computation and the cell with the largest value is the best-fit cell. The best-fit cell is chosen because it can conform the QoS requirements of services and enhances the network stability when the number of MNs increases. The determination has two situations to consider. One is a situation of not all utility values are zero; another is a situation of all utility values are zero.

3.4.1 *Case 1 - not all utility values are zero*

Generally, the utility values are used to express the preference for connection to either WLAN or WCDMA networks. If the utility value of the cell is closer to one, the cell has larger opportunities to be selected. On the contrary, the cell has the smallest chance to be selected if its utility values is near to zero. The target cell, $Target\_Cell^{(S)}$, is determined by

$$Target\_Cell^{(S)} = \arg\max_n (U_n^{(S)}). \tag{3.16}$$

3.4.2 *Case 2 - all utility values are zero*

Nevertheless, it may occur that all utility values are zero, that is, at lest one service requirement is not satisfied. The reason is that the terminal capability or the cells from the candidate cell group cannot accommodate the service. In this circumstance, RNC rejects the new service for the new service request. And for the single handoff request, it is terminated when all utility values are zero. On the other hand, for bundle handoff request, RNC prioritizes the handoff services and terminates the service with the lowest priority but keep other in higher priority ones. The RNC then does the UF computation again to find a cell that satisfies the service requirements. When services have the same priority or services are all high-priority, the service that requests the largest resource comparing to the other handoff services is regarded as the lowest priority and is ruled out. This action does not stop until a suitable cell is found. If only one handoff service remains, the handoff request will be terminated as long as no cell can be chosen. This situation will occur, for instance, at when the MN roams to a radio-sheltered place.

3.4.3 *The Scheduler in WCDMA and WLAN networks*

Once the network assignment is done, the scheduler of WLAN or WCDMA networks allocates the resources for services of all MNs. In the thesis, the scheduler in WLAN employs the EDCF mechanism proposed in IEEE 802.11e and the scheduler in WCDMA networks employs a priority-based round robin mechanism with traffic shaping.

In WCDMA networks, the priority-based round robin scheduler with traffic shaping (PRwTS) serves the MN with priority. The services of the same priority are served in the round robin fashion. For each served service, the allocated resource is based on token $\Lambda_{tok}(m)$. The PRwTS will not stop until the resources are completely allocated.

When the PRwTS programs the services of all MNs, it firstly selects the high priority service in round robin and schedules the low priority services secondly if the resources are not utilized. The resources in WCDMA networks is the interference which has to belong a threshold. The threshold is to ensure the receiver can resolve the transmitting data because WCDMA systems is the interference-based systems. Moreover, the priority of real-time group is defined to have higher priority than the delay-tolerant group.

The token presents the allowed transmission rate for the service of the MN so as to guarantee the required transmission rate. Therefore, the number of tokens is mainly determined by the last assigned tokens $\Lambda_{tok}(m)$, the transmitted tokens in every frame time Λ_{trans}, and the newly generated tokens Λ_{ngt}, where m is the time point that the scheduler programs. The number of tokens $\Lambda_{tok}(m+1)$ in the next time is obtained by,

$$\Lambda_{tok}(m+1) = \Lambda_{tok}(m) - \Lambda_{trans} + \Lambda_{ngt}. \tag{3.17}$$

The Λ_{ngt} is determined by the guaranteed transmission rate Λ_{req} and a deficient counter DC. The deficient counter DC is used to record the tokens numbers given in the last time.

$$DC = \Lambda_{req} - \Lambda_{tok}(m). \tag{3.18}$$

Since the transmission rate in WCDMA networks depends on spreading code, the number of newly generated tokens Λ_{ngt} in each time may be larger than the guaranteed transmission rate Λ_{req}. Here, Λ_{ngt} is compared with $\Lambda_{tok}(m)$ to ensure that the guaranteed transmission rate Λ_{req} is insured between two scheduling time point. Λ_{ngt} is given by,

$$\Lambda_{ngt} = \Lambda_{req} - DC. \tag{3.19}$$

Therefore, if the scheduler gave a number of tokens over than the guaranteed value last time, it gives less number of tokens this time so that the number of given tokens in average matches the guaranteed value.

All the tokens that stored in the service's bucket which is shown in Fig. 3.2. The input tokens are assigned by the scheduler in every time that the scheduler is invoked. In every slot time, few tokens Λ_{out} are output the bucket because the corresponding data are transmitted. Thus the number of transmitting data is in control to guarantee the transmission rate. The number of packets PKT that allowed to send is determined by,

$$PKT = \min(\Lambda_{que}, \Lambda_{tok}), \tag{3.20}$$

where Λ_{que} is the number of packets in the data queue on the MN. The determination chart of PKT is depicted in Fig. 3.3.

