Common Radio Resource Management for Access Selection in Multi-Access Networks

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Abstract—In this paper, we address the problem of access selection in multi-access networks. As admission and handover process durations are in the order of seconds and decentralized decisions are made over multiple cells spread over the network, such decisions have to be made quickly and in a distributed manner while keeping the network stable and its load balanced. We propose a utility-based approach to access selection. In this model, policies governing the network operations are embodied in the design of marginal utility functions and decisions are made using minimal computations. Developed algorithms are then evaluated using a Java-based multi-access simulator called MANSim that we developed.

I. INTRODUCTION

Next-generation wireless networks are expected to provide reliable, high-bandwidth, on-demand services with performance guarantees to a variety of users with diverse traffic characteristics and hardware capabilities. Users may freely move across all network providers and regions changing computing and communication devices while maintaining the continuity of their applications. In such a network referred to as a multi-access network, a mobile station (MS) is equipped with a hardware compatible to multiple radio access technologies (RATs). One of the key management issues in a multi-access network is the access selection for call admissions and and vertical handovers (handovers to cells using different RATs). Significant research has focussed on developing access selection schemes that incorporate network-, mobile-, and service-specific information.

In this paper, we present a utility-based access selection framework. Two implementation options are discussed, and the performance of each option is analyzed under a specific network operation model. The rest of the paper is organized as follows. In Section II, world-wide on-going projects in multi-access networks are briefly introduced with a relevant literature survey. In Section III, a system model and network operational policy rules are presented to demonstrate the validity of our proposed scheme. The design of marginal utility functions incorporating the given operational policy rules are then presented in Section IV. Using the utility values computed by the marginal utility functions, two implementation options are proposed in Section V. The performance of each implementation is analyzed using a simulator called the MANSim (Multi-Access Network Simulator) that we developed, and results are presented in

Section VI. Concluding remarks and the direction of future works are given in Section VII.

II. RELATED WORK

In a multi-access heterogeneous network, each individual network separately operates and provides services to users. Mobile stations are equipped with a hardware supporting multiple RATs, and an individual RAT is selected to provide service to a user. Thus, the main concept of the multi-access network is not to combine and control all possible networks together, instead, to provide a flexible and open architecture for a large variety of different mobile wireless networks, applications and services with different QoS demands, as well as different protocol stacks.

There are many research projects toward beyond third generation (B3G) networks aiming at multi-access heterogeneous networks such as the European Union 6th Framework Program (FP6), the FuTURE in China, the Future Wireless World launched by DoD in North America, the NGMC Forum in South Korea, and the Mobile IT Forum (mITF) in Japan. Among these, the Ambient Networks project, a part of the FP6, is in the most advanced stage. It has developed a generic multi-radio access architecture [1] and a conceptual framework for access selection and resource allocation by joint radio resource management across different RATs [2].

There are two architecture models commonly considered for inter-networking: IP level integration and radio access level integration. In the IP-based approach, the network remains independent of each other and potentially belongs to different administrative domains. In the radio access level integration, the control protocols of one network can be reused within the other network, and data traffic can be routed via the other's core network. The former is called loosely-couple while the latter is called tightly-coupled. The loosely-couples architectures are discussed in [3], [4], [5], and the tightly-coupled architectures are discussed in [6], [7], [8], [9]. An architecture for UMTS and 802.16 integration is presented in [10]. [11] presents a vertical handoff system that minimizes the vertical handoff latency for an individual user while keeping bandwidth and power overheads as low as possible. In [12], [13], the problem of allocating user connections to a set of base stations is considered with the objectives of minimizing power consumption of mobile stations and maximizing admitted traffic flows while

following access preferences of users using bin packing algorithm based heuristics. The issue of load balancing is not addressed in this paper. Another approach to access selected using heuristic bin-packing algorithm is presented. The problem of access selection between wireless LAN and HSDPA/Long Term 3G Evolved networks is addressed in [14], and a simple heuristic algorithm is presented. Most of existing works focus on the architecture and protocols, and consider minimizing handover delays. In [15], the authors consider general resource management issues in heterogeneous networks, and discuss several solutions. However, the utility-based access selection scheme proposed in this paper is different from the existing ones in which utility functions are designed to integrate the given operational policy rules and the loads are balanced across network cells to improve the overall throughput.

