國 立 交 通 大 學

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碩 士 論 文

異質無線網路中根據偏好值之網路選擇機制

Preference Value-Based Cell Selection Scheme in Heterogeneous Wireless Networks

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Mandarin Abstract

摘　要

在未來 4G 的時代，不同特性的無線網路逐漸整合，業者賦予行動用戶多模(multi-mode)的能力，使得行動用戶能無縫(seamless)的網路接取，使用者根據各自通道狀況及自身的服務品質需求(QoS requirement)選擇最適宜自己的無線網路。為了支援高傳輸速率的多媒體服務以及高速的行動用戶，一個 WCDMA/WMAN/WLAN 的異質無線網路被提出。

在 WCDMA/WMAN/WLAN 的異質無線網路系統中，在本篇論文中我們提出了一個根據偏好值的網路選擇機制，希望在保證使用者的服務品質需求下，增加可容納的使用者個數、降低換手(handoff)的發生頻率。此機制包含了三階段，分別是候選網路選擇(candidate cells selection)、偏好值計算(preference value calculation)、目標網路選定(target cell determination)。在得到候選網路後，我們計算每個候選網路的偏好值，每個偏好值考慮了三個因素：服務品質(QoS)、負載狀況(loading)、以及移動速度(mobility)來達到我們的目標，最後選擇偏好值最大的網路當成目標網路。模擬結果顯示我們提出的方法可以增加系統傳輸速率(throughput)以及滿足服務品質需求，並且增加可容納的使用者個數以及降低換手的發生頻率。

Preference Value-Based Cell Selection Scheme in Heterogeneous Wireless Networks

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English Abstract

Abstract

The thesis proposes a preference value-based cell selection (PVCS) scheme to satisfy quality of service (QoS) requirements, maximize accommodated number of calls and minimize handoff occurrence frequency in heterogeneous wireless networks. The PVCS scheme contains three stages, candidate cells selection, preference value calculation, and target cell determination. The candidate cells selection is used to sift out the candidate cells for the call request. All suitable cells form candidate cell set. The preference value calculation will calculate the preference value of each cell in the candidate cell set, which is optimized by considering QoS factor, loading factor, and mobility factor, for the purpose of maintaining call request's QoS requirements, maximizing overall system utilization, and minimizing handoff occurrence frequency. Eventually, the target cell, which has the maximum preference value, could be selected for the call request. Simulation results show that PVCS scheme achieves higher total throughput than UGT while satisfying the QoS requirements. It also has lower new call blocking rate and handoff call dropping rate than UGT, which means more accommodated calls than UGT. Besides, PVCS reduces the total handoff occurrence frequency by about 20% as compared to UGT.

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民國九十八年七月

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Chapter 1

Introduction

One of the main features of the evolving the next generation (4G) wireless networks would be heterogeneous wireless access in which a mobile station (MS) has multi-mode capability to connect to multiple heterogeneous radio access networks (RANs) simultaneously, such as wireless local area network (WLAN), wireless metropolitan area network (WMAN), wideband code division multiple access (WCDMA) cellular network [1]. This would facilitate high-speed connectivity and seamless Internet access through optimal network selection among different types of RAN. However, each RAN has different system characteristics such as cell coverage, capacity, loading, and carrier frequency, it is necessary to take system information and MS's quality-of-service (QoS) requirements into account when performing the network selection. In addition, load balancing is also indispensable to accommodate as many MSs as possible so as to increase overall system utilization for the heterogeneous wireless networks.

Mobility is also a very important factor in the heterogeneous wireless networks. Systems have to support handoff to provide service continuity. A handoff may be initiated by an MS to maintain wireless connection in the heterogeneous wireless system. In heterogeneous wireless networks, two types of handoff are usually considered: horizontal handoff and vertical handoff. Horizontal handoff means that an

MS hands over to another homogeneous cell. Vertical handoff means that an MS hands over to another heterogeneous cell. A high mobility MS has more opportunities to experience more handoffs during its call holding time. Generally, more handoffs imply more overhead and take higher risk of call dropping. Therefore, it is a significant topic to decrease the number of handoff through proper network selection.

A utility-based method would be an excellent approach for target cell decision problem. In [2], a market model is formulated to maximize total network utilities by adjusting the resource price. A utility function represents the satisfaction degree of the received QoS and the price mechanism acts as a lever to guide user's action and to control resource allocation. Ormond, Murphy, and Muntean proposed some possible utility functions based on different user's attitudes to risk. Their solution is a user-centric network selection strategy based on maximizing consumer surplus subject to meeting user-defined constraints in terms of transfer completion time [3]. In addition, the network selection scheme proposed in [4] adopted multi attribute decision making (MADM) method to consider multi-factors which will influence the final decision result. However, the papers mentioned above did not consider user mobility and physical channel effect. To address these two issues, the approach proposed in [5] defined a utility function, which is composed of four evaluation functions of mobility and QoS requirements such as required data rate, maximum tolerable delay, and packet error rate (PER), help the MS to determine which network is the most suitable.

Selecting a suitable RAN to serve the call request can be regarded as a kind of competition behavior. Game theory [6] is a common mathematical tool used to understand competitive behaviors for creating rational decision makers to achieve performance objectives. This mathematical tool can be adapted for radio resource management (RRM) mechanisms in a heterogeneous environment [7]. In [8], the authors modeled network selection between the access networks using a game theoretic approach, in which the competition with non-cooperative manner was applied to maximize the payoff. However, it may be unsuitable for only considering user preference as payoff of the game. Niyato and Hossain [9] used a bankruptcy game formulation which is a special type of N-person cooperative game to find the solution of the bandwidth allocation problem in a heterogeneous wireless network. But they only considered non-real time services and did not take user mobility into consideration. Later they also proposed a non-cooperative game-theoretic framework in heterogeneous wireless networks [10]. Nevertheless, the above papers of [9] and [10] assumed that a call request can use various RANs at the same time. This substantially increases the network complexity to maintain data synchronization/ordering. Charilas, Markaki, and Tragos [11] proposed a theoretical scheme that combines analytical hierarchy process (AHP) and grey relational analysis (GRA) to attain the goal of optimal network selection. In addition, call admission control (CAC) is also modeled as a non-cooperative game so that networks play against each other to maximize their payoff and ensure QoS guarantee for multiple simultaneous service requests from many users. In [12], a utility and game-theory (UGT) based network selection scheme is proposed for heterogeneous wireless networks. UGT calculates the utility value and preference value for each candidate network based on the QoS satisfaction of the call request and cooperative network preference game. Finally, the network, which has the maximum of linear combination, would be selected as the most suitable network for the call request.

Furthermore, in order to increase the overall system utilization for heterogeneous wireless networks, it is very important to consider load balancing. Suleiman, Chan, and Dlodlo proposed a load balancing scheme in the heterogeneous environment [13]. Each horizontal call admission control (HCAC) periodically sends a load report to the vertical call admission control (VCAC). The VCAC compares the load reports and makes decision for load balancing. In [14], a load balancing algorithm based on load state was proposed for the heterogeneous networks. The algorithm assigns new calls to under-loaded cells and only allows the MSs with non-real time service in overloaded cells to under-loaded heterogeneous cells since vertical handoffs have long latency. A dynamic load balancing algorithm based on sojourn time was proposed for the heterogeneous network [15]. Results show that the algorithm increases the total network utilization and decreases the new call blocking probabilities and the handoff call dropping probabilities at the cost of increasing number of handoff.

In this thesis, a *preference value-based cell selection (PVCS)* scheme is proposed for heterogeneous wireless access environment, where multiple classes of traffic are considered. The PVCS scheme contains three stages, *candidate cells selection*, *preference value calculation*, and *target cell determination*. The candidate cells selection is used to filter out unsuitable cells by checking three thresholds including the received signal strength constraint, cell loading constraint and dwell time constraint. All suitable cells form candidate cell set. The preference value calculation of each cell in the candidate cell set is optimized by considering QoS factor, loading factor, and mobility factor, for the purpose of maintaining call request's QoS requirements, maximizing overall system utilization, and minimizing handoff occurrence frequency. Ultimately, the target cell determination selects a best-fit cell for the call request.

The rest of this thesis is organized as follows. In Chapter 2, the system model is described. In Chapter 3, the proposed preference value-based cell selection (PVCS) scheme is illustrated. Simulation results and discussions are presented in Chapter 4. Finally, Chapter 5 gives the conclusions and future works.

Chapter 2

System Model

2.1 Heterogeneous Wireless Access Environment

A heterogeneous wireless access environment consisting of WCDMA, IEEE 802.16 WMAN, and IEEE 802.11 WLAN systems is considered. We assume that a MS with multiple radio transceivers can detect these radio interfaces simultaneously and select one cell/system to transmit data. The perfect power control is also assumed to ensure uniform available data rate across coverage area. As shown in Fig. 2.1, the subnetwork contains one WCDMA cell and one WMAN cell and four WLAN cells. Each subnetwork is deployed with such kind of topology, and overlapped with each other. Here WLAN cells serve as hotspots in the urban area to support high data rate services.

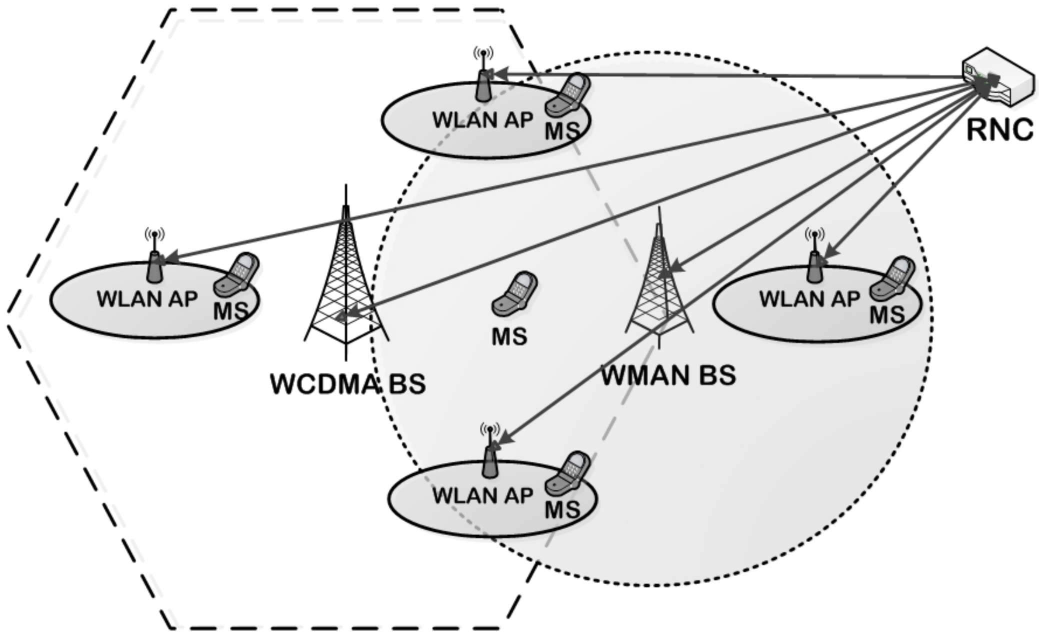


Fig. 2.1: The subnetwork topology of WCDMA, WMAN, and WLAN systems

Base stations (BSs) of WMAN and WCDMA systems and access points (APs) of the WLAN system can collect the information of a call request, including received signal strength (RSS), estimated velocity [16], position, direction of motion, and traffic class of a call request [17]. The proposed PVCS scheme is implemented in a radio network controller (RNC), which gathers information from BSs or APs to make cell selection decision. The three different wireless radio interfaces are described as follows.

