Uplink Resource Management Design in Multi-access Wireless Networks

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Abstract. In this paper, we develop a new uplink resource management scheme in heterogeneous networking environments that support multiple radio access technologies (RATs). A common radio resource management (CRRM) model is utilized to handle uplink traffic in multi-access radio networks. To evaluate the effect and performance of CRRM, a simulation study is conducted on scenarios where different scheduling algorithms are applied with and without vertical handoffs through the aid of CRRM.

1 Introduction

Rapid emergence of newer network infrastructure creates a heterogeneous wireless environment where multiple radio access technology co-exist over a single region with different characteristics. In order to support various radio access technologies (RATs) and provide better quality of service (QoS) for users, radio access terminals are being equipped with multiple RATs. One of key issues in such networking environment is how to efficiently utilize the resources of the different RATs while simultaneously providing the desired QoS for users. For service providers, a cost efficient system that balance the load among networks with different RATs is not only desirable but necessary. From the user's perspective, regardless of which networks their devices choose to use, the user experience must satisfy the QoS requirements. It is also critical to give users the freedom of moving across all network providers and regions and changing communication devices while maintaining the continuity of their service.

There are many research and projects that have focussed on how to manage the downlink traffic in multi-access network. However, the new trend in wireless services is shifting from downlink centric services to bidirectional and uplink centric services [1]. Through the popularity of social networking services (e.g. Facebook, YouTube, and Flickr), we are observing the ever increasing amount of user generated content (UGC) also known as user created content (UCC). Due to the rise of uplink traffic via UGC and new services such as video telephony and FTP upload, it is critical for a multi-access network to have an efficient resource management scheme that especially considers high uplink traffic.

In this paper, we develop a common radio resource management (CRRM) model in heterogeneous network environments that support multiple radio access technologies (RATs). Multiple scenarios are devised where different scheduling algorithms are applied with and without vertical handoffs through the aid of CRRM. The scenarios are then simulated on an in-house simulator called MNAS (Multi-Network Access Simulator).

Our paper is organized as follows. In section 2, we present enhanced uplink technologies, covering two most prominent networks available today that handles high amount of uplink traffic: HSUPA and WiMAX. The design of CRRM system that handle efficient management of network resources is presented in Section 3. Performance analysis of CRRM and each scheduling algorithms using a simulator called MNAS (Multi-Network Access Simulator), and its results are presented in Section 4. Finally concluding remarks and future work considerations are presented in Section 5.

2   Resource Management for Uplink Enhancements

Scheduling for uplink services, in contrast to downlink services [2][3], is more complicated due to various reasons. The uplink traffic amount is not known in advance to the central scheduler residing in the base station. Further complicating the scheduling mechanism, base station and mobile stations must work cooperatively in centralized and distributed manners. Moreover, as the transformation of mobile networks from homogeneous closed systems to Internet-connected open networks presents resource management challenges, uplink scheduling and access selection for call admission and vertical handover (handovers to cells using different RATs) have been considered as key management issues [1]. In this section, we briefly review typical uplink enhancement technologies with their well-known scheduling algorithms.

2.1   HSUPA

HSUPA is introduced to improve the capacity of WCDMA uplink in 3GPP Release 6. As the new uplink transport channel, Enhanced-Dedicated Channel (E-DCH) supports fast Node B based uplink scheduling, fast physical layer hybrid ARQ (HARQ) retransmission schemes and, optionally, a shorter transmission time interval (TTI) (2ms) to reduce delays, increase the data rate (up to 5Mbps) and improve the capacity of the uplink [4].

