Multitier Wireless Communications *

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Abstract. Next-generation computing systems will be highly integrated using wireless networking. The Rice Everywhere NEtwork (RENÉ) project is exploring the integration of WCDMA cellular systems, high speed wireless LANs, and home wireless networks to produce a seamless multitier network interface. We are currently developing a simulation acceleration testbed and a multitier network interface card (mNIC) consisting of DSP processors, custom VLSI ASICs, and FPGAs for baseband signal processing to interact with the various RF units and the host processor. This testbed will also allow us to explore high performance algorithm alternatives through computer aided design tools for rapid prototyping and hardware/software co-design of embedded systems.

Keywords: W-CDMA, Wireless LAN, Multitier networks, Vertical handoff

1. Introduction

The proliferation of computer laptops, personal digital assistants (PDA), and mobile phones, coupled with the nearly universal availability of wireless communication services is enabling the long-held goal of ubiquitous wireless communications [1, 2, 13, 14]. Unfortunately, to realize the benefits of omni-present connectivity, users must contend with the challenges of a confusing array of incompatible services, devices, and wireless technologies [8]. At Rice, we are currently developing RENÉ (Rice Everywhere NEtwork), a system that enables ubiquitous and seamless communication services. Our key innovations are a first-of-its-kind multitier network interface card, intelligent proxies that enable a new level of graceful adaptation in unmodified applications, and a novel approach to hierarchical and coarse-grained Quality of Service (QoS) provisioning. The design of RENÉ requires a coordinated, collaborative effort across traditional layers and across different time scales of the system (see Figure 1) to maintain uninterrupted user connectivity. The RENÉ project is a collaborative effort within the Center for Multimedia

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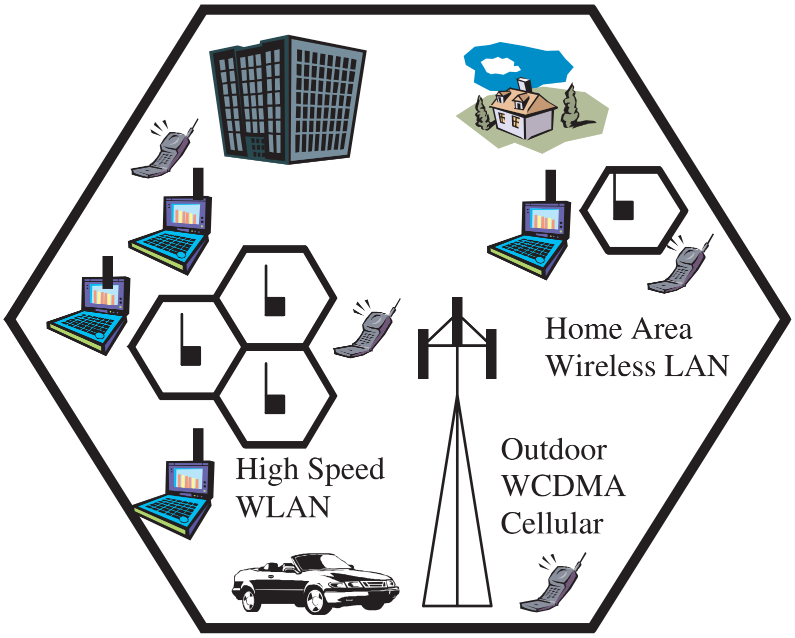

Figure 1. Multitier Wireless Architecture showing Geographical Overlay of Service Coverage.

Communication and also includes Profs. Behnaam Aazhang (Communications), Edward Knightly (Networking), Richard Baraniuk (Signal Processing), and Dan Wallach (Internet Security).

Figure 2 depicts the important time scales of the multitier wireless architecture. At the shortest time scales, medium access protocols dictate how users share the available capacity. At longer time scales, users hand off both horizontally among cells within a tier and vertically among network service tiers. At the longest time scales, users request sessions ranging from a voice "call" to a web browsing session [4]. To ensure that users obtain a seamless and high quality service in this environment, the physical layer and network interface must not only coordinate medium access but must also adapt to the diverse network conditions and standards encountered during horizontal and vertical handoffs [7]. At the network layer, session-based resource reservation can control the frequency, severity, and duration of overflow periods by monitoring system-wide mobility behavior [9]. Finally, when overload does occur, due to either overbooking of resources or vertical handoffs to lower capacity tiers, the filesystem layer (via the proxy) can gracefully

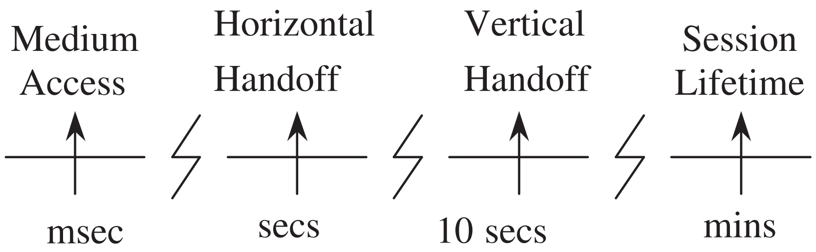

Figure 2. Key Time Scales for System Design.

adapt to the new conditions. This is an area of active research as a number of service enabling platforms for networked multimedia systems are being proposed [3, 6, 10]. Within the Rice RENÉ framework, we are developing (1) a multitier Network Interface Card (mNIC), (2) a proxy server for application adaptation, and (3) a framework for hierarchical QoS management. In this paper, we will focus on the mNIC card.