2.1.1 *WCDMA Cellular Network*

For the interference-limited WCDMA networks, the BS needs to control interference in the cell. In this thesis, only the uplink direction is considered, and it is assumed that whenever the uplink channel is assigned, the downlink is established. Also, it is assumed that the transmitted signal strength for each MS can be adaptively controlled in order to achieve the target received signal strength in the BS. Then the achievable bit rate for MS_j, denoted as AR_j, can be obtained by [18]

$$AR_j = \frac{W}{v_j \cdot (E_b / N_0)_j} \times \frac{RSS_j}{I_{total} - RSS_j}, \tag{2.1}$$

where W is the chip rate, v_j is the activity factor of MS$_j$, $(E_b / N_0)_j$ is the signal energy per bit divided by noise spectral density that is required to meet a predefined QoS of MS$_j$, RSS_j is the received signal strength of MS$_j$ from BS, and I_{total} is the total power including thermal noise power received at BS. Note that the $(E_b / N_0)_j$ requirement of MS$_j$ is determined from the bit error rate requirement, service type, estimated velocity, and so on of the MS$_j$.

2.1.2 *IEEE 802.16 WMAN*

IEEE 802.16 WMAN adopts orthogonal frequency division multiple access (OFDMA) [19]. Suppose there are L sub-channels in the IEEE 802.16 WMAN system, and each sub-channel consists of q spread out sub-carriers. Thus the channel condition of each sub-channel can be regarded as the same, and the frequency selective phenomenon can be compensated. Assume that each frame includes N OFDMA symbols, and the duration for each frame is T. The total number of resource block, defined as one sub-channel and one OFDMA symbol, in a frame will be $L \times N$. Moreover, equal power control, which means the same allocated power to each call request, is adopted. From [20], an approximation of modulation order M when the required BER, denoted by BER^*, is given can be obtained by

$$M = \frac{1.5 \times SINR_\ell^{(n)}}{-\ln(5 \times BER^*)} + 1, \tag{2.2}$$

where $SINR_\ell^{(n)}$ is the received signal to interference and noise ratio (SINR) of call request on sub-channel ℓ at the nth OFDMA symbol and BER^* is the required bit error rate of call request. However, there are 4 types of modulation: no transmitted, QPSK, 16-QAM, and 64-QAM. So the usable modulation order of call request on sub-channel ℓ for the nth OFDMA symbol, denoted by $m_\ell^{(n)}$, is given as

$$m_\ell^{(n)} = \begin{cases} 0, & \text{if } M < 4, \\ 2, & \text{if } 4 \le M < 16, \\ 4, & \text{if } 16 \le M < 64, \\ 6, & \text{if } 64 \le M. \end{cases} \quad (2.3)$$

Finally, the total allocated B bits to call request in the current frame can be obtained

$$B = \sum_{n=1}^{N} \sum_{\ell=1}^{L} q \cdot c_\ell^{(n)} \cdot m_\ell^{(n)}, \quad (2.4)$$

where $c_\ell^{(n)}$ is the allocation indicator. The value of $c_\ell^{(n)}$ equals to 1, if the scheduler allocates the resource on sub-channel ℓ at the nth OFDMA symbol to the call request. On the contrary, it will be 0.

2.1.3 *IEEE 802.11 WLAN*

The WLAN system supports distributed coordination function (DCF) mode and point coordination function (PCF) mode for media access. DCF adopts carrier sense multiple access with collision avoidance (CSMA/CA) protocol with a slotted binary exponential backoff scheme. PCF is a centralized polling protocol controlled by the AP. In order to support QoS and service differentiation, IEEE 802.11e, which has been included in IEEE Std 802.11™-2007, defines the hybrid coordination function (HCF), which includes the contention-based priority-supported enhanced distributed channel access (EDCA) and contention-free HCF controlled channel access (HCCA). HCF allows the AP and MS to initiate the duration of transmission opportunity in the contention or contention-free period [21]. The standard also defines four access categories (ACs) and eight priorities to support differentiated QoSs. MSs using EDCA mode to transmit data are assumed in this thesis.

Under the EDCA mode, a MS cannot transmit packets until the channel is sensed idle for a time period equal to the arbitration interframe space (AIFS). When a

MS senses the channel busy during the AIFS, the backoff time counter is randomly selected from the range [0, CW-1], where CW is the contention window. The value of CW is increased from CW_{min} to CW_{max} if consecutive fail transmissions occur, where CW_{min} is the initial value of CW, $CW_{max} = 2^m CW_{min}$ is the maximum value of CW and m is called the maximum backoff stage.

Different ACs have different AIFS [AC], CW_{min}[AC], and CW_{max}[AC]. Traffic classes with smaller values of CW_{min} and CW_{max} represent higher priorities. AIFS [AC] for a specific AC can be given by

$$\text{AIFS[AC]} = \text{AIFSN[AC]} \times \text{aSlotTime} + \text{aSIFSTime}, \tag{2.5}$$

where AIFSN[AC] is AIFS number of the AC, aSlotTime is the value of the correspondingly named PHY characteristic, and aSIFSTime is the time duration of a SIFS.

2.2 Channel Model

The wireless fading channel is composed of large-scale fading and small-scale fading. The large-scale fading comes from path loss and shadowing effect, while the small-scale fading is caused by multipath reflection. The pass loss is modeled as [22]

$$L_{pathloss} = 128.1 + 37.61 \times \log d_{bm} (dB), \tag{2.6}$$

where d_{bm} is the distance between the BS and the MS in kilometers. Assume the log-normal shadowing is with zero mean and standard deviation of 8 dB. The Jakes model [23] is used to simulate the small-scale fading channel. Furthermore, the channel is assumed to be fixed within a frame and varies independently from frame to frame.

2.3 Mobility Model

For a high mobility MS, it is assumed that the estimated speed v and direction of motion are unchanged. As shown in Fig. 2.2, r is the radius of cell coverage, θ is the angle between BS and the moving direction of MS, where $0 \le \theta \le \pi$, and d_{bm} is the distance between BS and MS, where $0 \le d_{bm} \le r$. Then the total travel distance in the cell, denoted by d, can be obtained by

$$d = \sqrt{r^2 - (d_{bm} \cdot \sin\theta)^2} + d_{bm} \cdot \cos\theta, \text{ where } 0 \le d \le 2r. \quad (2.7)$$

So we can calculate the estimated *dwell time* of the MS in this cell, T_{dwell}, by

$$T_{dwell} = d / v. \quad (2.8)$$

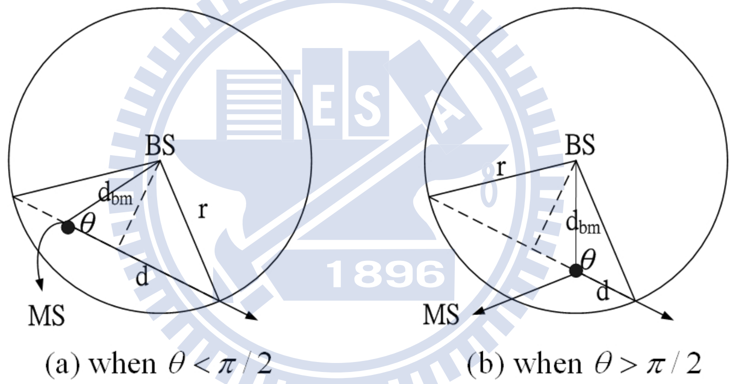


Fig. 2.2 : High mobility MS model

For a pedestrian or a normal mobility MS, they are also assumed that the speed is unchanged. But the direction will be changed randomly every certain fixed duration.

2.4 Traffic Classes

There are four traffic classes considered [24]: conversational class, streaming class, interactive class and background class. The conversational class represents real-time multi-media applications such as Voice over IP (VoIP). The streaming class includes streaming type of applications, like video on demand (VoD). The interactive class is composed of applications for Web-browsing, chat room, etc. Finally, the background class is the service using best effort transmission, such as file transfer protocol (FTP). It can be found that the first two classes are delay-sensitive (real-time), and the last two classes are delay-tolerant (non-real-time).

Each call request has different QoS parameters according to their service types. Intuitively, the real-time traffic requests low delay, low jitter, and the number of handoff must keep as low as possible. But they are tolerant of certain level of packet loss. On the other hand, non-real time traffic may request high bandwidth, and low packet dropping rate, etc. However, variable transmission rate is acceptable to them.

2.5 Source Model

The conversational class traffic is modeled as the ON-OFF model [25] shown in Fig. 2.3. During ON period, voice packets are generated with rate D_v bps. During OFF period, there is no packet generated. This model has a transition rate with value y in the ON state and a transition rate with value z in the OFF state.

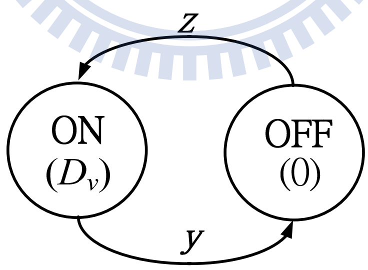


Fig. 2.3 : Packet trace of a typical on-off voice model

Fig. 2.4 depicts the packet trace of one video streaming session model, which is composed of a sequence of video frames generated regularly with a constant interval T_f [22]. Each video frame consists of a fixed number of slices N_s, where each slice corresponds to a single packet. The size of packet is denoted by P_s, and the inter-arrival time between each packet is T_p.

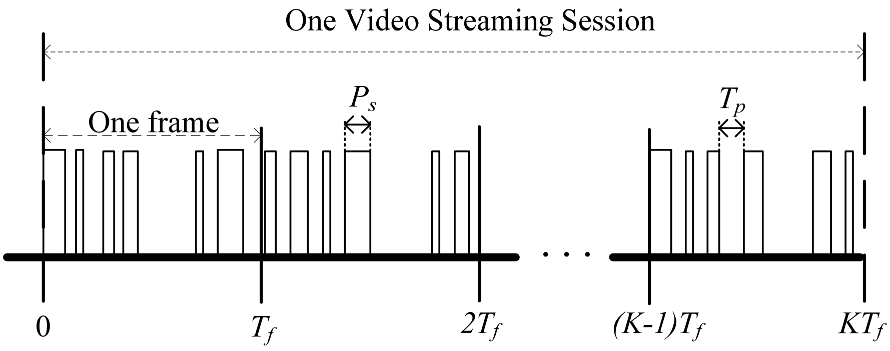


Fig. 2.4 : Packet trace of one video streaming session model

Fig. 2.5 shows the Packet trace of one HTTP session model. The interactive class traffic can be modeled as a sequence of packet calls (pages), and each packet call consists of a sequence of packet arrivals, which is composed of a main object and several embedded objects [22]. Four parameters, including the inter-arrival time $T_{reading}$ (reading time), main object size S_m, embedded object size S_e, the number of embedded objects per packet call N_e, and the packet inter-arrival time T_p are used in this model.