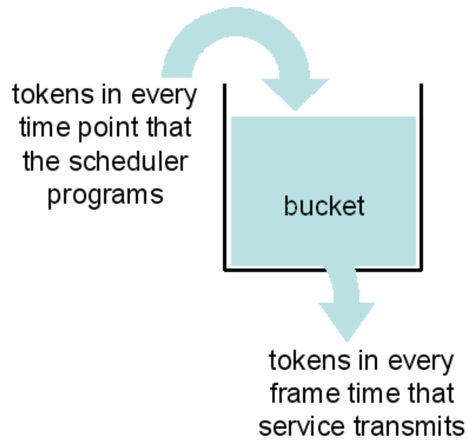


Figure 3.2: The chart of token buckets.

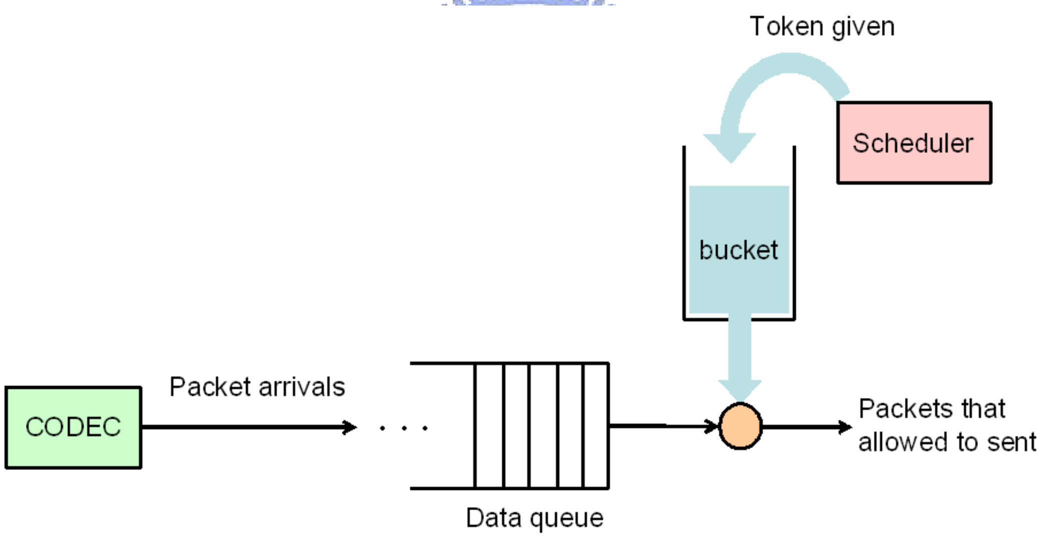


Figure 3.3: The chart of determining the number of transmitting packets.

Chapter 4

Simulation Results and Discussion

4.1 Simulation Environment

In our simulation, WLAN networks are built for two purpose. One is for adjacent WCDMA cells to support service continuity; another is for hotspots in the urban zone to support services for some people. Thus, in the boundary between two WCDMA cells, few WLAN cells are deployed as a complementary of WCDMA networks to support the vacant spaces. Additionally, some WLAN cells are built as hotspots in the urban zone. The simulation environment is shown in Fig. 4.1. A concatenated 19-cell environment is configured for simulating the performance of multi-cell WCDMA networks with WLAN networks. All WCDMA cells are wrapped around at the edges so as to avoid the edge effects. The central cell is labeled as cell 1, the cells in the first tier are cell 2 - cell 7, and the cells in the second tier are cell 8 - cell 19. Around cell 1, the right-handed cells are deployed for the urban environment and the leaf-handed cells are for the suburban environment. Between two WCDMA cells, 2-WLAN cells are deployed to support service continuity. In each WCDMA cell belonging to the urban environment, 10-WLAN cells are disposed continuously as a hotspot zone.