The overall goal of the scheduler is to allocate a large part of the shared resource to users who momentarily require high data rates, while avoiding large interference peaks to keep the operation of the system stable. To access this goal in the uplink direction, tolerance interference or the total received power at Node B is determined by the common resource shared among the mobile stations. This common uplink resource amount depends on data rate used and higher data rate requires larger transmission power and resource consumption. There are researches on the uplink scheduling subject to define an optimum power and
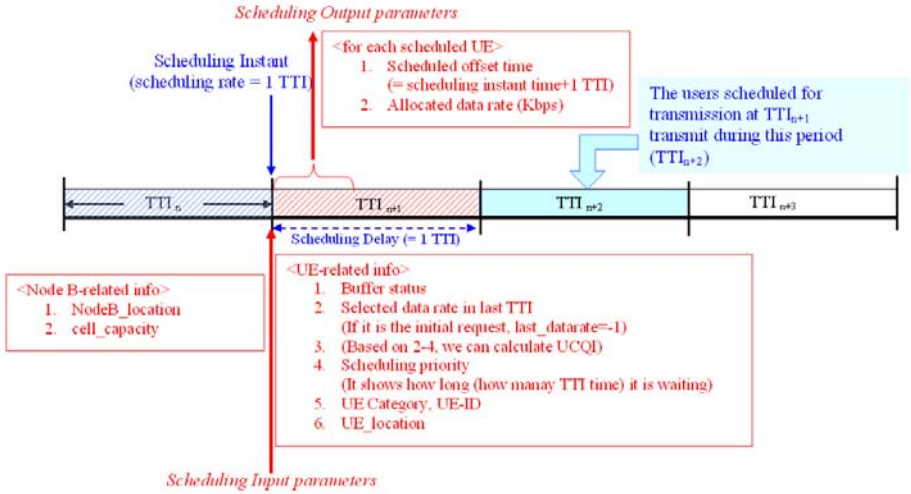
Fig. 1. HSUPA packet scheduler operation

rate allocation scheme that maximizes throughput [5][6]. All proposed solutions assume that the WCDMA system operates with a TDM overlay to perform a simultaneous rate and time scheduling.

Figure 1 illustrates the process of HSUPA packet scheduler (PS). The PS provides scheduled offset time and allocated data rate to each user equipment (UE) on every TTI. All UE requesting to be scheduled provide its buffer status, selected data rate in last TTI and scheduling priority data to the PS and PS allocates appropriate amount of resources to UE based on the cell capacity.

In MNAS, we implemented round robin (RR) and proportional fair (PF) algorithms in HSUPA PS. In RR, PS does not take into consideration the channel-quality but only uses UE's buffer-state data. The buffer-state data contains the delay of the packet at queue head. Before allocating resources for uploads, PS first sorts user equipment (UE) by the delay value in the buffer-state data. Then PS allocates resources based on UE's upload limitation and cell's available capacity in sorted order. If a UE is not scheduled then the delay value will increase, thus increasing its chance of being scheduled in the next round.

The PF algorithm, uses the Uplink Channel Quality Indicator (UCQI) as defined in [5] and average uplink rate to determine the resource allocation to a UE. As the average uplink rate increases, the scheduling priority rate of UE decreases where as the channel quality and the priority rate have direct relationship. This provides fail balance between user fairness and cell throughput.

2.2   WiMAX

WiMAX 802.16 has become the most promising wireless telecommunication technology that can be used for metropolitan area access networks. Though the standard of WiMAX has evolved from the original 802.16 to the latest 802.16e

which supports full mobility, some standard details have not been completed yet. The scheduling algorithm is one of them. In WiMAX 802.16-2004, four QoS categories are defined for both downlink and uplink traffic.

– Unsolicited Grant Service (UGS): It supports real-time data traffic with periodic fixed packet size. The typical T1/E1, VoIP without silence suppression belong to this class.
– Real-Time Polling Service (rtPS): It supports real-time data traffic also, but with various packet size. Video streaming is a typical rtPS service.
– Non-Real-Time Polling Service (nrtPS): It supports non real-time service with various packet size, the QoS requirement is not as strong as the former two. FTP and HTTP are nrtPS service.
– Best Effort Service (BE): All the applications that belong to this class do not have QoS requirements. For example, E-mail is a BE service.

In WiMAX 802.16e, a new QoS category Extended Real-Time Polling Service (ertPS) is added, which combines some features from both UGS and rtPS and supports Real-time traffic with variable data rate as well.

Generally, UGS has the highest priority to be scheduled since it is real-time required and the data are loaded periodically with fixed size. The Scheduler provides grants to each SS the assigned symbols and subchannels according to the Maximum Sustained Traffic Rate (MSTR), the Minimum Reserved Traffic Rate (MRTR) and the Maximum Latency. As for rtPS, it also has real-time requirement but with various packet size in fixed interval time. Since rtPS is a polling service, in the uplink scheduling, firstly, the BS calculate the polling interval time for each connection based on the QoS requirements before data transmission. The polls indicated in UL_MAP are broadcasted through the downlink channels to all SSs. After receiving the polls, only those SSs having been polled will be assigned uplink bandwidth which is used for uplink data transmission. Similarly, nrtPS is also real-time required service but has looser QoS requirements than rtPS. Usually nrtPS has a larger polling interval time up to one second. Besides unicast polling which is the same as rtPS, nrtPS is supported by contention-based polling as well. Since BE service doesn't have any QoS requirement, any BE connection will be admitted. BE has the lowest scheduling priority, i.e., BE connection is scheduled only if all other higher services have been scheduled.