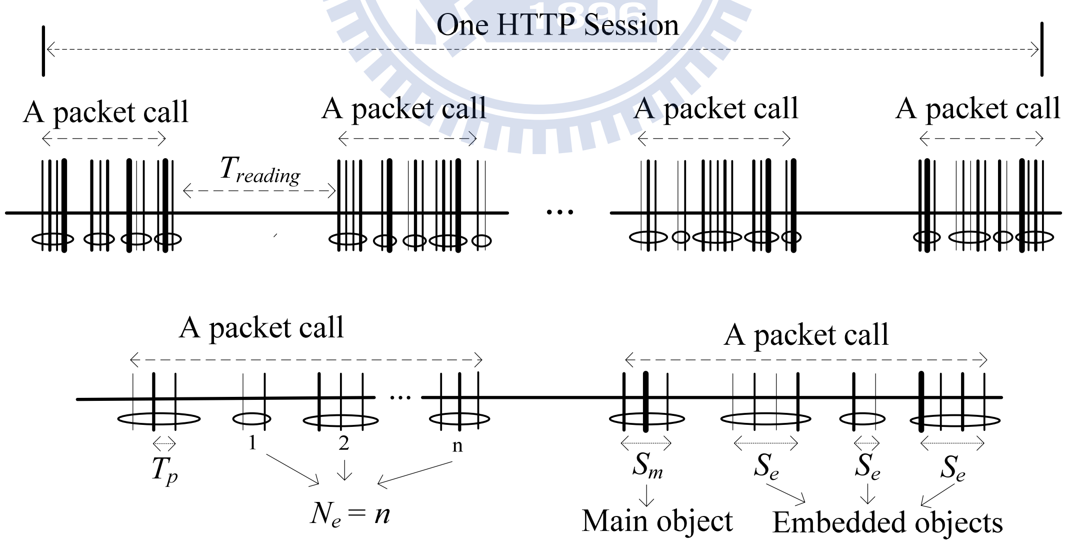


Fig. 2.5 : Packet trace of one HTTP session model

The background class traffic is modeled as a sequence of file downloads [22] and is shown in Fig. 2.6. Denote the size of each file by S_f, and the inter-arrival time between each file by T_f.

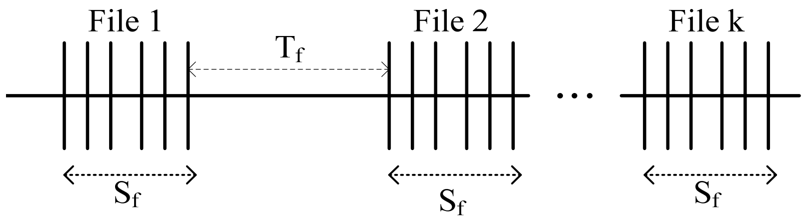


Fig. 2.6 : Packet trace of a typical FTP session model

Chapter 3

Preference Value-Based Cell Selection (PVCS) Scheme

3.1 Introduction

The proposed preference value-based cell selection (PVCS) scheme is composed of three stages, *candidate cells selection*, *preference value calculation*, and *target cell determination*. As shown in Fig. 3.1, for a MS's call request, the *candidate cells selection* is used to filter out unsuitable cells. All suitable cells form candidate cell set **C**, where **C**=$\{C_1, C_2, \ldots, C_K\}$. The *preference value calculation* calculates each preference value P_i of candidate cell C_i, $i = 1, 2, \ldots, K$, in the candidate cell set. These preference values are evaluated by considering the factors of loading, QoS, and mobility to maximize overall system utilization, maintain the call request's QoS requirements, and minimize handoff occurrence frequency. Ultimately, the *target cell determination* selects a best-fit cell for the call request of a MS. In the following, each stage is described in details.

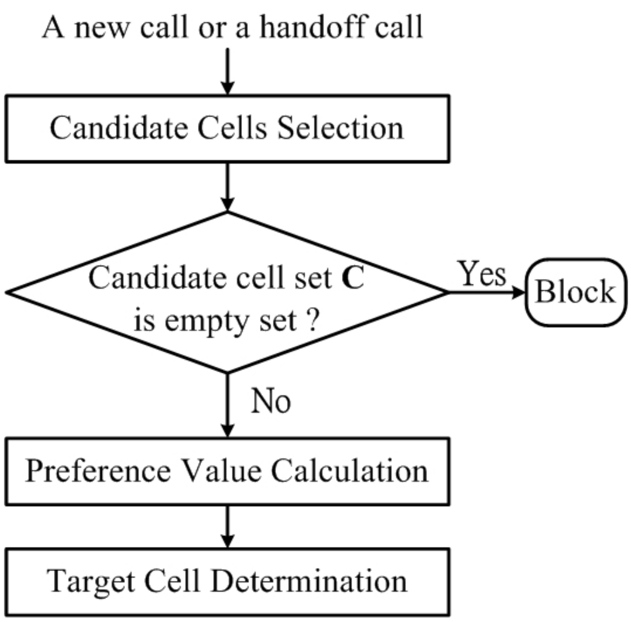


Fig. 3.1 : The block diagram of PVCS scheme

3.2 Candidate Cells Selection Stage

This is the first stage to sift out the candidate cells for the call request from all cells according to *received signal strength constraint*, *cell loading constraint* and *dwell time constraint*. A feasible cell has to meet these three constraints so as to be included in the candidate cell set **C** for a call request. If there is no cell in the candidate cell set **C**, the call request is blocked.

3.2.1 *Received Signal Strength Constraint*

The MS measures the received signal strength of pilot or beacon signal from the neighboring BSs or APs in order to pick out the cells which offer sufficient connection quality. If the received signal strength of pilot/beacon from cell i, denoted by RSS_i, exceeds a given received signal strength threshold RSS_{th}, the cell i will be categorized as an available cell which offer sufficient connection quality. In addition, the different power characteristics of different wireless radio interfaces make the predefined received signal strength threshold different.

3.2.2 *Cell Loading Constraint*

This constraint is used to guarantee that the admittance of a call request will not influence the QoS requirements of existing connections. The admission controller gathers loading information from all available cells. Assume that a call request is required to notify the BSs of its QoS requirements when it asks to access one cell to transmit data. The QoS requirements contain maximum bit rate, packet error ratio, transfer delay, etc. [24] Consequently, the loading intensity of cell *i* before admitting a new call request, denoted by $\rho_i\,(0 \le \rho_i \le 1)$, can be calculated as the sum of the loading intensity of existing call requests in the cell *i*, $\rho_i = \sum_{e=1}^{N} \rho_e$, where *N* is the number of existing call requests in the cell *i* [18].

Moreover, if infinite buffer size is assumed, the equivalent capacity can be derived as mean bit rate [26]. Thus we define the mean bit rate of a call request as its equivalent capacity to estimate the cell loading intensity increment $\Delta\rho$ when the call request enters the cell. If the call request is admitted by cell *i*, the cell loading intensity should not exceed a predefined threshold, ρ_{th}, which is set by the radio network planning. The cell loading constraint can be expressed by

$$\rho_i + \Delta\rho \le \rho_{th}. \tag{3.1}$$

Otherwise, the cell will be excluded from the candidate cell set.

In the WCDMA system, the loading increment $\Delta\rho$ can be estimated as [18]

$$\Delta\rho = (1+f)\frac{1}{1+W/(R\cdot v\cdot E_b/N_0)}, \tag{3.2}$$

where *f* is the other cell to own cell interference ratio, *W* is the chip rate of the WCDMA system, *R* is the bit rate of the new call request, *v* is the activity factor of the new call request, and E_b/N_0 is the bit-energy divided by noise spectral density for the required link quality of the new call request.

In the OFDMA-based WMAN system, the mean equivalent capacity of WMAN can be estimated as $4 \times q \times L \times N / T$ (bps). Then the loading increment $\Delta\rho$ can be estimated as

$$\Delta\rho = R \times v / (4 \times q \times L \times N / T), \tag{3.3}$$

In the WLAN system, the measurement-based cell loading estimation is used. Let T_s be the total busy occupation transmission time consisting of successful transmission time and collision time in the latest observation duration T_d. The loading of cell i is defined as $\rho_i = T_s / T_d$. The available cell i will be included in the candidate cell set if the following condition is satisfied,

$$\rho_i \leq \rho_{th}. \tag{3.4}$$

Note that the values of ρ_{th} in WCDMA, WMAN, and WLAN systems could be different.

3.2.3 *Dwell Time Constraint*

Generally speaking, if an MS can stay in the cell as long as possible, the MS's call request has high probability to finish data transmission in this cell. This also implies that the handoff occurrence frequency and signaling overhead for handoffs could be reduced. Assume that the maximal dwell time of an MS, which is acquired from the diameter of the cell i divided by the estimated velocity of the MS, is $T_{maximum,i}$. The dwell time $T_{dwell,i}$ for an MS in cell i can be calculated according to the estimated velocity, position, and direction of motion of the MS and cell coverage by using (2.7) and (2.8). Let $x_i = T_{dwell,i} / T_{maximum,i}$. $x_i = 1$ means that the MS travels along the diameter of the cell i and has larger chance to reduce handoff occurrence frequency. On the contrary, if x_i is smaller than a predefined threshold x_{th}, this means that the MS would enter and leave the cell i quickly and has high probability to initiate handoff. Note that the values of x_{th} in WCDMA, WMAN, and WLAN systems could be different.

Accordingly, the constraint is designed to check if the dwell time for an MS in cell i is too temporal to be suitable for the candidate cell. That is

$$x_i \geq x_{th}. \tag{3.5}$$

Otherwise, the cell will be excluded from the candidate cell set.