In WCDMA systems, the transmission is determined by the scheduler in the WCDMA

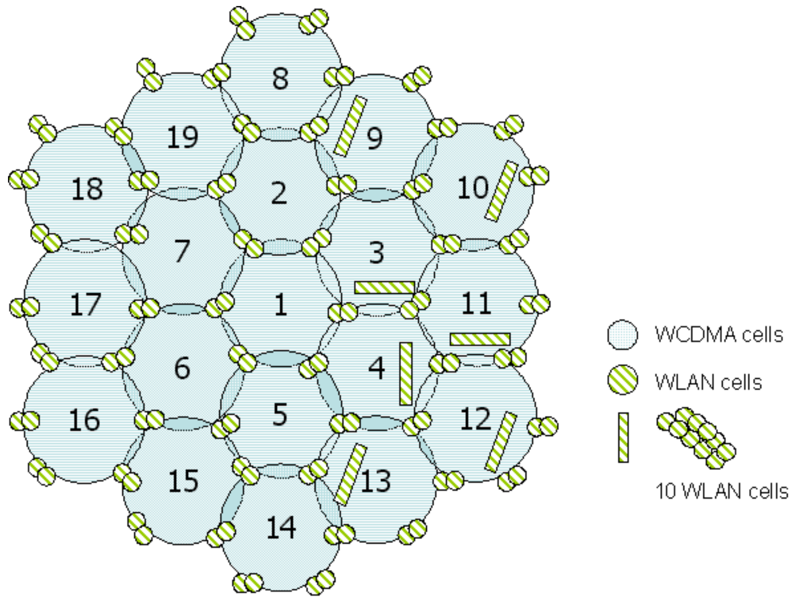


Figure 4.1: The system deployment in the simulation

cell. With the information of token numbers, the scheduler allocates the transmission rates for the service of the MN. In WLAN systems, an MN starts to transmit data when the MN obtains the transmission opportunity in the contention period. And all packets in the MN's queue will be transmitted at the time. The other detailed system parameters are shown in Table 4.1.

Real-time voice service and delay-tolerant web-browsing service are considered in this paper, which are high and low priority service, respectively. In the scheduler of WCDMA, the requirements of voice service are satisfied at first, then the remaining resources are allocated to web-browsing services. That is, resources are shared among web-browsing services based on the residual capacity, after subtracting the voice service requirements.

The mean rates of the voice service is 9.6Kbps and the mean holding time of voice service is 3 minutes. The value of α and β are 19 and 14 seconds, respectively; and therefore, the active factor is 0.58. The required value of SIR, delay, and BER are 5.6dB, 300ms, 0.05, respectively. The traffic parameters are depicted in Table 4.2.

Traffic Type	Traffic Parameters
WCDMA cell radius	1000m
WCDMA frame duration	10ms
WLAN cell radius	10m
WLAN slot time	2us
MN's average velocity	3km/hr for pedestrian 40km/hr and 80km/hr for vehicular
Block size in WCDMA systems	150 bits
Spreading factor of basic rate in WCDMA systems	256
ρ_{th} in WCDMA systems	0.7
ρ_{th} in WLAN systems	1.0
ρ_0	0.4
Number of WCDMA cells	19(9 cells are in urban area / 10 cells are in suburban area)
Number of WLAN cells in the border of WCDMA cells	2
Number of WLAN cells in urban area as hotspots	10

Table 4.1: System Parameters in The WCDMA/WLAN Interworking Networks

The mean rates of the web-browsing service is 144Kbps. The mean reading time $\kappa_{D_{pc}}$ in the web-browsing service is 30 seconds, the inter-arrival mean time κ_{D_d} is 0.125 seconds ,and the mean packet numbers during a packet call κ_{N_d} is 5. The mean of holding time is 300 seconds, and the mean number of packet call $\kappa_{N_{pc}}$ is 25. The web-browsing service has BER constraint of 0.005. The required SIR and delay are 3.2dB and 1 second, respectively. The detailed traffic parameters are listed in Table 4.3. The new service arrival rate of voice and web-browsing services are set to be exponentially distributed with mean arrival rate 0.02, 0.033, 0.05, 0.08, and 0.1, respectively.

We compared the performance of the proposed method with the policy-enabled (PE) handoff decision method across heterogeneous wireless networks [13]. The PE method uses a cost function which considers cost, power consumption and bandwidth. The cost function

Traffic Type	Traffic Parameters
mean talkspurt/slient duration	19/14 seconds
active factor υ	0.58
mean call holding time	180 seconds
Required E_b/N_0	5.6dB
Required delay	300 mini-seconds
Required BER	0.05

Table 4.2: The Parameters of Voice Service

Traffic Type	Traffic Parameters
κ_{S_d}	1858 bits
$\kappa_{D_{pc}}$	30 seconds
κ_{D_d}	0.125 seconds
κ_{N_d}	5
mean call holding time	300 seconds
$\kappa_{N_{pc}}$	25
Required E_b/N_0	3.2dB
Required delay	1 second
Required BER	0.005

Table 4.3: The Parameters of Web-browsing Service

is given by,

$$Cost_n = f(B_n, P_n, C_n), \tag{4.1}$$

where B_n is the bandwidth in cell n, P_n is the power consumption in cell n, and C_n is the cost of using cell n. The $Cost_n$ of the current cell is compared to other cells that may be used. If a cell has larger cost value then the current cell has, the handoff is processed. Thus, the strategy of the PE method selects WLAN mostly because the cost of WLAN is smaller than WCDMA networks and the bandwidth of WLAN is larger than then WCDMA networks.

