Optimal Joint Session Admission Control in Integrated WLAN and CDMA Cellular Networks with Vertical Handoff *

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Abstract **-** This paper considers optimizing the utilization of radio resources in a heterogeneous integrated system consisting of two different networks: a wireless local area network (WLAN) and a wideband code division multiple access (CDMA) network. We propose a joint session admission control scheme for multimedia traffic that maximizes overall network revenue with quality of service (QoS) constraints over both the WLAN and the CDMA cellular network. The WLAN operates under IEEE 802.11e medium access control (MAC) protocol, which supports QoS for multimedia traffic. A novel concept of effective bandwidth is used in the CDMA network to derive the unified radio resource usage taking into account both physical layer linear minimum mean square error (LMMSE) receivers and characteristics of the packet traffic. Numerical examples illustrate that the network revenue earned in the proposed joint admission control scheme is significantly larger than that when the individual networks are optimized independently with no vertical handoff between them. The revenue gain is also significant over the scheme in which vertical handoff is supported but admission control is not done jointly. Furthermore, we show that the optimal joint admission control policy is a randomized policy, i.e., sessions are admitted to the system with probabilities in some states.

Keywords **-** Mobile communication systems, algorithm design and analysis, Markov processes, linear programming.

*This work is supported by Natural Science and Engineering Research Council of Canada.

1 Introduction

Wireless local area network (WLAN)-based systems are emerging as a new means of wireless public access. Recent study shows that WLANs and wide area networks such as code division multiple access (CDMA) cellular networks will co-exist to offer Internet services to users [1], [2], [3], [4], [5]. WLANs offer relatively high data rates. However, WLANs can only cover smaller areas (hotspots), such as hotels and airports. On the contrary, CDMA cellular networks support low data rates, but offer a much wider area of coverage that enables ubiquitous connectivity. The complementary characteristics of WLANs and CDMA cellular networks make it attractive to integrate these two wireless access technologies. By offering integrated WLAN/CDMA services, operators can attract a wider user base and facilitate the introduction of high-speed wireless data services. Users would benefit from the lower overall cost and the enhanced performance of the combined services.

In integrated WLAN/CDMA systems, these two networks can use the same or share subscriber database for functions such as security, billing and customer management. Therefore, a mobile user of a laptop/handheld that supports both WLAN and CDMA access capabilities can connect to both networks by roaming agreements [1], [2]. *Vertical handoff* (also referred as handover in the literature) between WLANs and CDMA networks can be seen as the next evolutionary step from roaming in this integrated environment. The support of vertical handoff provides mobile users ongoing session continuity, in spite of movements across and between WLANs and CDMA networks [1], [4].

Although some work has been done to integrate WLANs and CDMA networks, most of previous work concentrates on architectures and mechanisms to support roaming and vertical handoff, and how to utilize the overall radio resource optimally subject to quality of service (QoS) constraints has not been studied in detail in this coupled environment. As a consequence, WLAN and CDMA networks are studied and optimized separately in the literature. However, the interplay between WLANs and CDMA networks plays an important role in designing the integrated systems. Therefore, the schemes optimized for only one network (WLAN or CDMA network) may result in unsatisfactory performance for the overall integrated systems. In order to fully utilize the best of these two wireless access technologies, it is important to consider the radio resource jointly. Authors in [3], [5] make fine attempts in this direction by proposing architectures and schemes for joint radio resource management

and QoS provisioning. Particularly, a *joint session admission control* (JSAC) function is identified as a crucial unit to utilize the overall radio resource efficiently in integrated WLAN/CDMA systems. However, no further development about an optimal JSAC scheme is reported in [3], [5].

In this paper, we propose an optimal joint session admission control scheme for multimedia traffic in an integrated WLAN/CDMA system with vertical handoff, which maximizes overall network revenue while satisfying several QoS constraints in both the WLAN and the CDMA network. The distinct features of the proposed scheme are as follows.

- It can optimally control whether or not to admit as well as which network (WLAN or CDMA network) to admit a new session arrival or a vertical handoff session between the WLAN and the CDMA network.
- The model takes into account the different revenue rates in the WLAN and the CDMA network, and the overall network revenue can be maximized.
- A novel concept of *effective bandwidth* [6] is used in the proposed scheme to measure the unified radio resource usage taking into account both linear minimum-mean square error (LMMSE) receivers and varying statistical characteristics of the packet traffic in the CDMA network. QoS constraints are signal-to-interference (SIR) and SIR outage probability in the CDMA network.
- IEEE 802.11e [7], which is a new standard for WLANs to provide QoS, is considered in our scheme. Throughput and packet delay are considered as QoS constraints in the WLAN.
- At the network layer of the integrated system, QoS constraints are blocking probabilities of sessions, including new and vertical handoff sessions in both networks. All the above QoS constraints can be guaranteed in the proposed scheme.