The service with lower priority is scheduled only when all services with higher priorities have been scheduled. Within each scheduling service type, we implement RR and PF scheduling algorithms. RR algorithm allocates its resources in the order of mobile stations (MS) IDs. PF uses the ratio between Signal to interference-plus-noise ratio (SINR) value and average uplink rate to determine the allocation ordering. In both algorithms, only those MSs whose queue is not empty and the size of allocation slot is less than the size of the available slot in the frame will be scheduled.
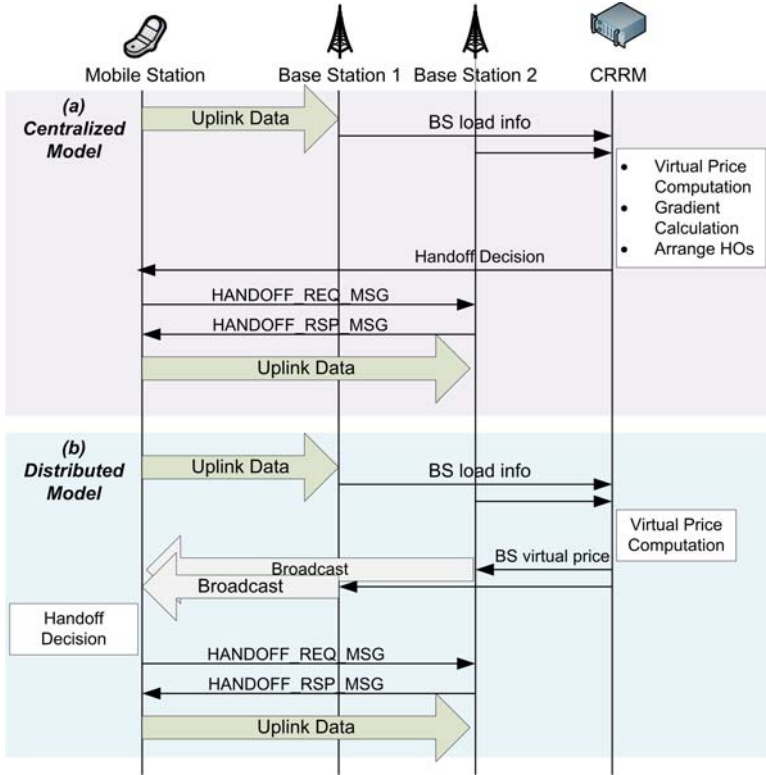
Fig. 2. Uplink CRRM Flow Diagram

3   CRRM System Model

There are many research projects that focus on effects of CRRM on heterogeneous networks with downlink traffic focus. [7] and [8] present a CRRM model based on marginal utility functions. [9] approaches the CRRM issue by minimizing the vertical handoff rate and service cost. [10] introduces a new entity in a multi-access network called Wireless QoS Broker that aids CRRM in QoS management. Most of current research efforts focus on the services that are geared towards downlink traffic. Our system model applies the concept of CRRM in a heterogeneous network environment that are composed of uplink services.

We propose two CRRM system models in making management decision within a multi-access network. First is centralized system where CRRM makes all the handoff decisions for each individual mobile station. Second is distributed system where handoff decisions are made by mobile stations.

3.1   Centralized Model

In centralized model, each base station reports the uplink load information to CRRM. CRRM computes the cost information (virtual price) of each base

station, using its uplink load (L_{up}) and capacity (C_{up}) information. MNAS only deals with data traffic. Within it, the virtual price of HSUPA and WiMAX is set as $(L_{up}/C_{up})^2 + 1$. This can be expanded to cover voice traffic, as it is done in [7], where operational policy and marginal utility function are implemented.