4.2 Simulation Results

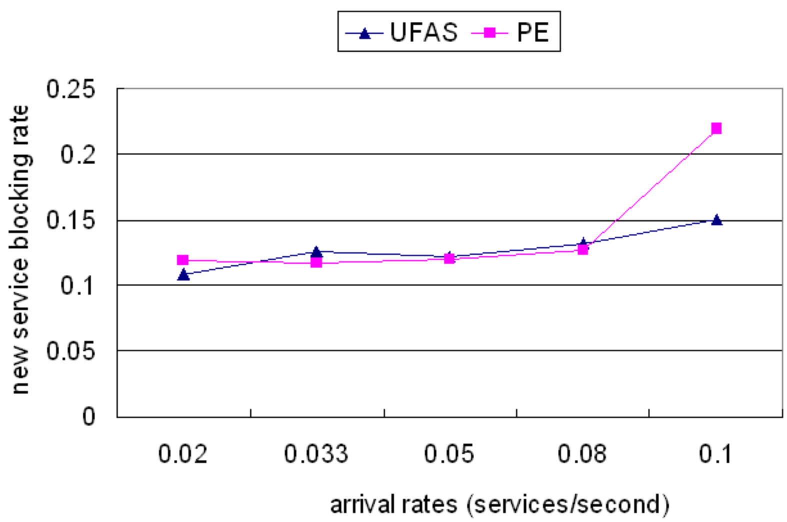


Figure 4.2: The new service request blocking rates

Fig. 4.2 illustrates the new service blocking rate in the proposed method and that in the PE method. It can be found the new service blocking rate of the UFAS method slightly rises when the arrival rate increases. The new service blocking rate in the PE method becomes greater than that in the proposed method as the service arrival rates become larger. It is because the UFAS method adopts the balancing index η to distribute the loading between cells, and more new services can be accommodated as the arrival rate increases.

The handoff behavior is shown in Fig. 4.3 (a) and (b), which depicts the handoff blocking rate and handoff occurrence rate, respectively. It can be found that the handoff blocking rate of the UFAS method is much smaller than that of the PE method. The gap enlarges when the arrival rate increases. In Fig. 4.3 (b), the handoff occurrences of the PE method inclines more sharply than the UFAS method does. This is because that the mobility evaluation function $f_{\nu,n}^{(s)}$ of the proposed method favors WCDMA networks for high-mobility MN. Therefore, the number of handoff occurrences is low. The mobility evaluation function $f_{\nu,n}^{(s)}$ also selects WLAN cells for low-mobility MN, and hence, the resources in WCDMA networks can be reserved for handoff services. The proposed method achieves lower handoff blocking than the PE method does, consequently.

Fig. 4.4 shows the throughput in the UFAS method and the PE method. The throughput is the average transmission bits per second in networks. Fig. 4.4 (a) depicts the total throughput of WCDMA and WLAN networks of UFAS method and the compared method. The total throughput is the sum of the transmission bits in WCDMA and in WLAN networks. Fig. 4.4 (b) and Fig. 4.4 (c) show the individual throughput in a WCDMA cell and in a WLAN cell, respectively. It can be found that the total transmission bits in the proposed method is larger than that in the PE method. The proposed method achieves 1.5Mbps throughput higher than the compared method. And the individual throughput in WCDMA networks of the UFAS method is smaller than those of the PE method. On the contrary, the individual throughput in WLAN networks of the proposed method is larger than the compared method. This phenomenon results from the design philosophy of the proposed algorithm. UFAS adopts service required data rate and mobility as the factors for network selection so that WLAN networks tend to accommodate low-mobility MN requiring high transmission rate and WCDMA networks tend to accommodate high-mobility MN requiring low transmission rate. This characteristic can be found from Fig. 4.4 (c) where the proposed

