Adaptive Resource Management in Two-Tier Wireless Networks

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ABSTRACT

In the next generation high-speed wireless networks, one of the most challenging issues will be supporting multimedia applications with different quality-of-service (QoS) requirements. Multimedia traffic, especially for the real-time variable bit rate (VBR) traffic, e.g. video, that occupies large amount of bandwidth. Inefficient bandwidth allocation may lead to under-utilization of network resources. This paper proposes two resource management schemes for multimedia services in two-tier wireless communication networks. A priority based resource reservation method will be proposed to adaptively reserve bandwidth in the resource management scheme 1(RMS 1). And a virtually adaptive based resource borrowing scheme (RMS 2) is presented to adjust the passive capacity to reduce the blocking probability of real-time calls. Simulation results show that the proposed schemes can reduce the call blocking and dropping probability for real-time and data calls to improve the system performance.

1: INTRODUCTIONS

There has been a rapid growth of wireless communications technology over the last decade. In a heterogeneous integrated wireless access environment, users are able to switch different access technologies based on their demands (e.g., bandwidth, mobility, application requirements…etc.), and expecting high reliability, QoS guarantees and seamless handoff. In order to support diversity applications with different QoS requirements, efficient resource management and call admission control (CAC) strategies are the key components in such a heterogeneous wireless system.

QoS provisioning for multimedia services in wireless networks is far more complex than in wired networks due to the limited link bandwidth resource and user mobility. For connections that require guaranteed services, a call is admitted to the network if and only if system has enough resources and without violating the service agreement level of the existing ones. For a mobile user, dropping an ongoing call is generally more unacceptable than blocking a new call request. Therefore, an guard-band based method is proposed to assign handoff calls with a higher priority over new calls in order to minimize the handoff dropping probability. However, there is always a trade off between the call blocking probability (CBP) and the call dropping probability (CDP), and the amount of reserved capacity should dynamically vary with the changing traffic conditions.

WiMAX, also known as IEEE 802.16, offers a high speed data and supports five types of QoS traffic for multimedia services over a lager coverage range. Unlike 802.11, WiMAX was designed specifically for deployment in outdoor environments. On the contrary, users of the IEEE 802.11 wireless local area network (WLAN) can connect to the Internet only in a limited range with an access point (AP). The limited coverage range of WLAN makes it difficult to fulfill the future of access to the network anywhere and anytime. The high traffic densities will force operators to resort to smaller cells. Therefore, a natural trend of combining WiMAX and WLAN will create a complete wireless solution for delivering high-speed Internet access to businesses, homes and hot spots. WiMAX access network may be used to support users who desire higher mobility over wider coverage areas, and broadband access based on the IEEE 802.11 specification to support users with relatively lower mobility over smaller geographical areas.

To guarantee QoS in the heterogeneous two-tier wireless network, we propose two resource management schemes (RMSs) in two-tier wireless networks. Each RMS includes the call admission control and resource reservation mechanism for multimedia services. The second RMS adapts a virtually adaptive resource borrowing mechanism to reduce the real-time CBP. For a multimedia service, especially for the real-time variable bit rate (VBR) traffic that exhibits highly bursty and non-stationary properties. Inefficient bandwidth allocation may lead to under-utilization of network resources or excessive traffic delay.

This paper is organized as follows. Section 2 surveys the related work and introduces IEEE 802.16e-2005 and IEEE 802.11 QoS architectures. Section 3 gives the system model and traffic types mapping between the WiMAX and the WLAN. Section 4 describes the system capacity, the proposed RMS. In section 5, the simulation model is addressed. Simulation results are presented in section 6. Finally, conclusions and future work are drawn in section 7.

2: RELATED WORK

In recent years, varieties of call admission control (CAC) and resource reservation schemes have been proposed to provide QoS guarantees for multimedia applications in wireless networks. The central role that the CAC plays in QoS provisioning in terms of signal quality, CBP, CDP, packet delay, loss rate and transmission rate. There are a number of surveys that classified the CAC into different design choices and approaches [1, 2, 3, 4]. The static guard band/guard channel approach was proposed by D. Hong and S. Rappaport [5]. This scheme kept a certain amount of channels for handoff calls exclusively and the remaining channels can be shared by both the new calls and the handoff calls. The handoff calls thus has higher priority over new calls, and as a result the reduction in the handoff probability comes at the expense of higher blocking rate [1]. Therefore, the guard band approach must, choose the number of reserved channels properly as a tradeoff between the new call blocking probability and the handoff dropping probability. Static guard band may not be efficient for varying traffic conditions in the wireless networks. Several adaptive resource reservation, CAC and bandwidth control mechanisms have been proposed to cope with the complex wireless network dynamically [6, 7, 8, 9]. Recently a dynamic admission control for WiMAX and a handoff algorithm for the hybrid network of WLAN and WMAX are proposed in [10, 11]. The former with static reservation scheme addresses a degradation of nonreal-time traffic in order to have more real-time connections in the system. The later proposed a seamless handoff mechanism in 802.16a and 802.11n to cope with the challenge in handoff between two different networks.