Suppose C is the set of all pairs of neighboring cells in the heterogeneous network. Then find a pair of neighboring cells (i, j) in C with the largest difference of virtual prices. If there exists at least mobile station within the overlapping area between i and j, pick a random mobile station from the area and assign a handoff between i and j. Remove (i, j) from C. Repeat the procedure until C is empty. This process is shown in Figure 2.

In this model, since all the decision related computation is done in CRRM and it must periodically request data from mobile stations and base station at a rapid rate CRRM tends to have high computational load [7]. According to [11] this management method falls on the higher end of the spectrum in the degree of interaction scale for CRRM. Although this high level of interaction can result in more efficient resource management, it comes with an overhead of having frequent interactions between mobile stations and CRRM. Instead most of the current researches focus on models that require low to intermediate interactions [11].

3.2   Distributed Model

The second and more popular CRRM model is a distributed system where the final decision in handoff between RATs is made by the mobile stations. The major steps involved in this decision model are as follows.

Virtual Price Computation: First, each base station periodically sends its attribute data over to the CRRM, which then computes the virtual price of each base station based on its load, capacity, or delay data, or combination of them. CRRM can be designed so that virtual price can be a based on the type of service that is being provided by the base stations.

Virtual Price Broadcast: Once the virtual prices has been calculated by the CRRM, those values are broadcasted to all the mobile stations. Period at which these broadcast occur is typically longer than the calculation period of centralized CRRM model

Handoff Decision: Finally mobile stations makes the handoff decisions based on virtual prices that it received. More precisely, handoff is made to the base station with lowest virtual price.

There are two problems that arises when the handoff decisions are made by the each individual mobile stations. One is mass handoff effect where all or most mobile station within a cell decides to switch at once. The other is ping-pong effect. This occurs when a mobile station decides to perform handoff one right after another. To prevent these problematic issues, a ping-pong time is set after a handoff where another handoff is prevented.

4   Performance Analysis

The performance of our CRRM (distributed model) is analyzed by using a C-based simulator called MNAS (Multi-Network Access Simulator) that we developed at GWU. In MNAS we implemented two uplink enhanced networks, HSUPA and WiMAX. For each network, we implemented two well-known scheduling algorithm, RR and PF. Thus the packet scheduler controls each terminal's transmitting time and the rate in the network and our CRRM handles the resource in the different RATs.

In our simulation the network topology consists of nine WCDMA-HSUPA cells and nine WiMAX cells arranged in a grid pattern. The cells are positioned closely so that each cell has overlapping area with its neighboring cells. The cell capacity of each cell type is defined as follows: 2Mbps with 700 meter radius for HSDPA cell; and 8.47Mbps with 500 meter radius for WiMAX. The type of uplink service generated by the mobile stations are described in Table 1. The four types of services, MMS, USB Modem, Video Telephony, and FTP Upload has the usage distribution ratio of 20 : 20 : 30 : 30, respectively. In WiMAX, the services are mapped as BE, nrtPS, rtPS, and nrtPS, respectively. 70 percent of the mobile stations has mobility of 5 meters per second. 1000 mobile stations with both HSUPA and WiMAX capabilities is simulated.

Table 1. Service Type Parameters

Service	Packet Size	Packet Interarrival Time
MMS	lognormal(1.28, 1.66)	N/A
USB Modem	lognormal(1.17, 5.97)	lognormal(2.04, -1.23)
Video Telephony	lognormal(6.1, 0.54)	deterministic(0.1)
FTP Upload	lognormal(14.45, 0.35)	exponential(180)

Service	Session Duration	Session Interarrival Time
MMS	lognormal(1.54, 0.54)	exponential(50)
USB Modem	lognormal(0.15, 0.003)	exponential(89388)
Video Telephony	lognormal(5.015, 0.06)	exponential(200)
FTP Upload	exponential(300)	exponential(500)

4.1   Scenario 1 – Without CRRM

For the total simulation time of 600 seconds, according to the distributions from Table 1, uplink traffic is generated. CRRM does not make any handoff decisions for this simulation. It uses proportional fair scheduling algorithm.

Figure 3 shows the throughput of each network type when CRRM is not applied. We observe here that amount of throughput on HSUPA and WiMAX is similar. However, when load is observed, HSUPA reaches near 80% in load and WiMAX is at around 10% - Figure 4 (a).