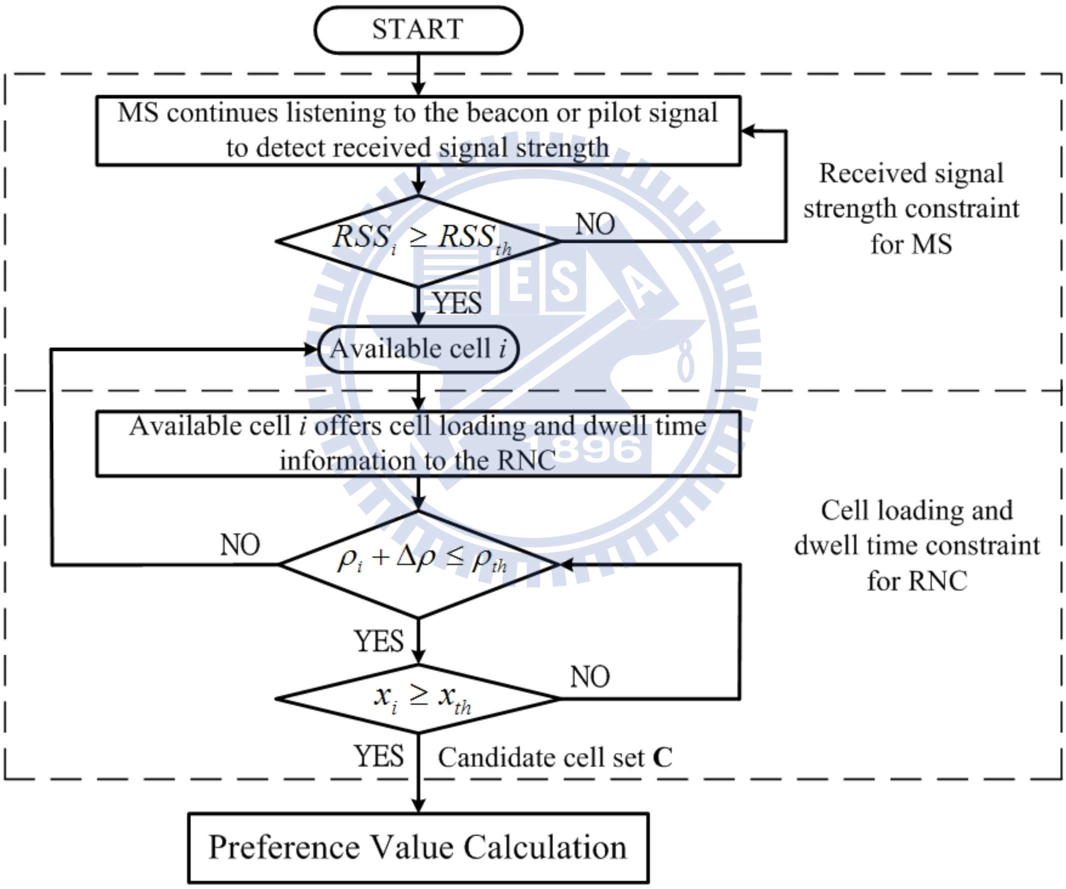


Fig. 3.2 : The flow chart of candidate cells selection

3.3 Preference Value Calculation Stage

After obtaining candidate cells for the call request, all candidate cells in **C** compete with each other to serve the call request according to their preference values. The meaning of preference value is to judge the degree of suitability for the target cell, which considers maximizing overall system utilization, maintaining the call request's QoS requirements, and decreasing the number of handoff. To achieve these goals, the preference value of candidate cell C_i, denoted by P_i, is defined as a linear combination of three factors given by

$$P_i = \alpha L_i + \beta Q_i + \gamma M_i, \tag{3.6}$$

where L_i is the loading factor of candidate cell i, Q_i is the QoS factor of candidate cell i, M_i is the mobility factor of candidate cell i, and α, β, γ are the weights of different factors whose relation is $\alpha + \beta + \gamma = 1$. The meaning of the three factors and how to design these factors are described as follows.

3.3.1 *Loading Factor*

The main concept of loading factor is to strike a balance between system utilization and cell loading. When a call request arrives, the PVCS scheme prefers to arrange it to the cell which can minimize overall cell loading differences. Through load balancing, it can achieve the objective of maximizing overall system utilization. Accordingly, the loading factor L_i can be defined as

$$L_i = \frac{1}{1 + \sum_{\substack{j=1 \\ j \neq i}}^{K} \left| \rho_i' - \rho_j \right| + \sum_{\substack{j=1 \\ j \neq i}}^{K} \sum_{\substack{k=1 \\ k \neq i \\ k \neq j}}^{K} \left| \rho_j - \rho_k \right|}, \tag{3.7}$$

where ρ_i' is the loading intensity of cell i after accepting new call request, ρ_j and ρ_k are the loading intensity of cell j and k before accepting new call request. In the denominator of equation (3.8), the first summation represents the differences in loading intensity between the cell *i* if the new call request is accepted and other cells. The last dual summation represents all combinations of loading intensity differences except the cell *i*. Obviously, if the denominator of L_i is smaller, it implies that the new call request would cause less loading difference if it is admitted by C_i, which is more likely to be a target cell.

3.3.2 *QoS Factor*

Utility is a measurement of call request's satisfaction level with the perceived QoS. The different forms of utility function characterize different elastic traffic class. In this thesis, voice services are assumed to be constant bit rate (CBR) traffic. Its QoS requirements on data rate, packet delay, packet dropping rate are so stringent that its utility function can be represented by a steep concave function. Video and HTTP services are assumed to be variable bit rate (VBR) traffic. Their QoS requirements are less stringent than voice services. Thus the slope of utility function is gentler than voice services. FTP services are assumed to be available bit rate (ABR) and greedy traffic, which means more data rate leads higher satisfaction level. An increasing concave function can describe its utility. Based on these utility concepts, a QoS factor Q_i for each candidate cell *i* is expressed as a product of three QoS-related utility functions, which is given by

$$Q_i = U(B_i) \times U(D_i) \times U(R_i), \tag{3.8}$$

where $U(B_i)$, $U(D_i)$, and $U(R_i)$ are the normalized utility functions of data rate, packet delay, packet dropping rate for candidate cell *i*, respectively. Note that the last two utility functions are only used for real time services. As shown in Fig. 3.2, Fig. 3.3, Fig. 3.4, if a candidate cell has greater QoS measures to fulfill the QoS requirements of the call request during the capability negotiation, then the utility values calculated from utility functions would increase exponentially. On the contrary, if a candidate cell does not have sufficient QoS measures to satisfy the QoS requirements of the call request, the utility values would be zero.

Therefore, the utility functions of data rate for four traffic classes described in Section 2.4 are defined as

$$U(B_i) = \max\left\{1 - e^{a_i - b_i \times B_i}, 0\right\}, \;\; a_i \geq 0, \; b_i \geq 0, \tag{3.9}$$

where B_i is the allowed data rate measured in the candidate cell i, a_i is the requirement parameter, b_i is the elasticity parameter, and $B_{y,req}$, y=*voice*, *video*, *HTTP*, and *FTP* denote the data rate requirement of the call request for four traffic classes, respectively. Note that the allowed data rate measured in WCDMA can be obtained by (2.1), the achievable modulation order in WMAN can be estimated by (2.2), (2.3), and the allowed data rate measured in WLAN is obtained by measurement-based cell loading intensity estimation. Besides, the larger value of requirement parameter a_i means higher data rate requirement and the larger value of elasticity parameter b_i means steeper curve, that is, less elasticity in data rate requirement. To ensure $U(B_i) \in [0,1]$, we define $B_{y,req} = a_i / b_i$.

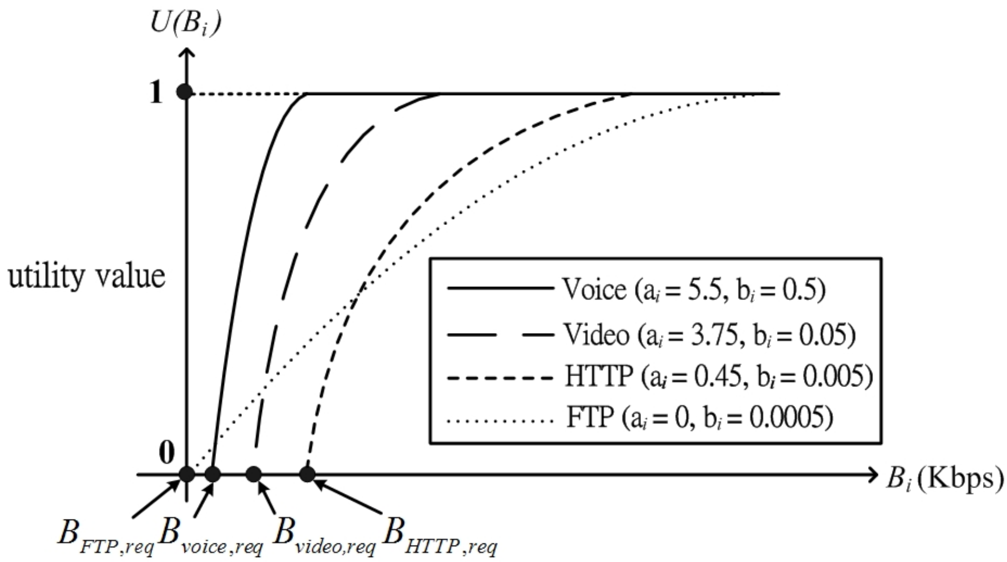


Fig. 3.3 : Utility functions of data rate for four traffic classes

Moreover, the utility functions of packet delay are defined as

$$U(D_i) = \max\{1 - e^{c_i \times D_i - d_i}, 0\}, \quad c_i \geq 0, \ d_i \geq 0, \qquad (3.10)$$

where D_i is the average packet delay measured in the candidate cell i, c_i is the elasticity parameter, d_i is the requirement parameter, and $D_{y,req}$, y=*voice*, *video*, is the maximum delay tolerance of the call request, respectively. Note that the values of average packet delay for real time services are computed separately. Different traffic class has different average packet delay in the same candidate cell. In addition, the larger value of requirement parameter d_i means higher maximum delay tolerance and the larger value of elasticity parameter c_i means steeper curve, that is, less elasticity in delay tolerance. To ensure $U(D_i) \in [0,1]$, we define $D_{y,req} = d_i / c_i$.

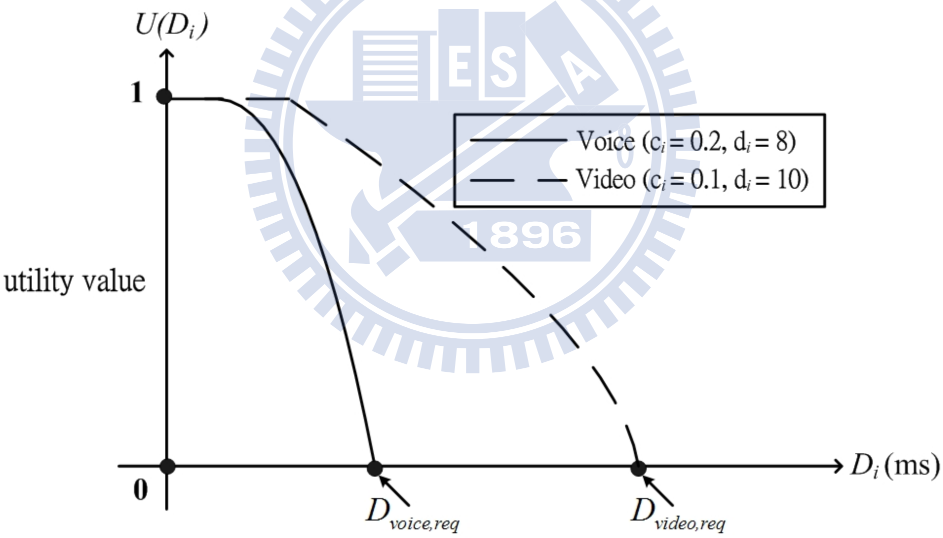


Fig. 3.4 : Utility functions of packet delay for real time services

Similarly, the utility functions of packet dropping rate are defined as

$$U(R_i) = \max\{1 - e^{e_i \times R_i - f_i}, 0\}, \quad e_i \geq 0, \ f_i \geq 0, \qquad (3.11)$$

where R_i is the average packet dropping rate measured in the candidate cell i, e_i is the elasticity parameter, f_i is the requirement parameter, and $R_{y,req}$, y=*voice*, *video*, is the maximum allowable dropping rate of the call request for real time services, respectively. Similar to the above case, the values of average packet dropping rate for real time services are computed separately. Furthermore, the larger value of requirement parameter f_i means higher maximum allowable packet dropping rate and the larger value of elasticity parameter c_i means steeper curve, that is, less elasticity in packet dropping rate. To ensure $U(R_i) \in [0,1]$, we define $R_{y,req} = f_i / e_i$.