3: System Models

Figure 1 illustrates a two-tier network architecture, where a macrocell (WiMAX system)[12,13,14] is an overlap of several microcells (IEEE 802.11e WLAN)[15]. WiMAX system is served as a backbone for WLAN hot spots, where mobile users can access the resources by Wi-Fi or WiMAX. Both the WiMAX and WLAN systems contain new calls and 2 types of horizontal handoff calls in terms of the horizontal arriving handoff call and the horizontal departing handoff call. In general, the WLAN users are considered to be essentially stationary. In addition to the new call and the horizontal call, the WiMAX BS has to deal with other types of calls: the WLAN vertical handoff call (handoff from WLAN to WiMAX) and the overlap call (WiMAX call moving into WLAN coverage). It is difficult for WLAN AP to reserve bandwidth for this type of overlap calls due to the MAC protocol of WLAN is based on CSMA/CA. When a mobile host enters the WLAN coverage, instead, it is handled by the WiMAX BS. On the contrary, if a mobile moves from the WLAN to the WiMAX, the WLAN vertical handoff procedure is initiated.

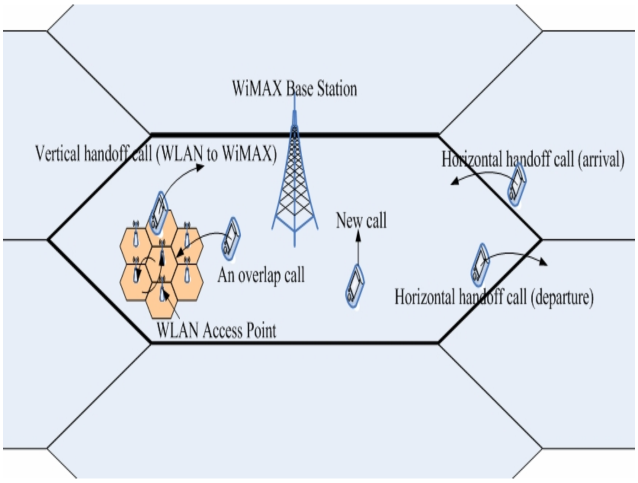


Figure 1. System model

In this paper, we consider the two types horizontal handoff probability in terms of arrival and departure are the same. The WiMAX BS is in charge of the call admission control and resource management for the new call in nonoverlap area, the horizontal arriving handoff call within WiMAX system, the WLAN vertical handoff calls from the WLAN boundary cells and the overlap call. As for calls handing off within WLAN cells (horizontal handoff) as well as new calls generated at the WLAN coverage, WLAN access point is responsible for handling these calls.

For WLAN vertical handoff calls, once the mobile user initiates handoff procedure, the system transfers the WLAN QoS architecture into the WiMAX QoS architecture. After classification, resource management scheme attempts to allocate the desired amount of bandwidth to the handoff connection. If the desired amount of bandwidth is available, the connection is accepted and the desired amount of bandwidth is allocated. In the case that the available bandwidth is less than the desired amount of bandwidth the handoff connection is dropped. The procedure of vertical handoff is shown in Figure 2.

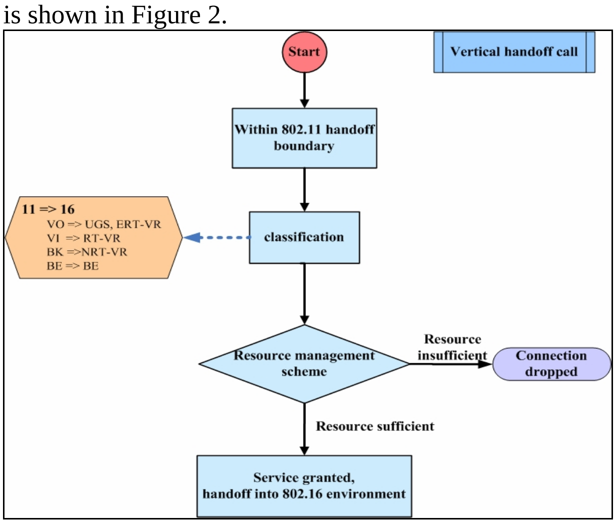


Figure 2 System procedure for WLAN vertical handoff calls.