III. SYSTEM MODEL

A. Architecture

Our inter-networking model assumes a tightly-coupled architecture in which a common radio resource management (CRRM) unit is introduced to connect RNCs of UMTS networks (e.g., WCDMA, HSDPA) and MSC of CDMA networks (e.g., CDMA1x, EvDO). The CRRM collects radio information from each individual network, processes collected information, and distribute results necessary for resource management to each network. The CRRM or each mobile station then makes a final suggestion (e.g., which mobile stations should handover to which network cells). In either case, the actual admission control or vertical handover decision is made by the corresponding LRRM using its own algorithm.

- The CDMA1x and EvDO operate on different spectrum bands while the WCDMA and HSDPA share the same spectrum band.
- Two types of the WCDMA system exist. One is operating alone called WCDMA-alone system. The other is sharing its spectrum with HSDPA called WCDMA-HSDPA system, and a fixed amount of the total power is allocated for WCDMA and HSDPA to share.

B. Operational Policy

The following operational policy rules are assumed.

- Voice traffic is served by CDMA1x system, WCDMA-only system, or non-HSDPA part of the WCDMA-HSDPA system.
- Data traffic is served by EvDO system or HSDPA part of the WCDMA-HSDPA system.
- Voice traffic has always higher priority than data traffic. Hence, a new voice traffic may be admitted to a non-HSDPA part of a WCDMA-HSDPA cell by dropping or redirecting existing data traffic in its HSDPA part.
- The CDMA1x or WCDMA-alone system has higher priority over WCDMA-HSDPA system for voice traffics.
- The EvDO system has higher priority over WCDMA-HSDPA system for data traffics.

IV. MARGINAL UTILITY FUNCTION

For a cell v serving voice calls, its load x_v (or capacity c_v) is defined as the number of voice calls currently served (or the maximum number of voice calls that can be served)

by v . For a cell d serving data traffic, its load x_d (or capacity c_d) is defined as the total amount of bandwidth provided by d to mobile stations currently in the cell (or the maximum bandwidth that d can provide). For a WCDMA-HSDPA cell that serve both voice and data traffics, the voice capacity is defined as the maximum number of voice calls that can be served using all the power allocated to the system, and the capacity of data traffic is defined as the maximum amount of bandwidth that the system can provide using all the power allocated to it.

Let α be a real number in $0 < \alpha < 1$. A marginal cost function for each cell, for voice or data, with a certain RAT is then defined as follows.

- For CDMA1x,

$$f_{voice}(x_v) = \begin{cases} (x_v/c_v)^2 & \text{if } x_v/c_v < \alpha \\ (x_v/c_v)^2 + 1 & \text{otherwise} \end{cases}$$

- For WCDMA-alone,

$$f_{voice}(x_v) = \begin{cases} (x_v/c_v)^2 & \text{if } x_v/c_v < \alpha \\ (x_v/c_v)^2 + 1 & \text{otherwise} \end{cases}$$

- For EvDO,

$$f_{data}(x_d) = (x_d/c_d)^2 + 1$$

- For WCDMA/HSDPA,

$$f_{data}(x_d) = (x_d/c_d)^2 / (1 - x_v/c_v)^2 + 1$$

$$f_{voice}(x_v) = (x_v/c_v)^2 + 1$$

To understand the idea behind the design of these functions, let's first consider voice traffics. The utility value of a CDMA1x (or WCDMA-alone) cell is lower than the utility value of non-HSDPA part of a WCDMA/HSDPA cell whose x_v/c_v value is same as CDMA1x cell's (or WCDMA cell's) as long as the ratio x_v/c_v is less than α . Hence, CDMA1x or WCDMA-alone cells will have higher priority over non-HSDPA part of WCDMA/HSDPA cells in serving voice traffics. For data traffics, an EvDO cell has lower utility value than a WCDMA/HSDPA serving voice traffic when both cells have the same ratio x_d/c_d . Hence, the EvDO cell has higher priority over the WCDMA/HSDPA cell. Finally, it is noted that the third operational policy rule is also satisfied from the functions defined for WCDMA-HSDPA cells.