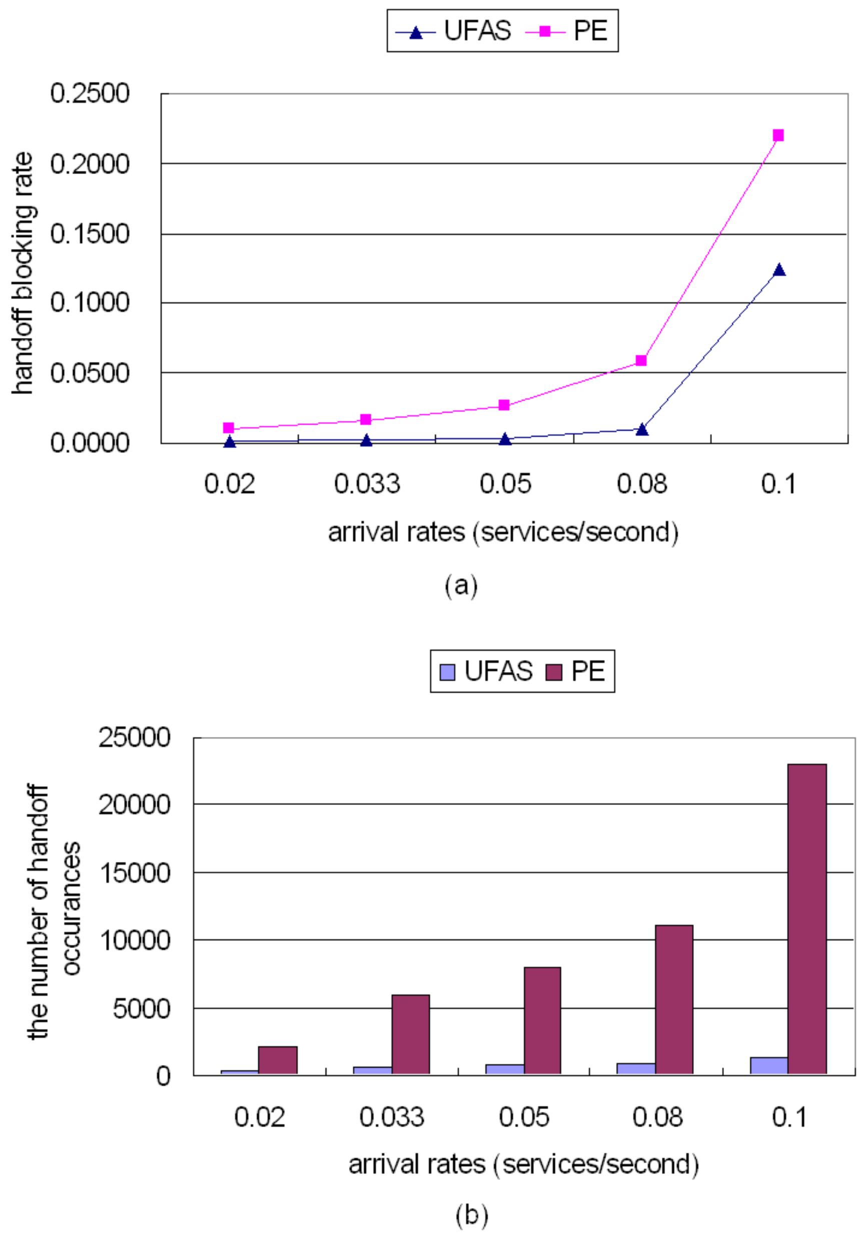


Figure 4.3: (a) The handoff request blocking rates (b) The number of handoff occurrences

