An Implementation of QoS Framework for Heterogeneous Networks

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***Abstract*—Due to the popularity of the IEEE 802.11-based LANs and fast development of the IEEE 802.16e MANs, we can expect a heterogeneous network consisting of 802.11-based and 802.16e networks in the near future. In such an environment, heterogeneous handoff is possible. How to keep guaranteeing the handoff connection its QoS demand, and in the meantime, avoid impacting on other connections is a challenge to support real-time applications in a heterogeneous network. In this paper, we develop a heterogeneous network in NS-2 simulator. In addition, we implement application mapping function, call admission control, and scheduling in this heterogeneous network to observe the QoS performance of a handoff connection. The simulation results show that our implemented modules support handoff connections' QoS demands in respect of throughput, and delay. In addition, the implemented call admission control algorithm reduces the blocking rate efficiently.**

***Index Terms*—Call admission control, scheduling, heterogeneous network, heterogeneous handoff**

I. INTRODUCTION

The IEEE 802.11-b/a/g is the most popular medium access control (MAC) protocols and physical (PHY) schemes in recent wireless communication. However, it does not support quality of service (QoS), which is essential in real-time multimedia applications. Therefore, IEEE 802.11e [1] was proposed and it is a supplementary standard of 802.11 to provide priority-based service differentiation for different kinds of applications. All applications are classified into four access categories (ACs): AC_VO (voice), AC_VI (video), AC_BE (best effort), and AC_BK (background). The service differentiations among four ACs are achieved by assigning each AC with different Arbitration InterFrame Space (*AIFS*), minimum contention window value (CW_{min}) and maximum contention window value (CW_{max}). The higher priority AC (e.g., AC_VO) has the smaller *AIFS*, CW_{min}, CW_{max} values than those of the lower priority ACs (e.g., AC_VI, AC_BE, and AC_BK).

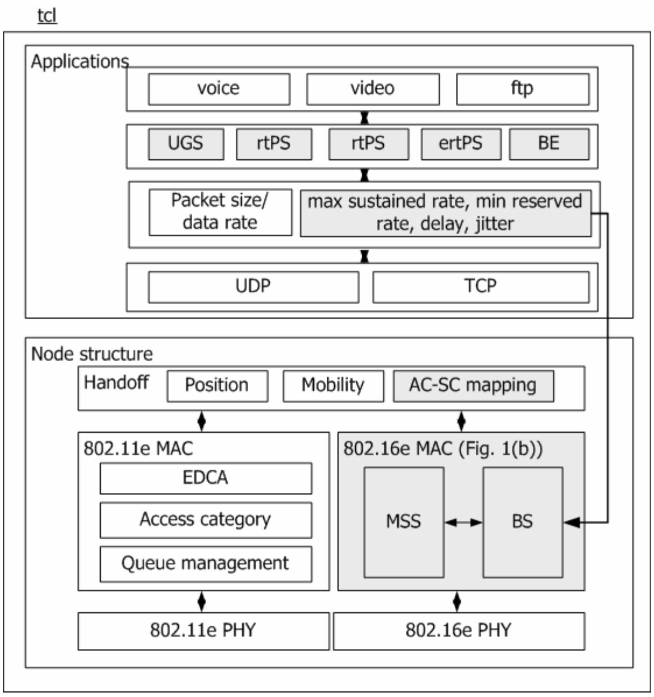
Due to the recent explosive Internet growth and customers' demands for advanced multimedia services, the IEEE 802.16e [2] is the focus of technology development. Advantages of the IEEE 802.16e system include rapid deployment, high speed data rate, high scalability, multimedia services, and lower maintenance, and upgrade costs. To support services with variable QoS demands, five service classes (SCs) are defined in the IEEE 802.16e system: unsolicited grant service (UGS), real-time polling service (rtPS), enhanced real-time polling service (ertPS), non-real time polling service (nrtPS), and best effort service (BE). QoS parameters a connection can set include minimum reserved rate, maximum sustained rate, maximum latency, and tolerated jitter.