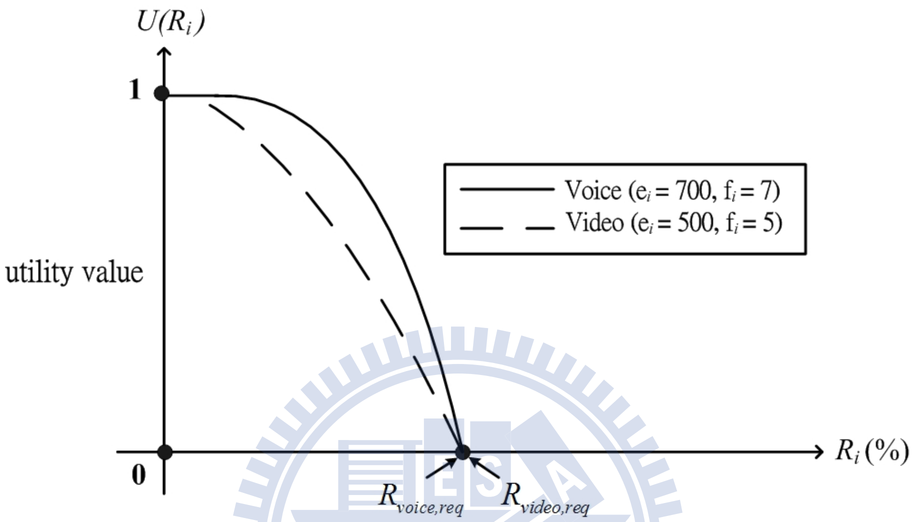


Fig. 3.5 : Utility functions of packet dropping rate for real time services

3.3.3 *Mobility Factor*

The mobility factor considers two aspects of an MS, inclusive of the dwell time and the relative position. In this thesis, the proposed PVCS scheme favors to arrange a high mobility MS to large cell for the purpose of avoiding frequent handoffs. A small cell that would incur more handoffs has a less chance of becoming the target cell.

For an MS, it is assumed that the average dwell time of total candidate cells is $T_{average}$. Let $r_i = T_{dwell,i} / T_{average}$. If r_i is larger than one, the MS has larger chance to finish data transmission in the large candidate cell *i*. However, if r_i is smaller than one, this means that the MS has high probability to initiate handoff when it enters the candidate cell *i*. Consequently, the mobility factor M_i for the aspect of dwell time can be defined as

$$M_{dwell,i} = \begin{cases} 0, & if\ \ r_i \le 0.25 \\ r_i - 0.25, & if\ \ 0.25 < r_i \le 1 \\ 0.75 + (r_i - 1), & if\ \ 1 < r_i \le 1.25 \\ 1, & if\ \ 1.25 < r_i \end{cases}. \tag{3.12}$$

On the other hand, the candidate cell i will be more suitable if the MS is nearer to the BS of candidate cell i. The mobility factor will be larger. In order to decrease the number of handoff, the mobility factor will get smaller if the MS is farther from the BS of candidate cell i. Therefore, the mobility factor M_i for the aspect of relative position can be defined as

$$M_{position,i} = \begin{cases} 1, & if\ \ d_{bm} \le cr_{i,th} \\ (cr_i - d_{bm})/(cr_i - cr_{i,th}), & if\ \ cr_{i,th} < d_{bm} \le cr_i \\ 0, & if\ \ cr_i < d_{bm} \end{cases}, \tag{3.13}$$

where d_{bm} is the distance between the BS of candidate cell i and the MS, cr_i is the cell radius of candidate cell i, and $cr_{i,th}$ is a predefined threshold. Note that the values of $cr_{i,th}$ in WCDMA, WMAN, and WLAN systems could be different. Finally, the mobility factor M_i can be calculated from the average of two aspects of an MS.

3.4 Target Cell Determination Stage

The preference value contains the preference from the viewpoints of the call request and the service provider. If the preference value of the candidate cell is maximal, it has the largest opportunity to satisfy the QoS requirement of call request and achieve the objective of service provider to maximize overall system utilization. Consequently, the *target cell determination* is formulated as an optimization problem given by

$$i^* = \arg\max_i \{P_i\}, \tag{3.14}$$

where i is the ith candidate cell in the candidate cell set $\mathbf{C}$, and i^* is the index of selected candidate cell for the call request.

Chapter 4

Simulation Results and Discussions

4.1 Simulation Environment

The simulation environment contains 7 subnetworks overlapping with each other, which subnetwork is as shown in Fig. 2.1. The system parameters in the heterogeneous wireless access environment are listed in Table 4.1. The channel model and pedestrian (3 km/hr) and normal mobility (30 km/hr) and high mobility (80 km/hr) models of MS have been introduced in Chapter 2.

Table 4.1: System parameters for WCDMA, WMAN, and WLAN

Parameters	**WCDMA**	**WMAN**	**WLAN**
Cell radius	2 Km	2 Km	0.1 Km
Frame (slot) duration	10 ms	5 ms	9 us
Carrier frequency	2 GHz	2.5 GHz	2.4 GHz
Number of cells	7	7	28
Loading intensity threshold (ρ_{th})	0.85	1	0.85
Dwell time threshold (x_{th})	0.05	0.05	0.2
the other cell to own cell interference ratio (f)	0.55	——	——
Number of subchannels (L)	——	4	——
Number of data subcarriers per subchannel (q)	——	48	——
Number of slots per frame (N)	——	16	——
Capacity	——	——	11 Mbps

4.2 Traffic Model Parameters and QoS Requirements

As described in chapter 2, there are four classes of traffic considered. The traffic model parameters for conversational, streaming, interactive, and background traffic classes are shown in Table 4.2, 4.3, 4.4, and 4.5, respectively.

Table 4.2: Conversational Class Traffic Model Parameters

Component	Distribution	Parameters
ON time	Exponential	Mean = 1 sec
OFF time	Exponential	Mean = 1.35 sec
Packets per second	Deterministic	50
Packet size	Deterministic	28 bytes
Call holding time	Normal	Mean = 90 sec, Variance = 20 sec
Data rate during active period	———	11.2 Kbps
Activity factor	———	0.426
Mean data rate	———	4.77 Kbps

Table 4.3: Streaming Class Traffic Model Parameters

Component	Distribution	Parameters
Inter-arrival time between each video frame (T_f)	Deterministic	100 ms
Number of packets (slices) in a video frame (N_s)	Deterministic	8
Packet size (P_s)	Truncated Pareto	Min. = 40 bytes, Max. = 250 bytes Mean = 100 bytes, α = 1.2
Inter-arrival time between packets in a frame (T_p)	Truncated Pareto	Min. = 2.5 ms, Max. = 12.5 ms Mean = 6 ms, α = 1.2
Call holding time	Normal	Mean = 120 sec, Variance = 30 sec
Data rate during active period	———	80 Kbps
Activity factor	———	0.8
Mean data rate	———	64 Kbps

Table 4.4: Interactive Class Traffic Model Parameters

Component	Distribution	Parameters
Main object size (S_m)	Truncated Lognormal	Min. = 100 bytes, Max. = 2 Mbytes Mean = 10710 bytes, Std. dev. = 25032bytes
Embedded object size (S_e)	Truncated Lognormal	Min. = 50 bytes, Max. = 2 Mbytes Mean = 7758 bytes, Std. dev. = 126168 bytes
Number of embedded objects per page (N_e)	Truncated Pareto	Min. = 2, Max. = 53 Mean = 5.64, α = 1.1
Inter-arrival time between each page ($T_{reading}$)	Exponential	Mean = 30 sec
Packet size	Deterministic	Chop from objects with size 1500 bytes
Packet inter-arrival time (T_p)	Exponential	Mean = 0.13 sec
Call holding time	Normal	Mean = 120 sec, Variance = 30 sec
Data rate during active period	———	92.3 Kbps
Activity factor	———	0.136
Mean data rate	———	12.55 Kbps

Table 4.5: Background Class Traffic Model Parameters

Component	Distribution	Parameters
File size (S_f)	Truncated Lognormal	Min. = 50 bytes, Max. = 5 Mbytes Mean = 2 Mbytes, Std. dev. = 722 Kbytes
Inter-arrival time between each file (T_f)	Exponential	Mean = 180 sec
Packet size	Deterministic	3000 bytes
Call holding time	Normal	Mean = 180 sec, Variance = 40 sec
Data rate during active period	———	88.9 Kbps
Activity factor	———	1
Mean data rate	———	88.9 Kbps

Different traffic classes have different QoS requirements. The QoS requirements of each traffic class are listed in Table 4.6.

Table 4.6: The QoS Requirements of each traffic class

Traffic class	Requirement	Value
Conversational (Voice)	Required BER	10^{-3}
	Required E_b/N_o	4 dB
	Max. delay tolerance	40 ms
	Max. allowable packet dropping rate	1%
Streaming (Video)	Required BER	10^{-4}
	Required E_b/N_o	3 dB
	Max. delay tolerance	100 ms
	Max. allowable packet dropping rate	1%
Interactive (HTTP)	Required BER	10^{-6}
	Required E_b/N_o	2 dB
Background (FTP)	Required BER	10^{-6}
	Required E_b/N_o	1.5 dB

4.3 UGT based network selection scheme

The proposed PVCS scheme is compared with the UGT based network selection scheme [12]. When a new call or a handoff call arrives, UGT will find which networks are suitable for the call request first. After obtaining the candidate networks, UGT will compute the utility value from the satisfaction of QoS requirements of the call request and the network preference from predefined cooperative game for each candidate network. Finally, by choosing the maximum linear combination of utility values and network preference from all candidate networks, the most suitable network for the call request can be obtained.