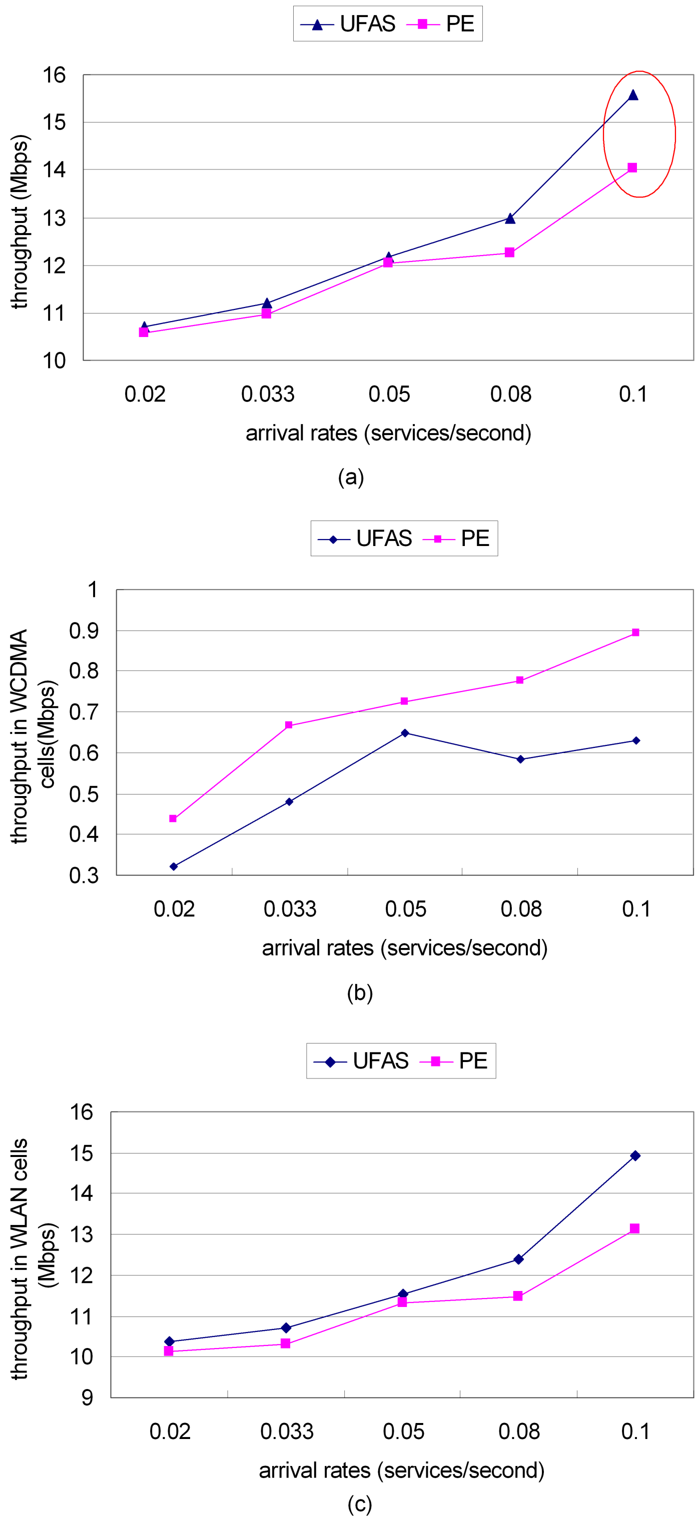


Figure 4.4: (a) The total throughput of WCDMA and WLAN networks (b)The individual throughput of WCDMA networks (c) The individual throughput of WLAN networks

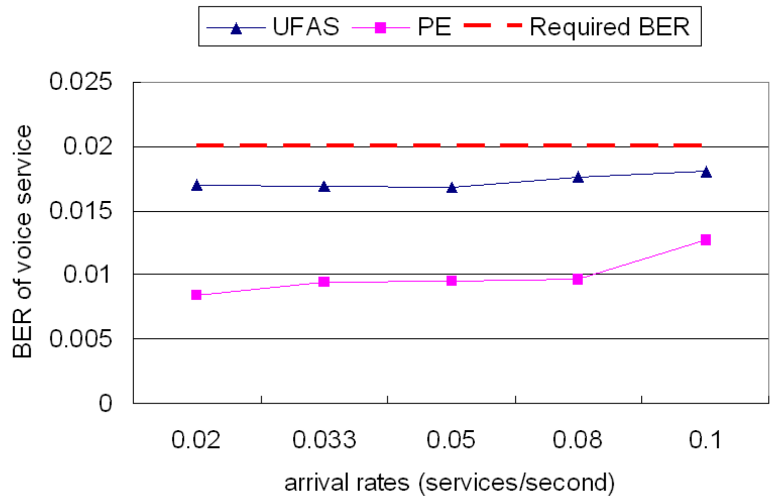


Figure 4.5: The average BER of voice service in WCDMA networks

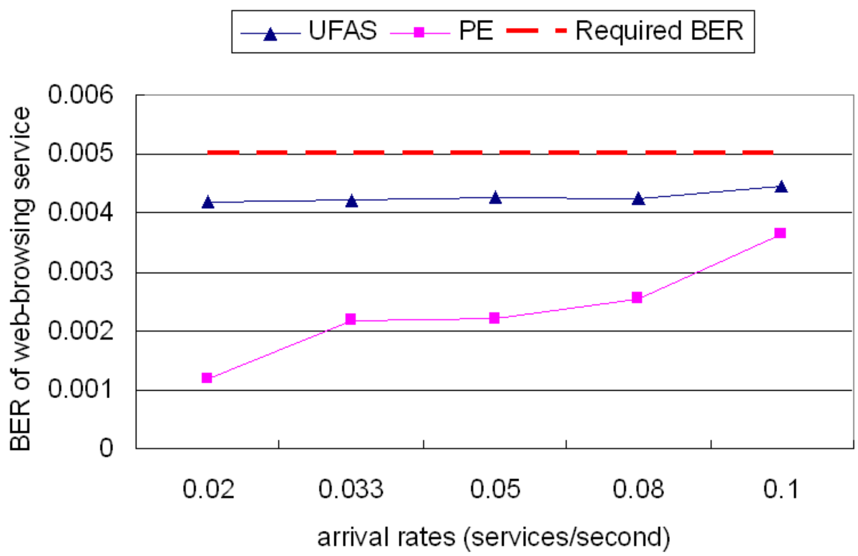
method achieves 0.5Mbps throughput higher than the PE method. Therefore, the total throughput of proposed method is larger than the PE method. Although, the throughput of the proposed method is lower then the PE method, some WCDMA resources are reserved for future handoff service of MNs.

Fig. 4.5 shows the BER of voice services in WCDMA networks. The dash line is the required value of voice services in average BER. It can be found that the average voice service BER of the UFAS method is larger than the compared method. The proposed method is to select a cell with resources close to the service requirements. Thus, the average BER of UFAS method is larger than the PE method but not over the service required BER. Moreover, the BER curve of the proposed method is almost flat because WCDMA networks accommodate low transmission rate services and operates in a stable state.