Computing the optimal value of α requires precise network modeling and in-depth analysis, and we simply assume $\alpha = 0.9$ in our simulations discussed later.

V. ALGORITHMS

Each base station periodically updates its utility values and reports them to the CRRM.

A. Network-Based Decision

When a connection request arrives from a mobile station, the CRRM selects a base station with the minimum utility value, and direct the mobile station to connect to the selected base station. In this approach, each mobile station must periodically report to the CRRM a list of cells (of any RAT type) to which it has enough signal strength to be connected. In this approach, the CRRM has high computation load. The details are as follows.

1. Every base station reports its load information to CRRM, and CRRM computes utility value for each cell.
2. Let $C(v)$ and $C(d)$, respectively, denote the set of all cells that can accommodate voice and data traffics.
3. While $C(v)$ is not empty, do the following:
 - (a) Find two neighboring cells, i and j , in $C(v)$ with the largest difference of utility values.
 - (b) Arrange handovers between i and j until they both have the same utility value or no more handover is possible.
 - (c) Delete i and j from $C(v)$.
4. While $C(d)$ is not empty, do the following:
 - (a) Find two neighboring cells, i and j , in $C(d)$ with the largest difference of utility values.
 - (b) Arrange handovers between i and j until they both have the same utility value or no more handover is possible.
 - (c) Delete i and j from $C(d)$.

1) MS-Based Decision: In this approach, the CRRM guides mobile stations to make final decisions in which the CRRM does not have information on which cells may be accessible by which mobile station (i.e., mobile stations do not report the signal strengths of their accessible base stations to the CRRM). Each base station maintains geographic information of its neighbor cells as specified in the MIH protocol [16]. Suppose MS m_j is connected to BS b_i whose neighbor set is denoted by S_i . Note that m_j may or may not be able to connect to all base stations in S_i , but the set of base stations to which the m_j can connect must be a subset S'_i of S_i . The network (or the CRRM) then delivers the utility value of each cell in the neighbor list S_i of b_i , and b_i informs the utility value of each cell in S_i to m_j . m_j then make a final decision using the information on signal strength to each base station in S_i . More precisely, m_j select a cell with the lowest utility value from S'_i .

VI. PERFORMANCE ANALYSIS

The performance of our CRRM is analyzed using a Java-based system level simulator called MANSim (Multi Access Network Simulator) that we developed. In our simulation, the network consists of the following cells: four CDMA1x cells, four EvDO cells, and two WCDMA-HSDPA. The CDMA1x cells and EvDO cells both cover the entire simulation area. The WCDMA-HSDPA cells each overlapping with at least one other WCDMA-HSDPA cell are deployed in a certain simulation area. The cell capacity of each cell type is defined as follows: 80 voice traffics (equivalently about 1.15Mbps) can be accommodated in a single CDMA1x cell; 1.2Mbps in an EvDO cell; 240 voice traffics (equivalently, about 3.45Mbps) in a WCDMA cell when no HSDPA data traffic is served; and 3.6Mbps in a HSDPA cell when no voice traffic is served. Each mobile station generates one of the five service types of traffic specified in Table I.

Service Type	Bandwidth Requirement (kbps)	Session Duration (sec)	Session Inter-Arrival Time(sec)
WAP	9.6	Weibull (110, 0.54)	Exponential (6)
VOD Streaming	64	Lognormal (3.0997, 0.8951)	Exponential (6)
VOD Downloading	48	Exponential (300)	Exponential (7)
Video Conferencing	64	Lognormal(6.7, 0.5)	Exponential (7)
Voice	14.4	Exponential (360)	Exponential (5)

TABLE I
SERVICE TYPE PARAMETERS

A. Scenario 1

The network-based decision was implemented. Initially, 400 mobile stations are randomly placed such that the