The IEEE 802.16e is designed for metropolitan are networks (MANs), and it has no intention to replace IEEE 802.11e networks. Therefore, we can expect a heterogeneous network consisting of IEEE 802.11e LANs and 802.16e MANs in the near future. When a mobile station (MS) has both IEEE 802.11e and IEEE 802.16e network interface cards, heterogeneous handoff is possible. Here the heterogeneous handoff means that a MS moves from an IEEE 802.11e (or IEEE 802.16e) network to an IEEE 802.16e (or IEEE 802.11e) network. Our motivation is to observe the QoS performance when heterogeneous handoff occurs. The contribution of this paper is the IEEE 802.11e+IEEE 802.16e heterogeneous network development in NS-2 simulator [3]. In addition, we implement several QoS-related modules which are essential for this observation.

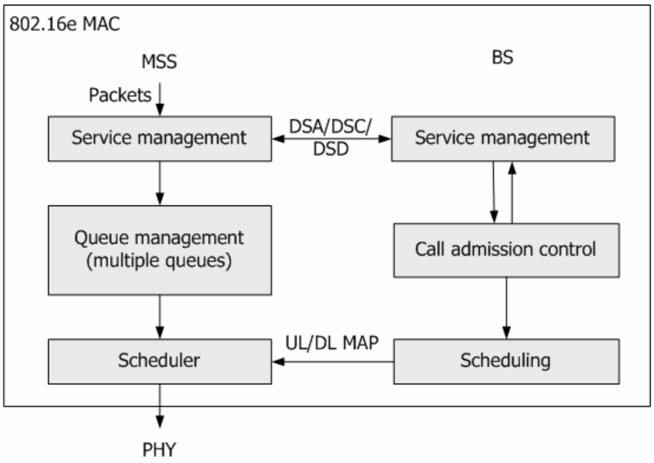
The remainder of this paper is organized as follows. Section II describes modules and algorithms we implement in NS-2 simulator. Section III is the performance evaluation. This paper concludes with Section IV.

II. THE IMPLEMENTED MODULES IN NS-2 SIMULATOR

To develop a heterogeneous network and do observation about connections' QoS performance, we implement several modules in the NS-2 simulator. These modules are node configuration, AC-SC mapping, CAC in 802.16e, and scheduling, as shown in Figs. 1(a) and 1(b). In Fig. 1, the existing modules/functions are



(a) QoS-related modules in NS-2 simulator



(b) Implemented modules in IEEE 802.16e MAC

Figure 1. Implemented QoS-related modules in the NS-2 simulator

represented as white blocks, and our implemented/modified modules are shown in gray blocks. We introduce each module in the following.

A. *Access Category-Service Class (AC-SC) Mapping*

The function of AC-SC mapping is to transform a connection's AC in IEEE 802.11e (or SC in IEEE 802.16e) to SC in IEEE 802.16e (or AC in IEEE 802.11e) when handoff occurs. The mapping rules are:

(1) When moving from an IEEE 802.11e-based network to an IEEE 802.16e-based network,
    (a) the SC of a handoff voice-type connection is set to be UGS;
    (b) the SC of a handoff video-type connection is set to be rtPS;
    (c) the SC of a handoff best effort-type connection is set to be either nrtPS or BE;
    (d) the SC of a handoff background-type connection is set to be BE.
(2) When moving from an IEEE 802.16e-based network to an IEEE 802.11e-based network,
    (a) the AC of a handoff UGS connection is set to be AC_VO;
    (b) the AC of a handoff rtPS or ertPS connection is set to be AC_VI;
    (c) the AC of a handoff nrtPS connection is set to be AC_BE;
    (d) the AC of a handoff BE connection is set to be AC_BE or AC_BK.

Note that an AC_BE connection could be mapped to nrtPS or BE service class. In the case that an AC_BE connection is accompanied a minimum QoS requirement, then it is mapped to nrtPS service class; otherwise, it is mapped to BE service class. Similarly, connections of BE service class could be mapped to AC_BE or AC_BK and it is determined by whether the QoS requirement is set or not.

When a connection incurs handoff from an IEEE 802.11e network to an IEEE 802.16e network, it first sends a dynamic service addition-request (DSA-REQ) message, which contains its QoS parameter settings, to the BS. The BS executes the AC-SC mapping function, and then does call admission control (CAC). The details of CAC are described in Sec. II.B.

B. *Call Admission Control (CAC)*

In IEEE 802.16e point to multipoint (PMP) mode, when and how long an MSS can send its data packets are determined by the base station (BS). To avoid exceeding the bandwidth and further failing to support QoS, a CAC algorithm is essential for a BS to admit or reject handoff connections' requests. CAC algorithm we implemented is based on the concepts of [4]. Considering a fact that the available channel capacity changes dynamically due to connection handoff, the implemented CAC algorithm has two phases, and both are described in the following.