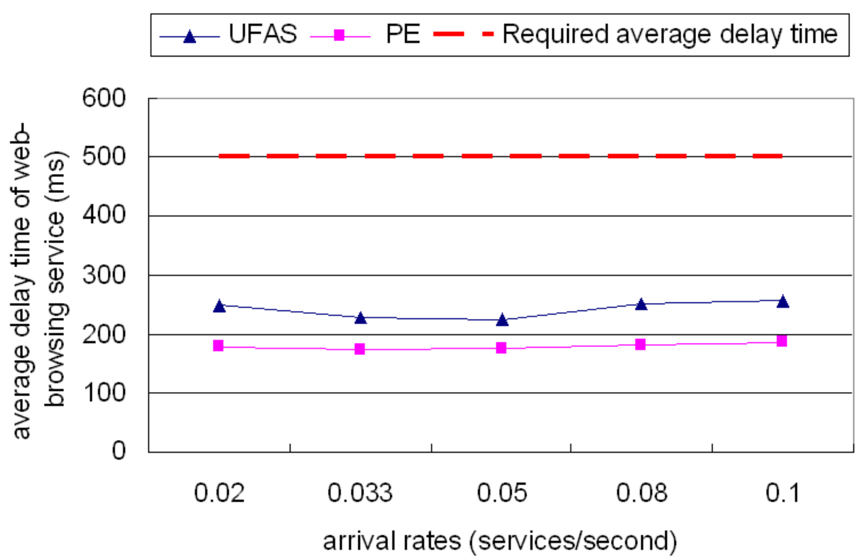
Fig. 4.6 (a) and Fig. 4.6 (b) show the average BER and delay time of web-browsing services in WCDMA networks, respectively. The average web-browsing service delay time and BER of the UFAS method are larger than the compared method. The reason is that the proposed method is to select a cell with resources close to the service requirements.

The service requirements are satisfied in the proposed method but are not better than the PE method. WCDMA networks mostly serve high-mobility MN requiring low-rate services. This phenomenon can be observed from Fig. 4.4 (c), which shows that the services requiring high-transmission rate prefers WLAN networks.

The average delay time of web-browsing service in WLAN networks are shown in Fig. 4.7. And the web-browsing service's delay time of the proposed method is almost the same as the PE method. The WLAN networks employ the EDCF algorithm for contention resolution. From 4.4 (c), the capacity in WLAN networks is not in full so that the average time is the same.



(a)



(b)

Figure 4.6: The QoS measures of web-browsing services in WCDMA networks: (a) BER (b) average delay time

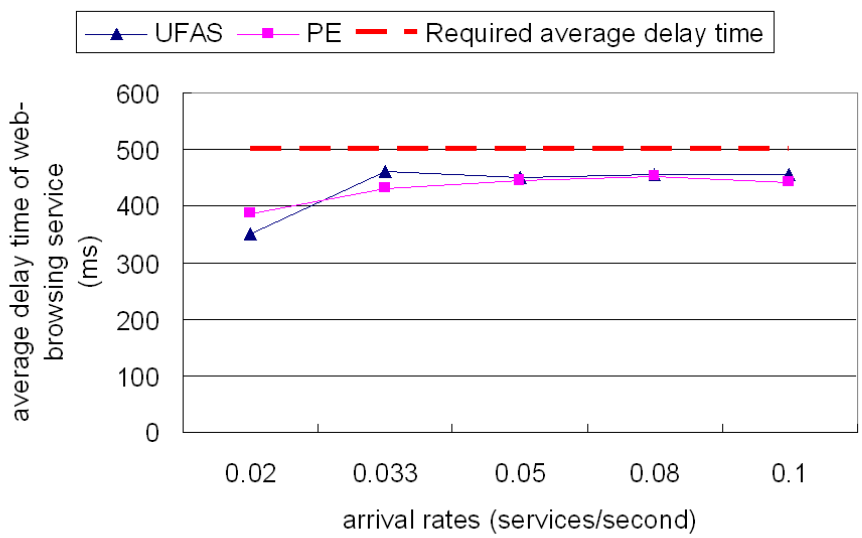


Figure 4.7: The average delay time measures of web-browsing services in WLAN networks

Chapter 5

Conclusions and Future Works

An interworking WCDMA/WLAN networks is considered to support high-data-rate multimedia services and high mobility. In this thesis, we propose a utility function-based access selection method (UFAS) to determine a cell for serving a mobile node's service request. The proposed method contains three parts, *cells classification*, *utility function computation*, and *target cell determination*. The cells classification filters feasible cells for the MN; the utility function computation calculates utility values of the feasible cells by a utility function; the target cell determination selects a best-fit cell according to the utility values. The utility function of the proposed method comprises of delay, bit error rate, data rate, and mobility evaluation functions. Moreover, in the utility computation, a balancing index is also adopted to tighten up the QoS requirements so that the utility values of heavily loaded cells would be reduced.