4: Resource Management Schemes

The proposed resource management scheme including three functionalities in terms of Call Admission Control, Local Resource Allocation and Distant Resource Reservation is illustrated in Figure 3. For a call request arriving at the system, the call admission control decides whether the call is accepted or blocked based on current local and distance network conditions. When a new call is generated, the proposed RMS not only attempts to allocate bandwidth, it also reserves bandwidth for this call in the neighboring cells. At the same time, the reserved bandwidth in the cells which are no longer neighboring to the target cell is released. The WLAN provides a low-mobility service and requires users to be essentially stationary. Reserving bandwidth for all the WLAN vertical handoff calls within the WLAN boundary may bring out lower the bandwidth utilization. Instead of reserving bandwidth for the WLAN vertical handoff calls, we propose a WLAN access threshold to decide whether the WLAN vertical handoff call is granted or rejected and which is discussed on next section.

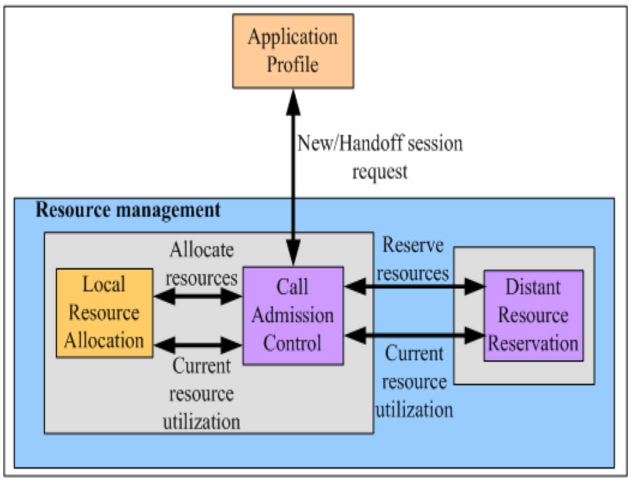


Figure 3. Block diagram of the proposed RMS

Two resource management schemes are proposed in this paper to compare with each other. The first resource management scheme (RMS 1) admits a new call or handoff call based on that the target cell as well as all the neighboring cells with enough capacity. The second resource management scheme (RMS 2) uses a resource-borrowing mechanism for real-time new calls to reduce the real-time call blocking probability.

4.1 Resource Management Scheme 1 (RMS1)

The proposed RMS 1 for a new connection within the WiMAX system. If it is the UGS or ERT-VR traffic, this kind of traffic contains CBR or VBR with little burst rate characteristic. The scheme first verifies that the system has enough capacity to support the traffic QoS requirement. If the system has enough capacity to support traffic QoS requirement and succeeds in resource reservation, the new connection is accepted and allocated with desired amount of bandwidth. Otherwise, if the amount of available bandwidth in the target cell is less than the desired amount of bandwidth, the new connection is blocked. In the case that the system has enough capacity but reservation fails in any of the neighboring cells, also the new call is blocked.

For the RT-VR traffic, since this kind of VBR traffic exhibits highly bursty and nonstationary properties, the effective bandwidth must be designed to handle the worst-case input scenario in order to avoid excessive delay or even the connection is dropped. This implies that the system must support the minimum required bandwidth in order to guarantee the maximum tolerable end-to-end delay. If the desired amount of bandwidth can be provided and succeed in the resource reservation, the new call is accepted and allocated with desired amount of bandwidth.

As for the NRT-VR and BE traffics, they are accepted as long as there is enough residual capacity available in the target cell. We provide no resource reservation for this kind of traffic due to non-real-time packets or data packets which can tolerate longer transmission delay.

For the horizontal handoff connection, each cell reserves bandwidth for real-time handoff calls in the neighboring cells. If it is a real-time traffic (i.e. UGS, ERT-VR and RT-VR), RMS 1 first verifies whether the system has enough capacity like residual bandwidth to support desired amount of bandwidth. If the capacity is enough to support the QoS requirement, the handoff call is granted. Meanwhile, the scheme also tries to reserve bandwidth in the new neighboring cells. A handoff call may be dropped if it fails in the resource reservation.