Phase 1: upon receiving a DSA-REQ message, the BS checks if the handoff connection *i*'s QoS demand can be satisfied or not. The check is based on the rule listed in (1).

$$rate_{\min}(i) + \sum_{j\in\{UGS\}} rate(j) + \sum_{k\in\{rtPS\}} rate_{\min}(k) + \sum_{l\in\{ertPS\}} rate_{\min}(l) + \sum_{m\in\{nrtPS\}} rate_{\min}(m) \le \alpha \times C, \qquad (1)$$

where $rate_{min}(i)$is the minimum QoS demand of the new connection i, and $rate_{min}(*)$ is the minimum reserved data rate of a connection, and that connection can be rtPS, ertPS or nrtPS service class. C is the channel capacity, α is a predefined constant whose value is within (0, 1] and is used to indicate the percentage of allocated channel capacity. $\{UGS\}$, $\{rtPS\}$, $\{ertPS\}$, and $\{nrtPS\}$ indicate the connection sets of four service classes. Connection i can be admitted entering the IEEE 802.16e network when equation (1) is true.

Phase 2: when the available channel capacity cannot support connection i's QoS demand and connection i does not belong to $\{UGS\}$, the BS negotiates with the MSS to temporarily lower the requirement by sending dynamic service change-request (DSC-REQ) message. If the MSS agrees on this suggestion, it then responds a dynamic service change-response (DSC-RSP). The BS then executes scheduling based on the updated QoS demand. The BS records the original minimum QoS requirement for future adjustment, too. In the case that the MSS denies to lower down its requirement, the BS sends the MSS a dynamic service deletion-request (DSD-REQ) to reject its entrance.

The flowchart of CAC algorithm is shown in Fig. 2.

C. Scheduling Algorithm

The objective of scheduling algorithm is to allocate bandwidth to all admitted connections to support their QoS demands. To achieve it, we implement two timers in the NS-2 scheduler module.

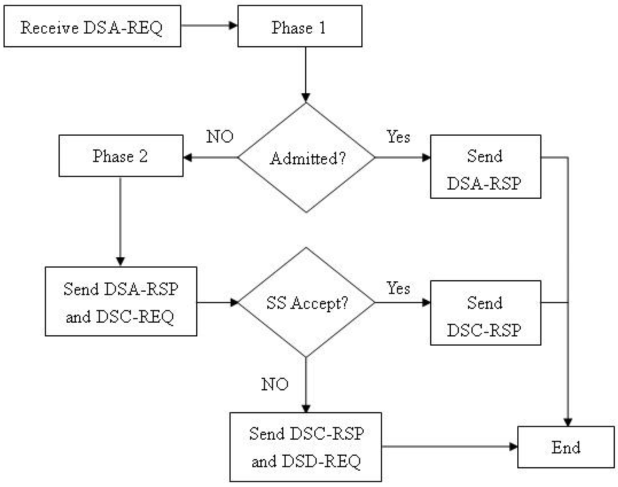


Figure 2. The flowchart of CAC algorithm

The first timer, denoted as $T_1(i)$ is to satisfy connection i's minimum requirement (i.e., $rate_{min}(i)$); the second timer, denoted as $T_2(i)$, is used to allocate the could-share residual bandwidth to connection i. Here we assume fixed packet size L in bits. To guarantee connection i with its minimum QoS demand, the connection must transmit at least $rate_{min}(i)/L$ packets per second. That means the BS needs grant connection i one packet transmission opportunity every $L/rate_{min}(i)$ seconds. We set $T_1(i)$ be $L/rate_{min}(i)$. Each time $T_1(i)$ counts down to zero, the BS allocates one packet transmission opportunity to connection i, and then the timer is refreshed to be $L/rate_{min}(i)$ again.