4.4 Simulation Results and Discussions

It is assumed that a call request could only connect to one cell at the same time in this thesis. For each cell, it is assumed that the new call arrival rate of conversational, streaming, interactive, and background traffic class calls in the heterogeneous wireless access environment are AR, $AR\times1/3$, $AR\times1/3$, and $AR\times1/6$ (calls/second), respectively, where AR is the unit arrival rate. In the simulation, AR is chosen from 0.1 to 0.9.

Fig. 4.1 shows the new call blocking rate. It can be found that PVCS has lower new call blocking rate in the high arrival rate. The reason is that PVCS chooses the cell which can minimize overall cell loading differences by using loading factor in order to achieve load balancing. However, UGT selects the cell which has the most resource. It may cause non-real-time calls to be blocked when the cell loading is close to the predefined threshold. The result comparison also implies that the system with PVCS can accommodate more calls than the system with UGT when the arrival rate becomes high. Number of accommodated calls is shown in Fig. 4.2.

Fig. 4.3 shows the handoff call dropping rate, which is defined as the probability that a call will be forced terminated during the call holding time. It can be found that PVCS has lower handoff call dropping rate. The reason is that PVCS utilizes dwell time constraint to reduce forced termination probability and the number of handoff. Nevertheless, UGT may still have the chance to permit a few high mobility MSs to enter and leave the WLAN cells quickly. Some of these MSs may have no enough time to complete handoff procedure due to contention and backoff. Number of total handoff calls is shown in Fig. 4.4.

Moreover, it can be found that the trends of new call blocking rate and handoff call dropping rate are different. That is because the system always reserves 5% resource for handoff calls. When the loading intensity of one cell exceeds 95% of

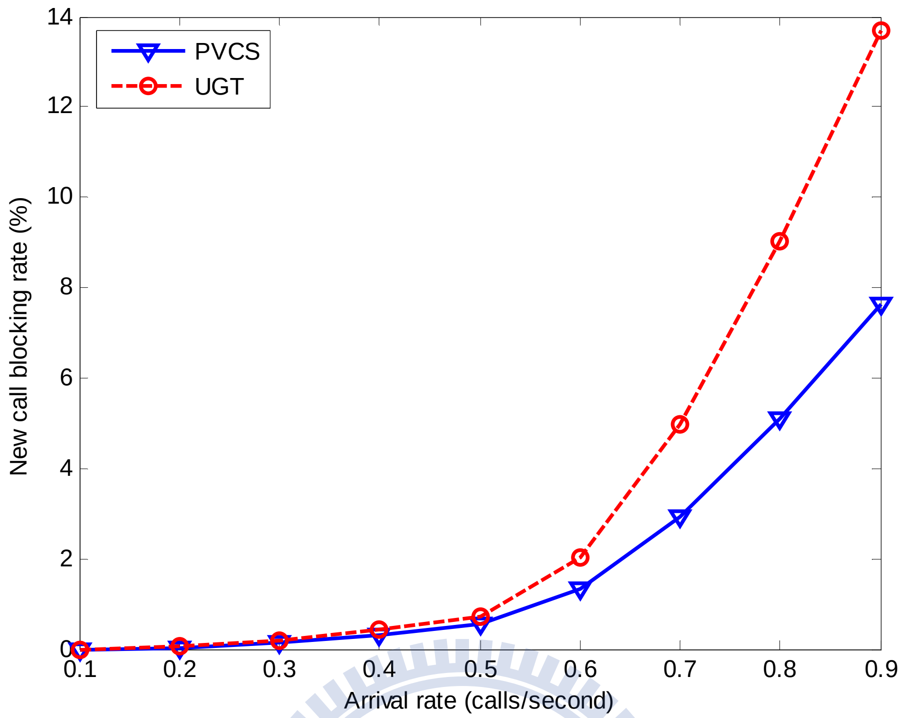


Fig. 4.1 : New call blocking rate

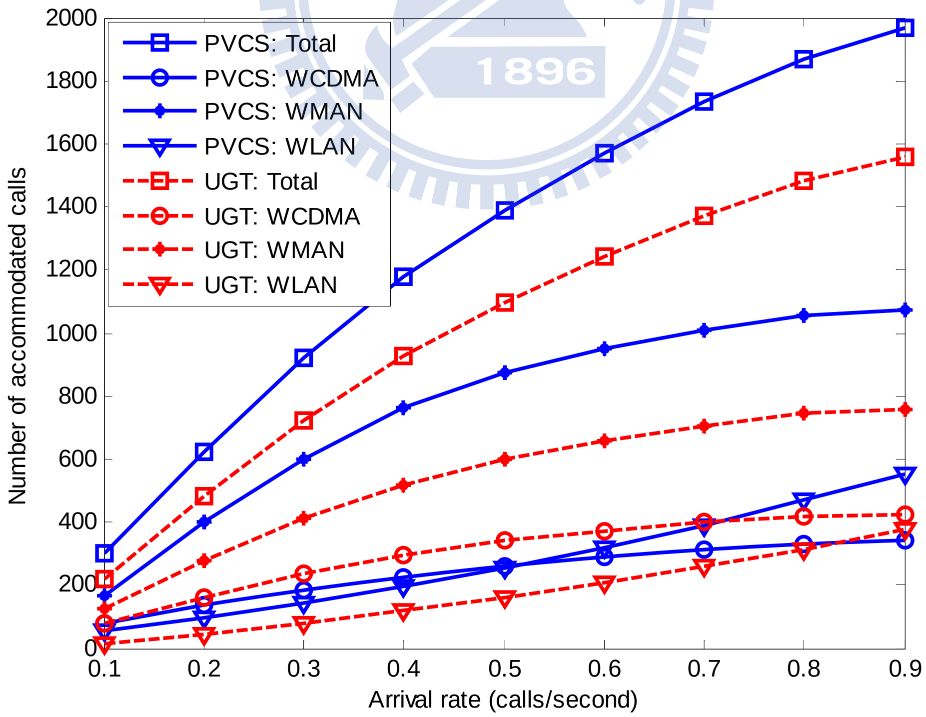


Fig. 4.2 : Number of accommodated calls

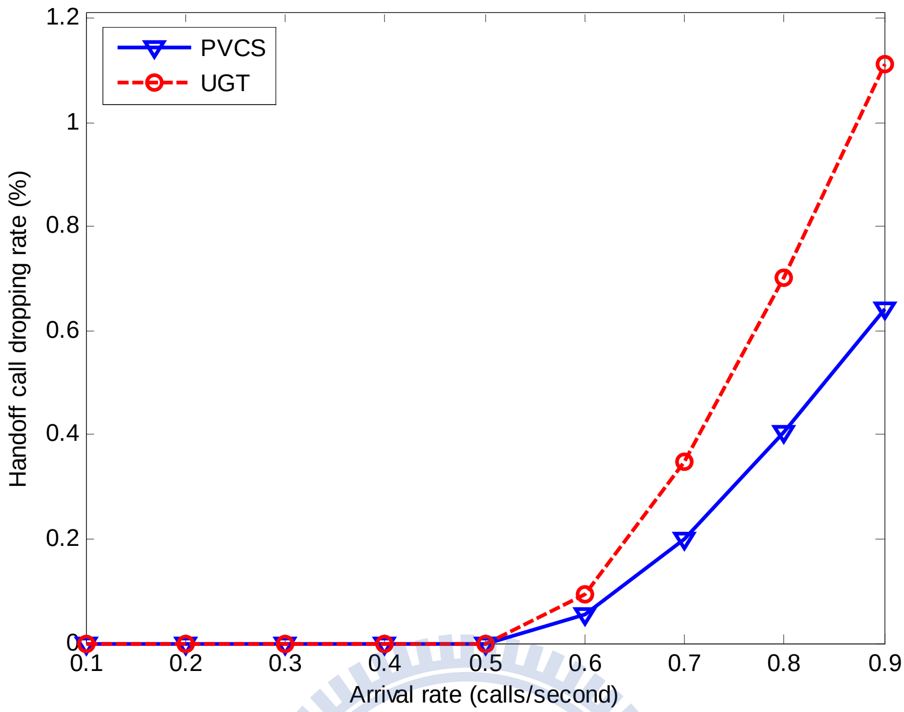


Fig. 4.3 : Handoff call dropping rate

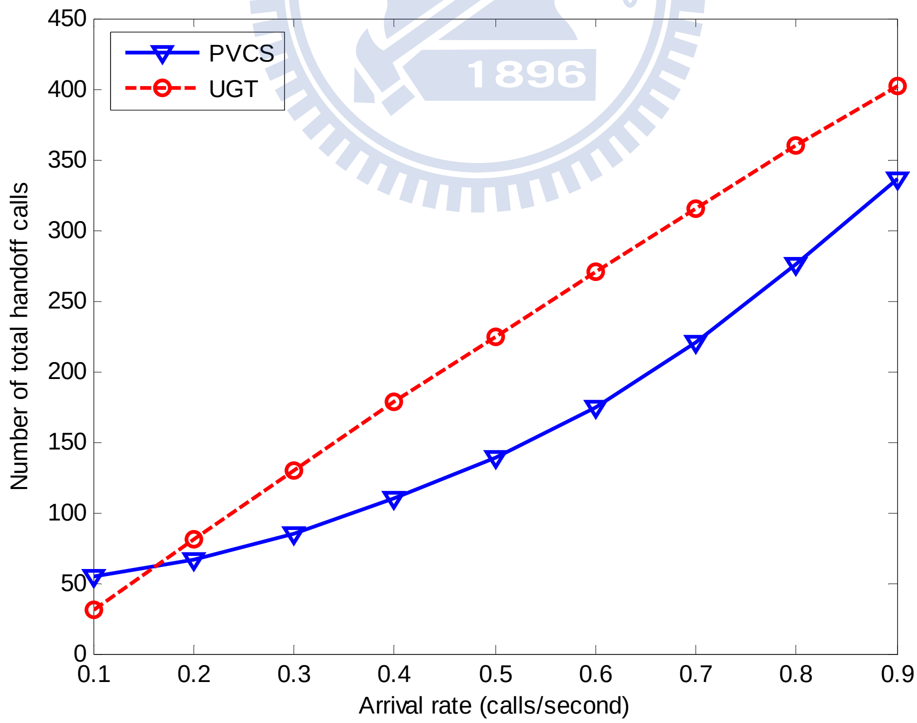


Fig. 4.4 : Number of total handoff calls

predefined threshold, a new call will be blocked immediately. On the other hand, a handoff call will not be dropped until the loading intensity reaches predefined threshold. This causes the new call blocking rate to increase exponentially, while handoff call dropping rate rises slightly when the arrival rate becomes high.

Fig. 4.5 shows the handoff occurrence frequency, which is defined as the average number of handoff that a call has experienced during the call holding time. Generally, the total handoff occurrence frequency in PVCS is about 20% lower than that in UGT. The reason is that PVCS uses dwell time constraint to reduce the number of handoff and the mobility factor in PVCS has higher influence on target cell decision than that in UGT. Besides, it can be found that PVCS has lower real-time and non-real-time handoff occurrence frequency in the high arrival rate. Since the high mobility MS with PVCS has more chances to finish data transmission in the large cell than that with UGT.