4.2   Scenario 2 – With CRRM

Likewise, according to the distributions from Table 1, uplink traffic is generated for 600 seconds. This time, however, CRRM uses distributed model to allow handoff in mobile devices. It also uses proportional fair scheduling algorithm.
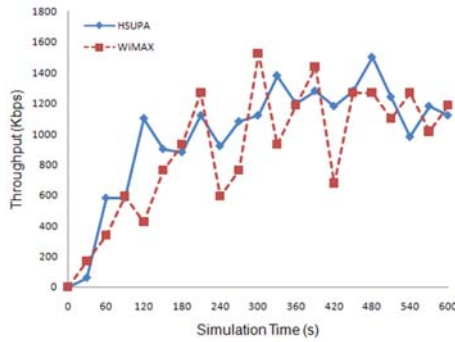
Fig. 3. Throughput without CRRM

(a) Load without CRRM
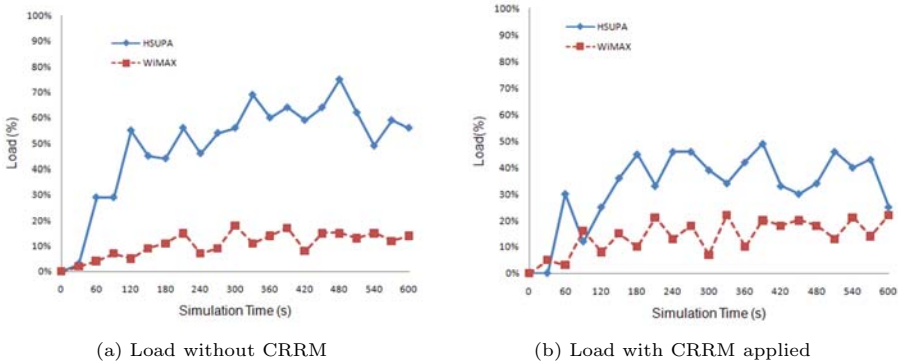

(b) Load with CRRM applied

Fig. 4. Simulation Results with and without CRRM

Figure 4 (b) shows the load of each network type when CRRM is applied. We observed that when CRRM is applied, load balancing occurs, effectively dropping HSUPA's average load from 52.74% to 36.19%, while increasing the average load on WiMAX from 12.17% to 15.45%.

Call delay for a mobile station is measured from where a particular packet arrives at the top most position in the transfer buffer to the time when it leaves the buffer. Table 2 and 3 show the average call delay of all the cells in the network. In the case where CRRM is applied, not only network experiences load balancing but call delay gets balanced over the networks.

4.3   Scenario 3 – CRRM with Scheduling Algorithms

Similar to Scenario 1, with CRRM applied, uplink traffic is generated for 600 seconds according to the distributions from Table 1. Instead of using proportional fair, round robin scheduling algorithm is used.

As shown in Table 2 and 3, when CRRM is applied, the network is effected differently depending on the scheduling algorithm used. In the case of RR, it exhibits fair scheduling regardless of the service types nor channel conditions. It performs worse than PF scheduling algorithm which considers the system's average throughput and the current available data rate. Moreover, due the fact that RR does not take in to the consideration the delay data in scheduling, it experiences higher average call delay. Therefore, to achieve efficient resource management scheduling algorithm must be considered along side with CRRM.

Table 2. PF Scheduling Algorithm Simulation Results Without CRRM

	HSUPA	WiMAX
Cell Throughput	1,054,708 bps	1,030,541 bps
Cell Load	52.74%	12.17%
Cell Delay	873 ms	54 ms

Table 3. Scheduling Algorithm Simulation Results With CRRM

	HSUPA (PF)	WiMAX (PF)	HSUPA (RR)	WiMAX (RR)
Cell Throughput	723,807 bps	1,308,216 bps	697,654 bps	1,110,836 bps
Cell Load	36.19%	15.45%	34.88%	13.11%
Cell Delay	232 ms	61 ms	1328 ms	33 ms

5   Conclusion and Future Work

In this paper, we surveyed the current uplink driven wireless network technology and proposed an efficient technique for access selection in multi-access networks. Results obtained through simulations using MNAS showed that distributed CRRM system significantly performs better than when CRRM is not present. Moreover, our simulation result indicates that scheduling algorithm must be taken in to consideration along side with CRRM in order to achieve efficient resource management. It should be interesting to implement and analyze an environment where both uplink and downlink traffic are considered together. We plan to extend our research effort in this direction.

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