To set $T_2(i)$, we first calculate the residual bandwidth (denoted as $BW_{residual}$) after satisfying all connections' minimum QoS demands, as in (2).

$$BW_{residual} = \alpha \times C - \sum_{i\in\{UGS\}} rate(i) - \sum_{i\in\{rtPS\}} rate_{\min}(i) - \sum_{i\in\{ertPS\}} rate_{\min}(i) - \sum_{i\in\{nrtPS\}} rate_{\min}(i). \qquad (2)$$

We then determine the $BW_{residual}$ share ratio among rtPS, ertPS, nrtPS connection sets, as (3).

$$\sum_{i\in\{rtPS\}} \left(rate_{\max}(i) - rate_{\min}(i)\right) : \sum_{j\in\{ertPS\}} \left(rate_{\max}(j) - rate_{\min}(j)\right) : \sum_{k\in\{nrtPS\}} \left(rate_{\max}(k) - rate_{\min}(k)\right) = a : b : c, \qquad (3)$$

where $rate_{max}(i)$is the maximum sustained rate of connection i Thus for connection i, j and k, their could-share residual bandwidth, denoted as $BW_{residual}(i)$, $BW_{residual}(j)$ and $BW_{residual}(k)$ are in (4), (5) and (6).

$$BW_{ex}(i) = \frac{a}{a+b+c} \times BW_{residual} \times \frac{\left(rate_{max}(i) - rate_{min}(i)\right)}{\sum_{l\in\{rtPS\}} \left(rate_{max}(l) - rate_{min}(l)\right)} \qquad (4)$$

$$BW_{ex}(j) = \frac{b}{a+b+c} \times BW_{residual} \times \frac{\left(rate_{max}(j) - rate_{min}(j)\right)}{\sum_{l\in\{ertPS\}} \left(rate_{max}(l) - rate_{min}(l)\right)} \qquad (5)$$

$$BW_{ex}(k) = \frac{c}{a+b+c} \times BW_{residual} \times \frac{\left(rate_{max}(k) - rate_{min}(k)\right)}{\sum_{l\in\{rtPS\}} \left(rate_{max}(l) - rate_{min}(l)\right)} \qquad (6)$$

Similarly to $T_1(i)$, the BS grants connection i one packet transmission opportunity per $L/BW_{residual}(i)$ seconds. Each time $T_2(i)$ counts down to zero, the BS allocates one packet transmission opportunity to connection i again, and then the timer is refreshed to be $L/BW_{residual}(i)$.

III. PERFORMANCE EVALUATION

In this section, we evaluate the QoS performance when considering handoff in a heterogeneous network by using NS-2 simulator. In NS-2 simulator, we implement several modules including AC/SC mapping, CAC and scheduling.

A. Simulation environments

There are one access point (AP) and 10 motile stations (MSs) in an IEEE 802.11e network; one BS and 15 mobile subscribe stations (MSSs) in an IEEE 802.16e network. The heterogeneous topology is shown in Fig. 3. The bandwidth of IEEE 802.11e and 802.16e networks are 6 Mbps and 20 Mbps, respectively. In our simulation, α is set to be 0.9. The parameter settings of connections in IEEE 802.11e and 802.16e networks are listed in Table I. We do not simulate best effort connections in our experiments.

The performance metrics include throughput, delay and blocking rate, and their definitions are described below.

(1) Throughput (φ_i): the successfully transmitted data of the specific AC or SC i divided by the simulation time.

(2) Delay (d_i): the average packet delay time of the specific AC or SC i. we only count the successfully transmitted packets in.

(3) Blocking rate: the percentage of handoff connections which are rejected by the BS to enter the IEEE 802.16e network due to failed CAC check.

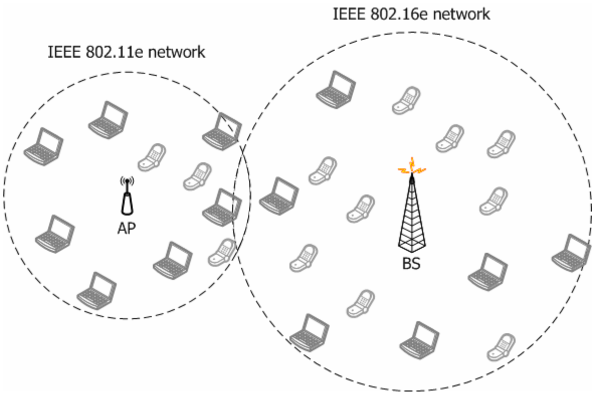


Figure 3. Network topology in our simulation

Table I. Connection settings in both IIIEEE 802.11e and 16e networks

IEEE 802.11e			
Priority	Rate (Kbps)	Pkt size (bytes)	Max. delay
1	56	210	25 ms
2	1024	512	100 ms
3	128/256	512	200 ms