80% of mobile stations generate voice traffic, and the 20% generate data traffic by randomly choosing service types. New mobile stations join the networks following the Poisson distribution with average arrival rate 20 mobile stations per minute during the entire simulation time. From time 0 to time 2,200 seconds, no station departs from the network, and the new mobile stations joined in this time period only generate voice traffic, hence, the network becomes gradually saturated with voice traffic. From time 2,200 to 3,500 seconds, mobile stations with voice traffic depart the network with average departure rate 20 stations per minute, while mobile stations with data traffic continue to arrive with average arrival rate 20 stations per minute. (No new station with voice traffic arrives from time 2,200 to 3,500 seconds.) Hence, the network becomes dominated by data traffic in this time period.

Figure 1(a) shows the throughput of each cell type (we only show the performance of a single cell in each type as cells of the same type perform similarly). The following observations are made from this simulation result, which conforms the operational policy rules. • During the almost entire simulation period, the CDMA1x cell fully serves for voice traffic with almost full load while the WCDMA part of the WCDMA-HSDPA cell serves for the voice traffic increasingly between simulation time 0 to 2,200 seconds and decreasingly between simulation time 2,200 to 3,500 seconds.

• During the first 1,200 seconds, the HSDPA cell (i.e., the HSDPA part of the WCDMA-HSDPA cell) has higher throughput than EvDO cell. This is because the network is not yet fully saturated with the voice traffic, and in this time period, the price of the HSDPA cell is lower than the price of the EvDO cell due to the higher capacity of the HSDPA cell.

• The throughput of HSDPA cell decreases from simulation time around 500 seconds to 2,200 seconds as WCDMA increasingly take more voice calls, and it increases from simulation time 2,200 through the end as the voice traffic taken by the WCDMA decreases.

Figure 1(b) shows the weighted call drop with and without our CRRM applied in which the weighted call drop denotes the total amount bandwidth requested by the mobiles stations dropped from the network. The following observations are made from the results shown in this figure.

• When the CRRM is applied, in simulation time around 1,700 seconds, the voice input reaches 92.5% of the network's voice capacity and the voice call drop starts at around the same time.

• When the CRRM is applied, in simulation time around 2,100 seconds, the voice input reaches the voice capacity of the network with about 4% call drop.

• When the CRRM is applied, in simulation time around 2,400 seconds, the data input reaches 90.7% of the network's remaining capacity after serving voice traffic, the data call drop starts at around the same time.

• When the CRRM is not applied (i.e., no vertical handover is performed after each mobile station is admitted to one of the accessible cell), voice calls start to drop from simulation time around 500 seconds and continue to drop significantly. Data calls also drop significantly when compared to the data call drop with the CRRM applied.

Fig. 1.

B. Scenario 2

Initially 200 mobile stations are randomly placed such that the 80% of them generate voice traffic, and the 20% generate data traffic randomly selecting service types from Table I. The simulation time is 3,000 seconds, and new mobile stations arrive in the area where all four types of RATs are deployed following the Poisson distribution with the average arrival rate 15 mobile stations per minute during the entire simulation period. The 80% of the new incoming mobile stations generate voice traffic while the remaining 20% generate data traffic. The utility value is updated in every second.

Figure 1(c) shows the throughput of each cell type when the network-based CRRM is applied while Figure 1(d) shows the throughput when the MS-based CRRM is applied. We observe here that the performance of each cell type when the MS-based CRRM is applied fluctuates a lot while it is rather stable when the network-based CRRM is applied.

VII. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a novel technique for access selection in multi-access networks. Our algorithms are based on utility values computed by marginal utility functions incorporating any given operational policy rules. Two possible implementations were discussed: network-based and MS-based implementations. Results obtained through simulations using the MANSim simulator that we developed showed that the network-based CRRM approach performs significantly better than the performance without CRRM or the MS-based approach. It should be interesting to further analyze the tradeoff in terms of the performance gain and the system overhead. Such an effort should be based within the standard activity such as the MIH protocol, and we plan to extend our research efforts to this direction.

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