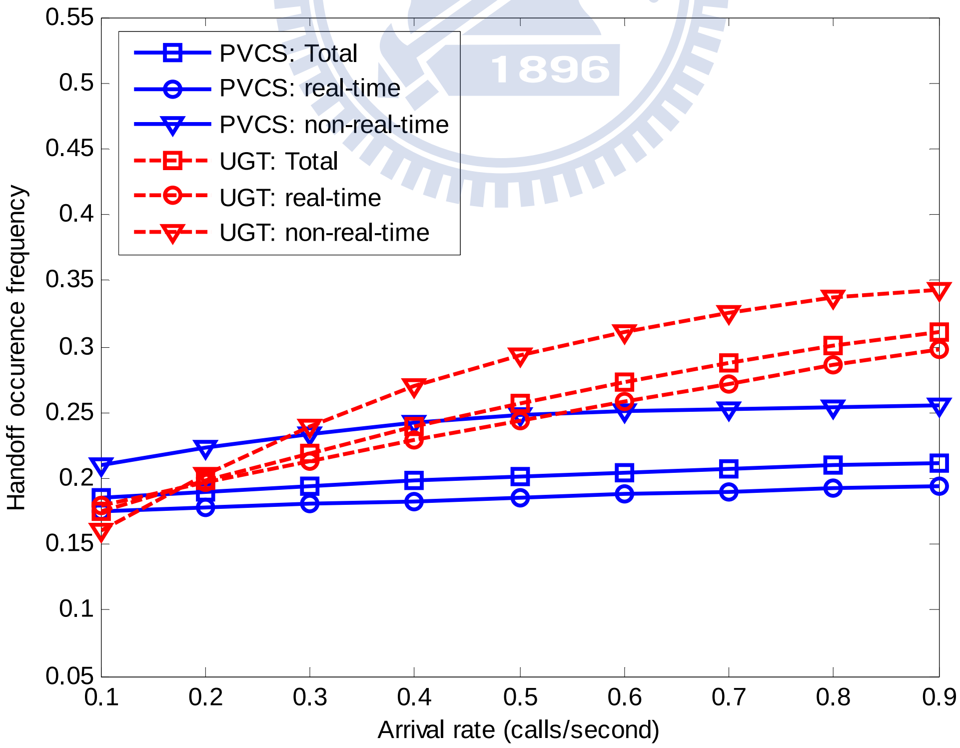


Fig. 4.5 : Handoff occurrence frequency

Fig. 4.6 shows the total throughput and throughput of each system. It can be found that PVCS has higher total throughput than UGT. Fig. 4.7 (a) and (b) depict the number of accommodated real-time calls and non-real-time calls, respectively. It can be found that PVCS allows more non-real-time calls of WLAN than UGT does. By using PVCS, the non-real-time calls will tend to select WLAN cells, which have the highest capacity by loading factor, so the throughput increment would be significant. Besides, we can also find that the real-time calls in WCDMA cells are more than those in WLAN cells when the arrival rate is low. It is because the allowed data rate in WCDMA and WLAN systems is much higher than the calls' requirement. The real-time calls will tend to select larger WCDMA cell because of mobility factor. On the other hand, PVCS allows more non-real-time calls in WCDMA cells than UGT does when the arrival rate is high. The reason is that PVCS allows more real-time calls to select WMAN cells than UGT does, so WCDMA cells would have enough resource to accommodate more non-real-time calls. Therefore, the throughput of WCDMA in PVCS gradually approaches that in UGT.

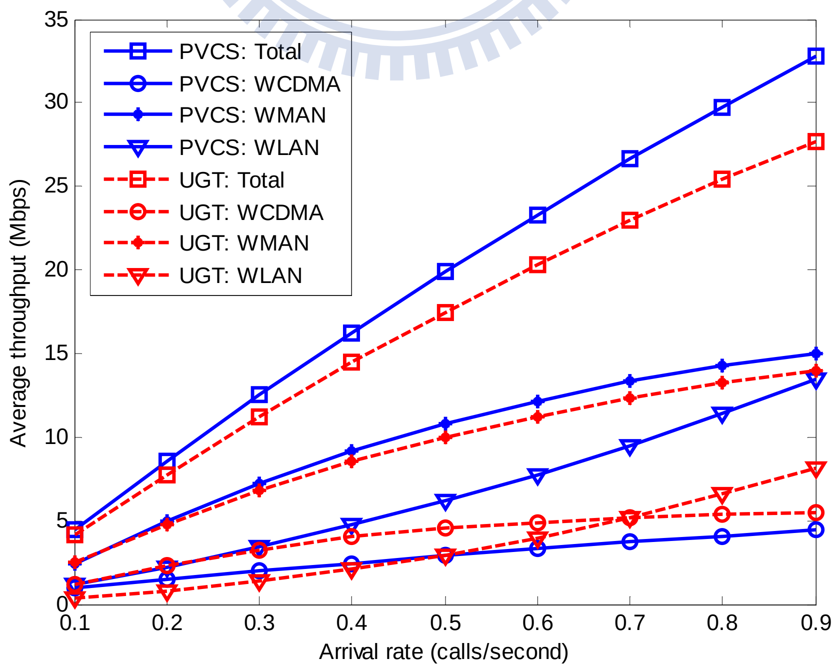
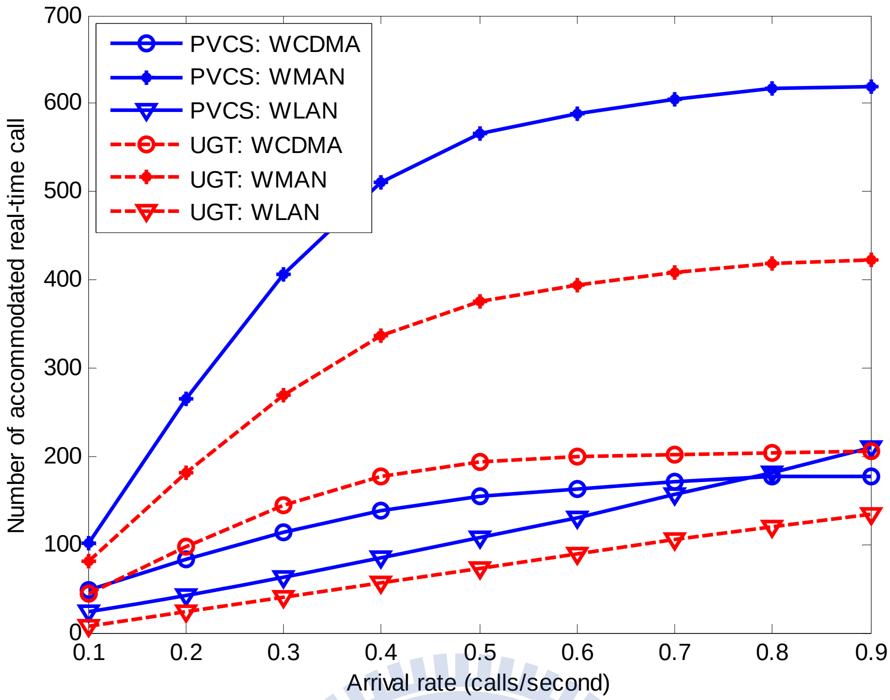
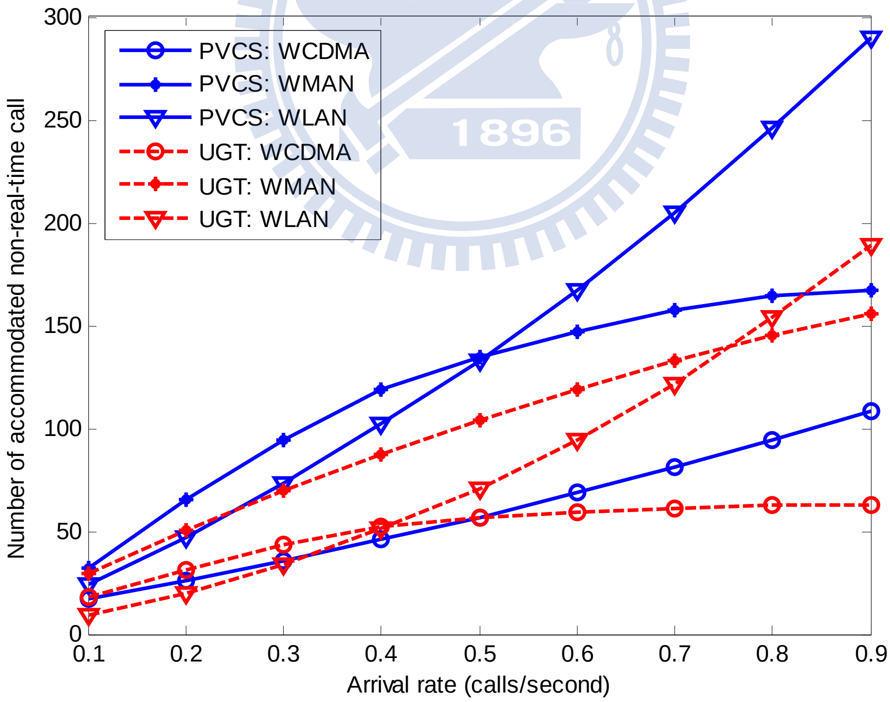


Fig. 4.6 : Total throughput and throughput of each system



(a) Number of accommodated real-time calls



(b) Number of accommodated non-real-time calls

Fig. 4.7 : (a) Number of accommodated real-time calls (b) Number of accommodated non-real-time calls

The average delay of voice and video calls in the heterogeneous wireless networks are shown in Figs. 4.8 and 4.9, respectively. It can be found that the results of average delay with PVCS and UGT are almost the same in WCDMA and WMAN systems and the delay requirements are all satisfied. The reason is that voice and video calls have the highest priority and the scheduler will serve the real-time calls first. As for the result in WLAN systems, the average delay with UGT only increases slowly. It is because the WLAN cell with the most available resource for the real-time calls is not necessarily the most suitable cell if the mobility of MS is considered. However, it is equally important for the available resource and mobility to decide the target cell in PVCS. Accordingly, the average delay with PVCS is kept low.

The packet dropping rate of voice and video calls are shown in Figs. 4.10 and 4.11, respectively. It can be found that the maximum packet dropping rate requirement is satisfied in both schemes. However, the packet dropping rate of WLAN system is higher in UGT than that in PVCS. The reason is similar to the average delay of WLAN system in UGT. More voice and video calls with high mobility in UGT are allowed to enter the WLAN cell than that in PVCS. Therefore, it increases collision probability and has more chances to exceed the delay tolerance bound. On the contrary, PVCS uses dwell time constraint to prevent high mobility MSs from entering the WLAN cell, so the collision probability can be decreased. Moreover, PVCS would jointly consider the load balancing and handoff occurrence frequency, and the results also show that the candidate cell with the most available resource for the real-time calls is not necessarily the most suitable one. Consequently, the packet dropping rate in WLAN systems for the real-time calls would be improved significantly.