IEEE 802.16e				
	Max rate (Kbps)	Min rate (Kbps)	Pkt size (bytes)	Max. delay
UGS	56	56	210	25 ms
rtPS	1024	128/256/512	512	100 ms
ertPS	1024	128/256/512	512	100 ms
nrtPS	128/256	32	512	200 ms

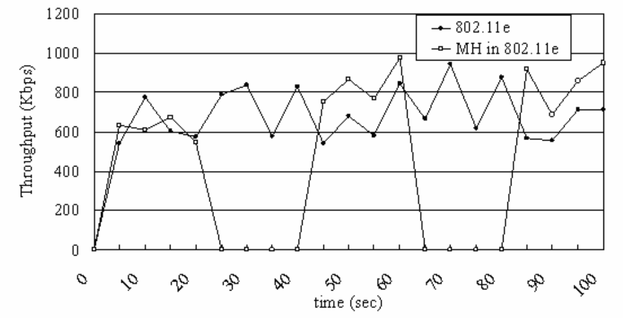
B. Simulation results

(1) QoS performance of the handoff connection

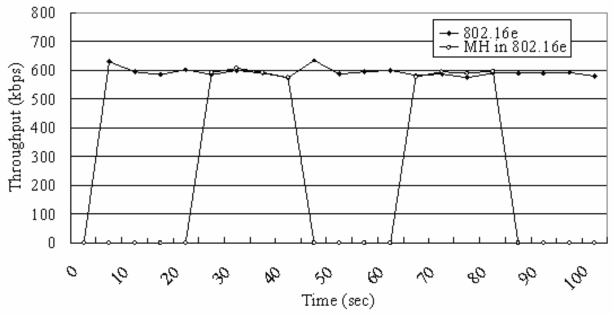
In this experiment, an MS/MSS handoffs between the IEEE 802.11e and 802.16e networks periodically. We set the period be 20 seconds, that is, the MS/MSS incurs handoff at the 20th second, 40th second, 60th second, and so on). The MSS has either a voice or video connection. In addition, both networks are with heavy traffic.

The throughput performances when the MS/MSS has a video connection are shown in Figs. 4(a) and 4(b). It's obvious that in the 802.11e network, the throughput varies significantly. The reasons are twofold: an MS contends channel to transmit data with others in IEEE 802.11e network; and the backoff value is randomly selected. Thus a connection's throughput performance is not guaranteed. In the IEEE 802.16e network, the throughput performances of the handoff connection and other existing connections differ little. The reason is that the BS performs CAC well, always allocates each connection's minimum QoS requirements first by setting T_1 timer, and then allocates residual bandwidth fairly by setting T_2 timer.

Figs. 5(a) and 5(b) show the average delay of video connections. Similarly to the throughput performance, the delay performance

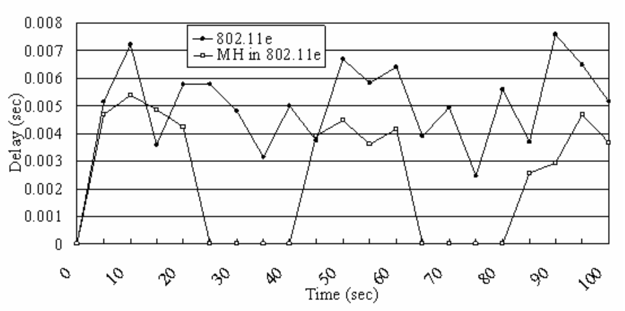


(a) Throughput performance of video connections in the IEEE 802.11e network

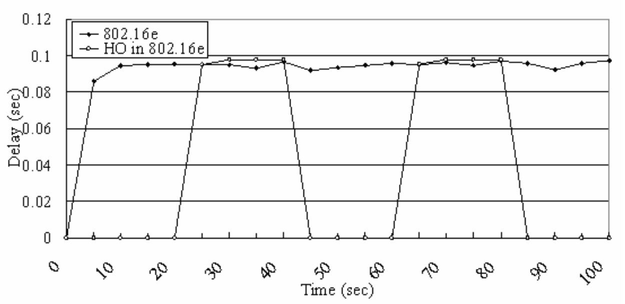


(b) Throughput performance of video connections in the IEEE 802.16e network

Figure 4. Throughput performance in the heterogeneous network



(a) Delay performance of video connections in the IEEE 802.11e network



(b) Delay performance of video connections in the IEEE 802.16e network

Figure 5. Delay performance in the heterogeneous network

varies significantly in the 802.11e network and is stable is the IEEE 802.16e network. However, the delay in IEEE 802.16e network is larger than that in the IEEE 802.11e network. It is because the generated packets of an MSS are kept in the queue and wait for the transmission opportunity grant issued by the BS. On the other side, low average delay in the 802.11e network is caused by a fact the many packets are dropped after exceeding retry limits.