We compare our scheme with two other WLAN/CDMA integration schemes using numerical examples. It is shown that the proposed scheme results in significant revenue gain over the scheme in which optimization is done independently in individual networks and no vertical handoff is supported between the WLAN and the CDMA network. The revenue gain is also significant when it is compared with the scheme in which vertical handoff is supported but no joint admission control is used in the

system. In addition, we show that the optimal policy obtained from our scheme is a randomized policy, i.e., sessions are admitted to the system with some probabilities when the system is in certain states.

The rest of the paper is organized as follows. Section 2 describes integrated WLAN/CDMA systems and the joint session admission control problem. Section 3 describes the QoS considerations in WLANs and CDMA networks. Section 4 presents our new approach to solve the joint session admission control problem. Some numerical examples are given in Section 5. Finally, we conclude this study in Section 6.

2 Joint Session Admission Control in Integrated WLAN/CDMA Systems

In this section, we introduce the integrated WLAN and CDMA cellular networks considered in this paper. Then, we present the joint admission control problem in this integrated environment. We also give an overview of the proposed joint admission control algorithm.

2.1 Integrated WLAN/CDMA systems

There are two different ways of designing an integrated WLAN/CDMA network architecture defined as tight coupling and loose coupling inter-working [1], [2]. Fig. 1 shows the architecture for WLAN/CDMA integration, where UMTS is used as a specific example of CDMA networks.

In a tightly coupled system, a WLAN is connected to a CDMA core network in the same manner as other CDMA radio access networks. In this approach, WLANs and CDMA networks would use the same authentication, mobility and billing infrastructure, and the WLAN gateway needs to implement all the CDMA protocols required in the CDMA radio access network. The main advantage of this solution is that the mechanism for authentication, mobility and QoS in the CDMA core network can be reused directly over the WLAN. However, this approach requires the modifications of the design of CDMA networks to accommodate the increased traffic from WLANs.

In the loose coupling approach, a WLAN is not connected directly to CDMA network elements. Instead, it is connected to the Internet. In this approach, WLANs and CDMA networks use different

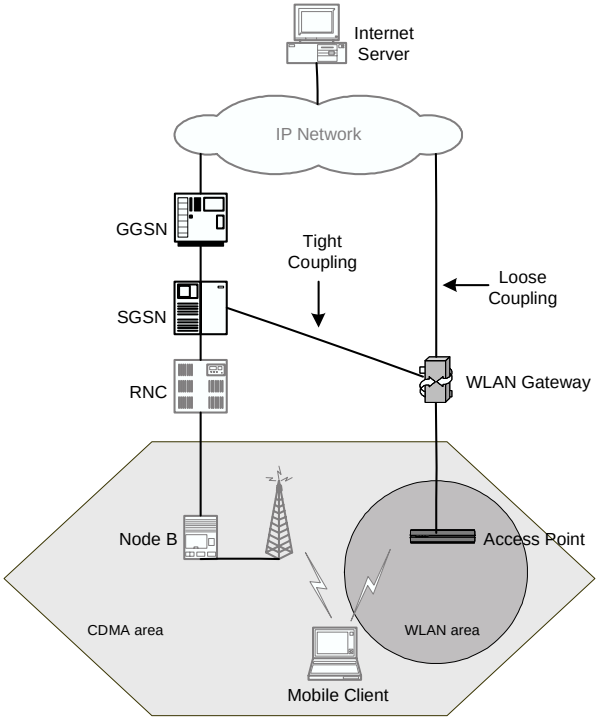

Figure 1: Integrated WLAN and CDMA cellular networks.

mechanisms and protocols to handle authentication, mobility and billing, and the WLAN traffic would not go through the CDMA core network. Nevertheless, as peer IP domains, they can share the same subscriber database for functions such as security, billing and customer management.

Since mobile users are free to move in integrated WLAN/CDMA systems, the support of handoff between these two networks, which provides ongoing service continuity and seamlessness, is needed in this integration [1], [4]. Handoff in a heterogeneous network environment is different from that in a homogeneous wireless access system, where it occurs only when a mobile user moves from one base station (or access point) to another. While handoff within a homogeneous system is called *horizontal handoff*, handoff between different wireless access technologies is referred as *vertical handoff* [4].

2.2 The Joint Session Admission Control Problem

To support QoS in WLANs, an efficient admission control scheme is required in IEEE 802.11e WLANs [8], [9], whereas admission control is also crucial in designing CDMA networks [11], [12], [13]. Since joint radio resource management in integrated WLAN/CDMA systems is largely ignored