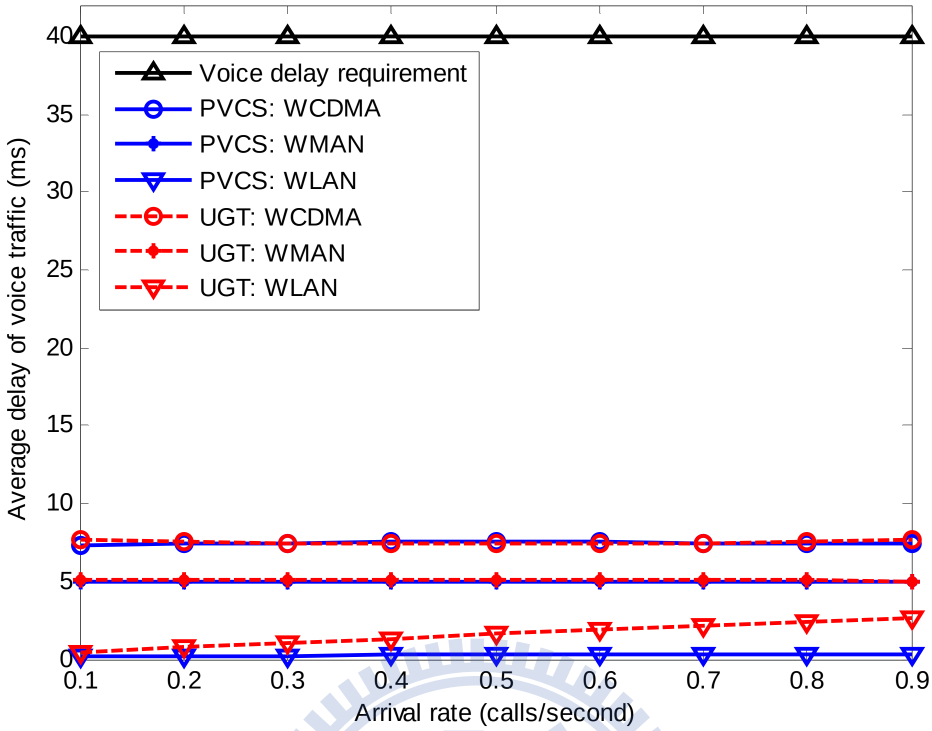


Fig. 4.8 : Average delay of voice traffic

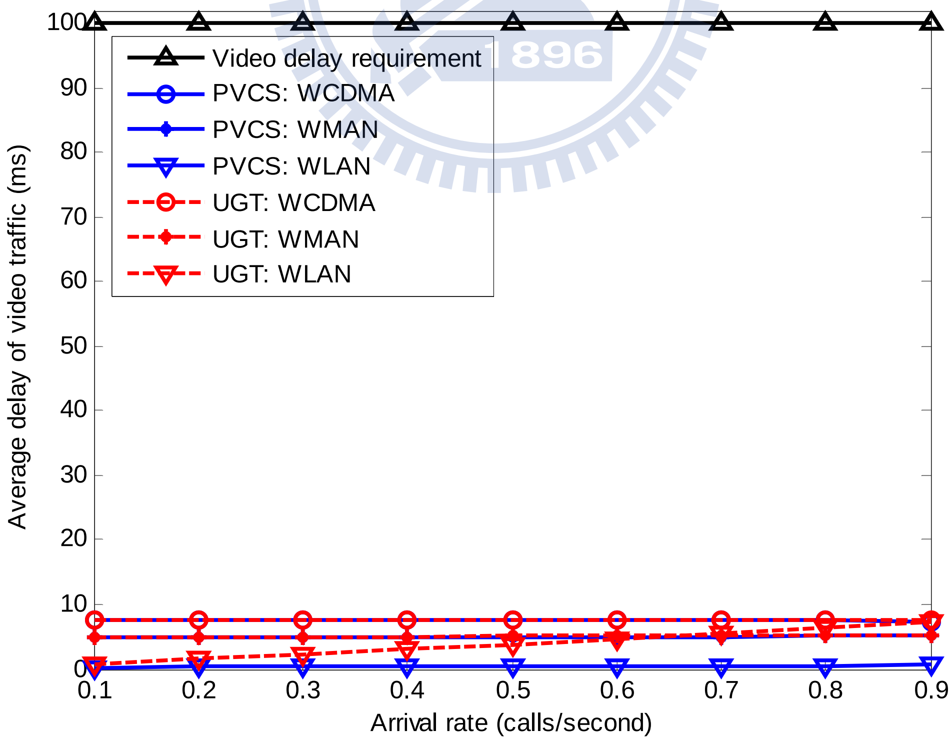


Fig. 4.9 : Average delay of video traffic

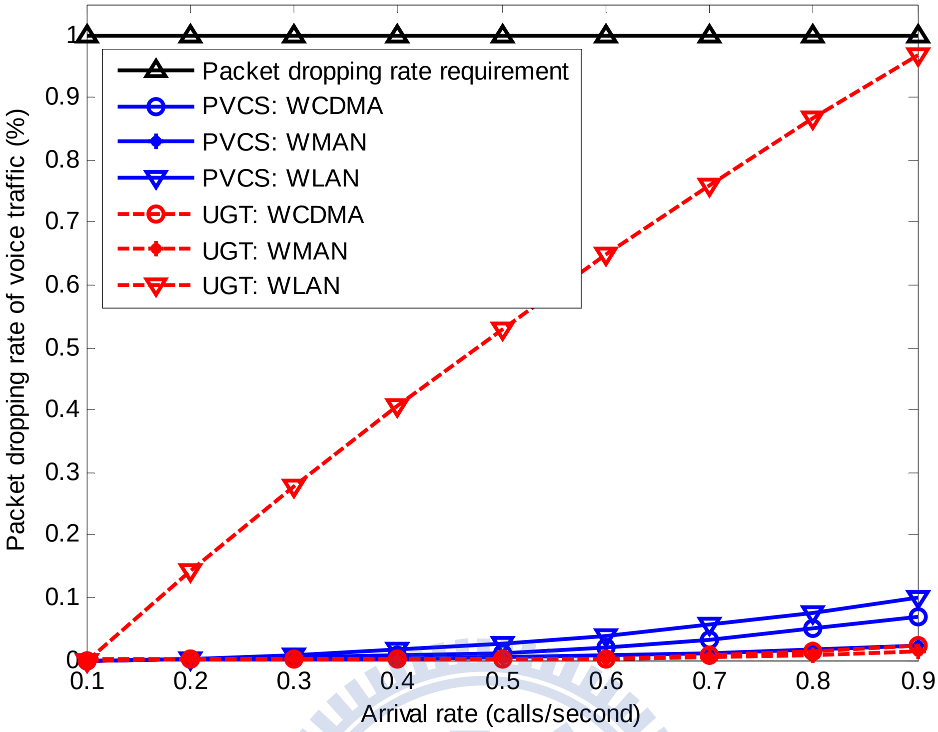


Fig. 4.10 : Packet dropping rate of voice traffic

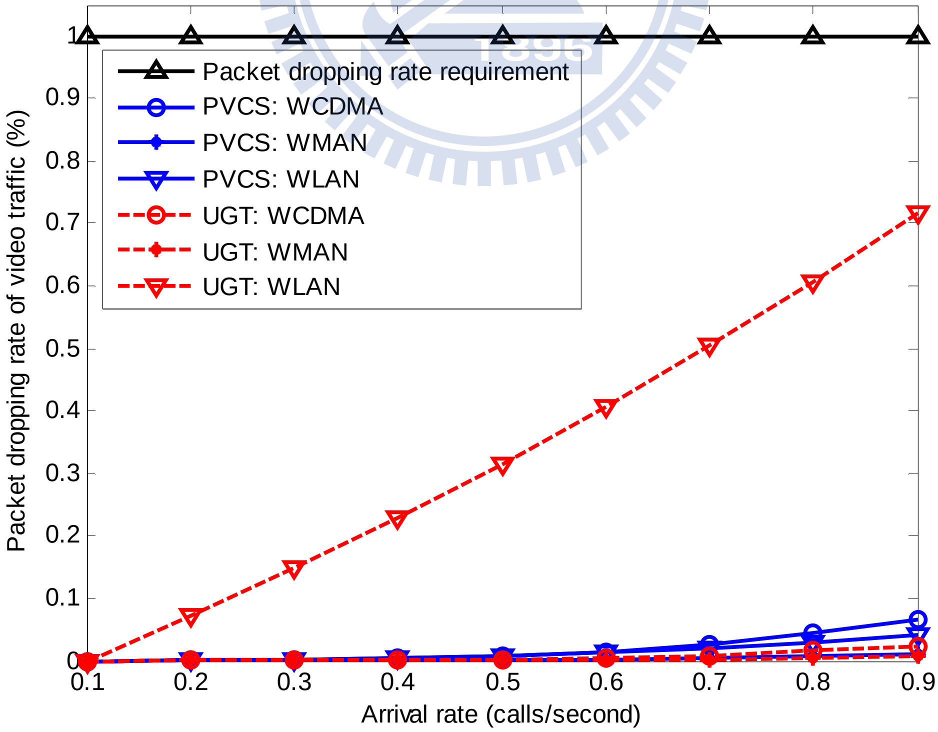


Fig. 4.11 : Packet dropping rate of video traffic

Chapter 5

Conclusions

In this thesis, a *preference value-based cell selection (PVCS)* scheme is proposed for heterogeneous wireless access environment, where four multimedia services are considered, including conversational, streaming, interactive, and background. The PVCS scheme contains three stages, *candidate cells selection*, *preference value calculation*, and *target cell determination*. The candidate cells selection is used to filter out unsuitable cells by checking three thresholds including the received signal strength constraint, cell loading constraint and dwell time constraint. All suitable cells form a candidate cell set. The preference value calculation of each cell in the candidate cell set is optimized by considering the factors of loading, QoS, and mobility to maximize overall system utilization, maintain the call request's QoS requirements, and minimize handoff occurrence frequency. Finally, the target cell, which has the maximum preference value, could be selected for the call request.

Simulation results show that PVCS scheme can achieve higher total throughput than UGT while satisfying the QoS requirements of each traffic class. The WLAN system has significant improvement in throughput and accommodates more non-real-time calls. In addition, the PVCS scheme has lower new call blocking rate and handoff call dropping rate than UGT, which means the heterogeneous wireless system with PVCS scheme can accommodate more calls than that with UGT when the arrival rate becomes high. Besides, the total handoff occurrence frequency in PVCS is about 20% lower than that in UGT because PVCS uses dwell time constraint to reduce the number of handoff. As a result, the handoff overhead can be reduced significantly. The average delay and packet dropping rate of real-time calls satisfies QoS requirements in PVCS and UGT, but the results in UGT is slightly higher than those in PVCS in WLAN. It is because that the cell with the most available resource for the real-time calls is not necessarily the most suitable one if the mobility of MS is considered.

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