(2) CAC performance

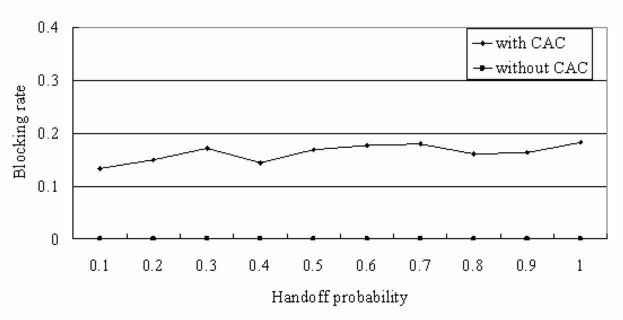
In this experiment, we observe the effect of the implemented CAC module. We simulate an environment that the total minimum QoS requirements of connections exceed the provided network bandwidth.

Fig. 6(a) shows the corresponding blocking rate. As expected that when implementing CAC, the handoff probability increases, and the blocking rate increases, too. However, the system guarantees the throughput performances of the existing and handoff connections (both UGS and nrtPS service classes), as shown in Figs. 6(b) and 6(c).

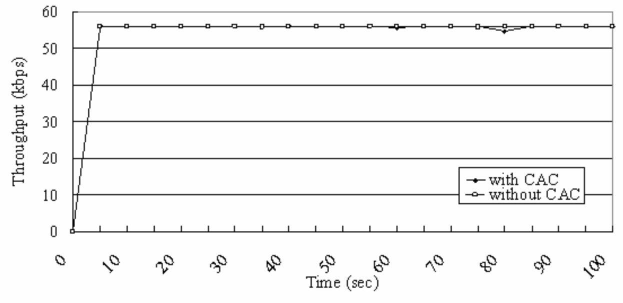
For the case that we do not implement CAC in an IEEE 802.16e network, every handoff connection is admitted to enter such a network, and its blocking rate is definitely zero, as shown in Fig. 6(a). However, its throughput performance may not be guaranteed. From Fig. 6(b), we found that no matter implementing CAC or not, UGS connections are not affected (since they are scheduled first), and their average throughput is 56Kbps (same as the demand). For nrtPS connections, their average throughput is less than 10 Kbps and thus their minimum QoS demands (i.e., 32 Kbps) are not satisfied due to the bandwidth shortage, as shown in Fig. 6(c).

IV. CONCLUSIONS AND FUTURE WORK

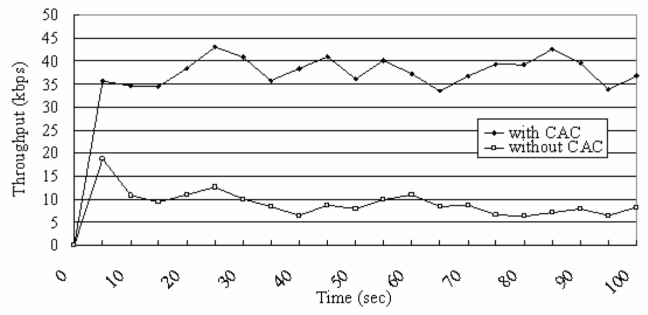
In this paper, we implemented a QoS framework, including AC-SC mapping, CAC, and scheduling, for a heterogeneous network by using NS-2 simulator. The heterogeneous network



(a) Blocking rate vs. handoff probability



(b) Throughput performance of UGS connections



(c) Throughput performance of nrtPS connections

Figure 6. The observation of CAC impact in the IEEE 802.16e network

consists of IEEE 802.11e and 802.16e networks. Our implemented modules support heterogeneous handoff. In addition, the simulation results show that the QoS demands of handoff connections are satisfied, and the CAC performs well to eliminate the impact of handoff connections on other existing connections. The modified CAC reduces the blocking rate efficiently, too.

Our future work will integrate the signal-to-noise detection, mobility model, and signaling process of handoff into our QoS framework.

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