The simulation results show that the proposed method has lower new service blocking rate than the PE method. The loading between cells are distributed, and more new services can be accommodated as the arrival rate increases. On the other hand, the UFAS method has lower handoff blocking rate and handoff occurrences than the PE method. It results from the design philosophy of the UFAS method tending to select WLAN networks to accommodate low-mobility MN requiring high transmission rate and WCDMA networks to accommodate high-mobility MN requiring low transmission rate. Consequently, the total throughput of the proposed method is larger than the compared method, and some WCDMA resources can be reserved for future handoff service of MNs. The simulation results also show that the UFAS method maintains the service requirements both in WCDMA and WLAN networks.

Our work can be extended to combine the software-defined radio (SDR) and multi-rate transmission technologies. To be more flexible to utilize system resources in the future, a software-defined radio (SDR) is adopted to enhance the MNs ability. The SDR introduces a flexible terminal reconfiguration by replacing radio completely implemented in hardware by ones configurable or even programmable in software to a large extent [21]. It can address the under-utilizing issue of RF modules because no beacon signal is found or the pilot signal strength is weak. The SDR application makes the radio resource management more efficient since the traffic may be split into multiple sub-streams to fully utilize the RF resource and the total transmission time can be reduced. Obviously, this transmission scenario raises the necessity of link-level coordination between heterogeneous networks.

On the other hand, WLAN networks have much high transmission bandwidth than WCDMA networks. For accommodating high-transmission-rate MNs from WLAN, WCDMA networks may employ a multi-rate transmission control to adapt the transmission rate. A multi-rate transmission control changes the transmission rate by transmission power, processing gain, modulation and coding. For transmission rate control, a sophisticated QoS mapping between WCDMA and WLAN is a basic fundamental work. It would be an interesting future research topic to introduce the SDR and multi-rate transmission into the design of access selection method.

Chapter 6

Appendix : Calculation of Cell Loading

The calculation of cell loading ρ_n , which has different calculations in WCDMA and WLAN networks, is described in this section.

6.1 WCDMA Calculation of Cell Loading ρ_n for WCDMA cells

From the definition of spectral efficiency of an MN in a WCDMA cell [20], (E_b/N_0) is the energy per MN bit divided by the noise spectral density. Thus, the derivation of spectral efficiency of MN j is shown below,

$$(E_b/N_0)_j = \frac{W}{\upsilon_j R_j} \cdot \frac{P_j}{I_{total} - P_j}, \tag{6.1}$$

where W is the chip rate, R_j is the total bit rate of the jth MN, and υ_j is the voice activity factor of the jth MN. From the Eq. (6.1), the relationship between the received power P_j from MN j and the total power I_{total} can be written as,

$$P_j = L_j \cdot I_{total}, \tag{6.2}$$

where L_j is the load factor of MN j, which is formulated by,

$$L_j = \frac{1}{1 + \frac{W}{(E_b/N_0)_j \cdot R_j \cdot \upsilon_j}}. \tag{6.3}$$

When we sum up the load factor of all MNs, the cell loading ρ_n can be derived. Additionally, the other cells interference must be considered by the ratio of other cells to home cell interference i. Therefore, the cell loading ρ_n is shown as,

$$\rho_n = (1+i)\sum_{j=1}^{J} L_j. \tag{6.4}$$

Notably, the E_b/N_0 is the required value of services in an MN, W, R_j and J are well-known by RNC, and υ_j is the average value based on the measurements.

6.2 Calculation of Cell Loading ρ_n for WLAN cells

In WLAN networks, assume that all QoS stations (QSTAs) can be divided into two classes, high-class (H) QSTAs and low-class (L) QSTAs. The ρ_n is given by

$$\rho_n = \frac{\sum_j (\text{data rate from user } j)}{\zeta}, \tag{6.5}$$

where ζ is the available bandwidth. By [22], ζ can be expressed as

$$\begin{aligned} \zeta &= \frac{E[\text{payload information in a slot time}]}{E[\text{length of a slot time}]} \\ &= \frac{(\tau_H(1-P_H)+\tau_L(1-P_L))E[P]}{P_{idle}\cdot\sigma + P_{one}T_{suc} + (1-P_{idle}-P_{one})T_{col}}, \end{aligned} \tag{6.6}$$

where τ_H and τ_L are the probabilities of a high-class QSTA and low-class QSTA transmissions in a randomly chosen time slot, P_H and P_L are referred as the conditional probabilities that high-class QSTA and low-class QSTA transmit in a generic busy slot, $E[P]$ is the average payload size for both classes, Let P_{idle} be the probability that no QSTA transmits during σ, P_{one} is the probability that only one QSTA transmits in a randomly chosen time slot, T_{suc} is the average channel busy time due to successful transmissions, and T_{col} is the average channel busy time due to collisions. Eq. (6.6) is an upper bound of transmission in WLAN networks because transmission is not always in full-load. However, in the proposed method, the worse case is needed to express the heaviest cell loading.

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Vita

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