For non-real-time handoff calls (i.e. NRT-VR or BE), they are accepted as long as there is enough residual capacity available in the target cell and no resource reservation is provided for this kind of traffic.

The WLAN users are considered to be essentially stationary (lower mobility). Therefore, for the WLAN vertical handoff calls, we define the WLAN handoff threshold e $(0 < e < 1)$ for real-time traffic to give better QoS guarantee for high priority traffics. The real-time vertical handoff calls will be dropped if the residual capacity in the target cell is less than the WLAN entry boundary ($e \times C_{down}$), where C_{down} denotes the WiMAX system downlink capacity. The resource reservation is inefficient for WLAN vertical handoff calls caused to lower horizontal handoff probability in the WiMAX system. Therefore, only target cell residual capacity is considered in the proposed scheme.

4.2 Resource Management Scheme2 (RMS2)

Figure 4 shows the adaptive guard-band approach. It reserves a certain amount of capacity for handoff calls exclusively and the remaining capacity can be shared by both new calls and handoff calls. This approach gives a higher priority to the handoff call as compared to the new call request. However, reserving a large amount of bandwidth results in higher blocking probability and lower dropping probability due to less capacity can be occupied by the new calls. Therefore, the amount of reserved capacity should dynamically vary with the changing traffic conditions.

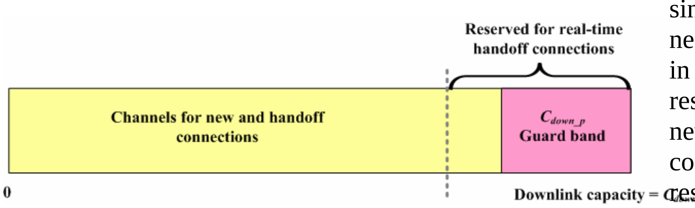


Figure 4. Guard band scheme.

In this paper, the system calculates the active capacity of real-time traffics in the neighboring cells to decide the passive capacity C_{down_p} of the target cell. Since the active capacity of the neighboring cells may change through time, the system is able to adjust passive capacity dynamically.

Thus, to improve the system performance a virtually adaptive method is proposed in RMS2. If a real-time new call arrives and the target cell or neighboring cells do not have enough capacity to support traffic QoS requirements. The system is allowed to *borrow* the bandwidth from the passive capacity (reserved capacity for handoff calls) to improve the CBP performance.

The borrowing capacity is only available for new real-time calls. The reservation scheme can reduce the handoff dropping probability, but it comes to increase the new call blocking probability. The purpose of borrowing mechanism is an efficient management concerned with passive capacity that can reduce the blocking probability for real-time new calls; the proposed RMS 2 is shown in Figure 5. C_B denotes the system capacity; C_{down_resi} denotes the residual bandwidth.

For a new call within WiMAX

IF UGS or ERT-VR traffic
  IF $C_{down\_resi} + C_B \geq$ desired amount of bandwidth
    Allocate desired amount of bandwidth.
    Reservation Scheme
  ELSEIF $C_{down\_resi} + C_B <$ desired amount of bandwidth
    Connection blocked
IF RT-VR traffic
  IF $C_{down\_resi} + C_B \geq$ desired required bandwidth
    Allocate desired amount of bandwidth - *d*
    Reservation Scheme
  ELSE IF $C_{down\_resi} + C_B <$ desired amount of bandwidth
    Connection blocked
IF NRT-VR or BE traffic
  IF $C_{down\_resi} <$ minimum amount of bandwidth
    Connection blocked

Figure 5. The RMS 2 algorithm.

5: Simulation Model Discussion

The simulation model is composed of 7 cells with a single cell as a target cell, and the remaining 6 cells as the neighboring cells for macrocells and microcells as shown in Figure 1. Each cell contains a BS or an AP, which is responsible for the connection setup and teardown of new connections, horizontal and WLAN vertical handoff connections. The BS is also responsible for the reservation and borrowing of bandwidth.

Three types of calls are considered in the simulation in terms of new calls, horizontal handoff calls and WLAN vertical handoff calls. For the overlap call, it is assumed to be handled by the WiMAX base station, therefore is treated the same as other on-going calls within the WiMAX system.

Simulation parameters are summarized in Table 1. Calls are generated with following Poisson distribution of each traffic class. The connection hold duration for each traffic class are exponentially distributed. The horizontal handoff probability (connections handoff between 802.16 systems) is set to 50%. The WLAN vertical handoff probability is set to 5%, since WLAN is assumed an essentially statiousary. Here, we choose the value of target dropping probability p_{D_tar} to be 0.02 [6, 7].

C	Total capacity within each macrocell	75Mbps
C_{uplink}	Uplink capacity	25Mbps
$C_{downlink}$	Downlink capacity	50Mbps
f	Frame duration time	1ms
T	Total timeslot in each frame	5000
a	UGS reservation ratio	1.0
b	RT-VR reservation ratio	0.5
k	ERT-VR reservation ratio	1.0
e	WLAN handoff threshold	0.1
T_{th}	throughput threshold	0.7
p_{D_tar}	Target dropping probability	0.02
p_{hh}	Horizontal handoff probability	0.5
p_{vh}	Vertical handoff probability	0.05

Table 1. Simulation parameters

In Table 1, the reservation ratio of UGS and ERT-PS are set to 1.0. Since the transmission rates of these two traffics are relative small (64Kbps and 32Kbps), the system is capable of reserving bandwidth for these two kinds of traffics. As for the RT-VR traffic, since each RT-VR traffic may decrease at most 50% of the desired amount of bandwidth. Therefore, the reservation ratio is set to 0.5. We also set the WLAN access threshold to be 0.1; therefore the WLAN vertical handoff calls can enter the WiMAX system when the downlink residual capacity is more than 5Mbps. Since the WLAN vertical handoff calls can still transmit data through 802.11 AP around the boundary cells, it is better to lessen the burden of WiMAX BS and give higher priority to WiMAX connections when system is heavy loaded.

6: Performance Evaluation

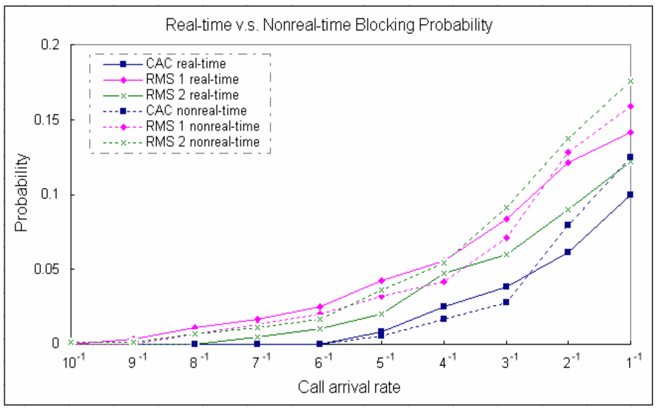
Simulation results are shown to evaluate each of the proposed schemes. Call blocking probability (CBP), call dropping probability (CDP) and call rejecting probability (CRP), the total number of calls being rejected in the system where the value of CRP is the sum of CBP and CDP, are evaluated for each scheme. A regular CAC (without reservation and borrowing mechanism) is compared to the proposed RMS 1 and RMS 2.

6.1: CAC, RMS1 and RMS2

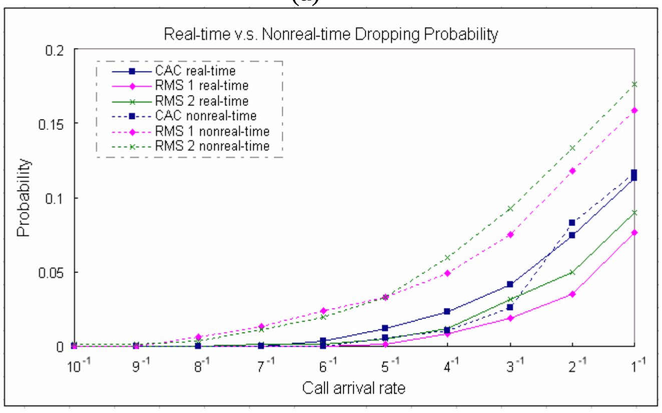
Figure 6 (a) and (b) present the blocking and dropping probability of real-time and nonreal-time connections for the CAC, RMS 1 and RMS 2 with different arrival rates. These two figures show that both the CBP and the CDP of real-time and nonreal-time increase as the arrival rate increases.

Figure 6 (a) shows the CBP for the new connections. Since the proposed RMS 1 and RMS 2 reserves bandwidth for handoff calls, less bandwidth is available for newly arriving calls. It results in the CBPs of both proposed schemes of RMS 1 and RMS 2 are higher than the regular CAC. In addition, the CBP of RMS 1 has the worst performance due to the RMS 1 reserves bandwidth for handoff calls and no borrowing capacity for new calls to reduce the CBP. It also shows that with RMS 2, newly arriving connections are allowed to borrow capacity to improve the performance, then the CBP is reduced for real-time connections. The nonreal-time CBP increase rapidly as the arrival rate increases caused by the connection duration of a real-time call is relatively long (150secs for voices calls, and 300secs for video calls), and the capacity occupied by a real-time connection can be large (512kbps~1Mbps for video calls). In addition, as the arrival rate increases, more real-time connections are introduced entering into the system causes the increase of nonreal-time CBP. Figure 6 (a) also shows that the nonreal-time CBP of RMS 2 increases more rapidly than RMS 1 due to the same reason applies to this phenomenon. Not only data new calls cannot borrow capacity to improve the CBP, the borrowing capacity also introduces many extra real-time new calls into the system. Therefore, the reduction of real-time CBP affects the performance of nonreal-time connections.

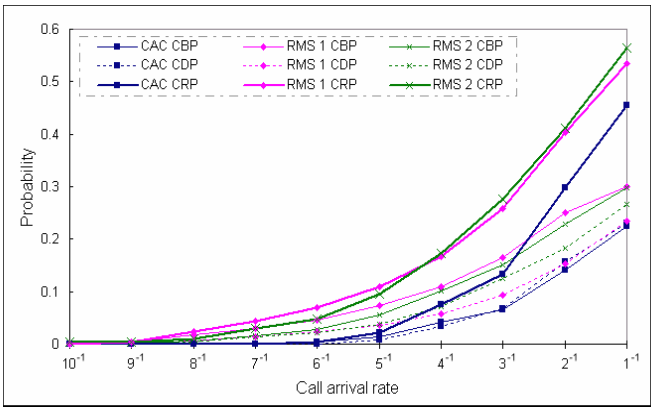
Figure 6 (b) shows the CDP for handoff connections. The real-time dropping probability is relatively small due to the bandwidth is reserved by the RMS 1 and RMS 2. Therefore, it comes at the expense of larger nonreal-time dropping probability since less bandwidth available nonreal-time handoff connections. The real-time dropping probability of RMS 2 is slightly larger than RMS 1 but still smaller than CAC. It is due to some of the passive capacity is "borrowed" by real-time new calls so less reserved capacity is available for real-time handoff calls. The borrowing capacity also causes the nonreal-time CDP of RMS 2 increases more rapidly than RMS 1. With the extra real-time new calls are introduced entering into the system, nonreal-time handoff calls still cannot borrow capacity to improve the performance, finally results in the increase of nonreal-time CDP.



(a)



(b)



(c)

Figure 6. (a) Call blocking probability of Real-time vs. Nonreal-time for CAC, RMS 1 and RMS 2, (b) Call dropping probability of Real-time vs. Nonreal-time for CAC, RMS 1 and RMS 2, (c) CBP, CDP, and CRP of CAC, RMS 1 and RMS 2 for real-time.

Figure 6 (c) presents the overall CBP, CDP and CRP of these three schemes for real-time connections. It shows that in heavy loaded situation, the CDP of CAC is slightly higher than the CBP. The reason is that the calculation of CDP includes the dropping of WLAN vertical handoff calls. In section 4-1, the real-time WLAN vertical handoff calls can enter the system only when the residual capacity is greater than $e \times C_{down}$. Therefore, when the system is heavy loaded, less capacity is left for WLAN calls, and the dropping of real-time WLAN vertical handoff calls increases. This figure also shows that the proposed schemes have a larger overall CBP, CDP and CRP than the regular CAC mechanism. However, the RMS 1 achieves the real-time CDP that is 51.2% lower than the CAC, and the real-time CDP of RMS 2 is 27% lower than the regular CAC.

7: Conclusion & Future Work

In this paper, two resource management schemes are proposed in the heterogeneous two-tier wireless communication networks. A priority based resource reservation method is proposed to adaptively reserve bandwidth, thus it is more efficient. A resource borrowing scheme is also presented to adjust the passive capacity to reduce the blocking probability of real-time call. Simulation results show the overall CRP of the proposed RMS 1 and RMS 2 is higher than the regular CAC due to the increase of nonreal-time CBP and CDP. Nevertheless, the proposed schemes are capable of keeping the real-time CDP relatively low and reducing the real-time CBP. Future works will be emphasized on several issues, which are Fuzzy resource management mechanisms, adopted mobility patterns and resource management for overlap calls will also be put into our future consideration.

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