2. Reconfigurable Multitier Network Interface Card (mNIC) for Service Continuity

Physical layer technologies for home-area networks, wireless LANs, and cellular radio systems have been developing in isolation: each occupies a different frequency band and has developed different physical interfaces and implementations. Our goal is to develop an integrated baseband architecture to seamlessly support each physical layer and to provide intelligent vertical handoff among tiers. With the rapid advances in VLSI design and technology and the related advances in high-level computer- aided-design and simulation systems, we can now discover and exploit the algorithmic commonality among these interfaces.

Our ongoing work has been focused on third and fourth generation cellular system advanced receiver structures for Wideband Code Division Multiple Access (WCDMA) [11, 12]. We are developing through support from Nokia and Texas Instruments an algorithm simulation testbed using TI DSP processors. We will leverage this testbed infrastructure effort to integrate advanced prototype algorithm implementations for High Speed and Home/Desk Area Wireless LANs (WLANs). Our goal at the physical layer is to enable the development of a compact, low power reconfigurable baseband network interface card (NIC) to seamlessly support at least three tiers of WLAN service as shown in Figure 3. This network interface will support soft handoff among different cells within one tier and also soft handoff to different cells in other tiers. These handoff algorithms will require tracking of channel parameters, control signaling with the appropriate tier base stations and interfacing with the network operating system of a mobile PDA or personal computer. In the following subsections, we outline some of the key features, implementation, and integration issues for an integrated baseband transceiver.

2.1. High-Speed WLAN

A large number of WLAN systems have been introduced over the past several years. The initial data capabilities of these systems is 1.6 Mbps and 11 Mbps under the IEEE 802.11 standard. Research is underway to increase the access rate to the order of 25 Mbps in the near term and to 100 Mbps in the next generation. The high-speed wireline modem technology, which made possible the increase in rate from 14.4 Kbps to over 30 Kbps, efficiently applied advanced techniques such as coded modulation, shaping and precoding to the data transmission problem. In order to approach the tetherless future, we need to have a similar "quantum leap" in technology for wireless LAN. Currently, we are investigating advanced coding, modulation and equalization techniques especially for the indoor wireless channel using sophisticated diversity techniques, such as multiple transmit and receive antennas. We are also addressing implementation issues of orthogonal frequency division multiplexing (OFDM) to study a wavelet based OFDM system which results in spectrum efficient and reduced complexity transmitters and receivers. The key implementation challenges for the baseband processing are the integration of real-time FFT (or wavelet) functional unit blocks with high speed coding and decoding blocks. This interface will consist of a hybrid DSP architecture with ASIC or FPGA modules to meet real-time data requirements and to limit power consumption for the mobile mNIC in the RENÉ system.

2.2. Cellular Radio Network

Cellular radio network infrastructure plays a major role in providing ubiquitous access to both the Internet and telephony networks in the outdoors. CDMA has recently emerged as a standard in cellular radio systems for voice transmission. Proposals for Wideband CDMA systems are the leading contenders for the next generation of cellular wireless radio networks both in Europe and Japan. Wideband CDMA is a very flexible multiple access technique that will enable cellular radio systems to offer services beyond voice and support data, image and video traffic [11].

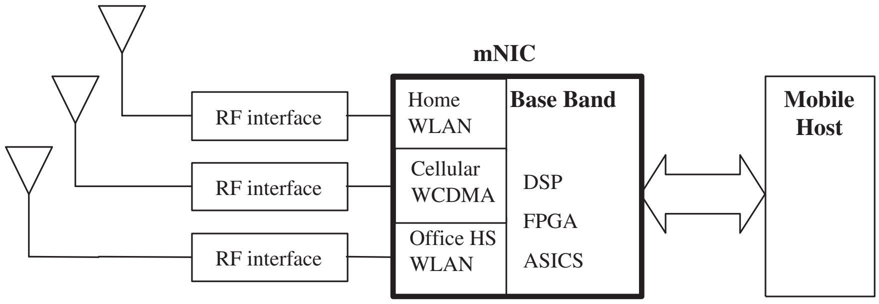

Figure 3. Reconfigurable Baseband Architecture.

The application of signal processing algorithms and information and coding theory to the design of channel estimation and multiuser detection techniques for wireless multiuser communication systems promises to improve system capacity. During the last few years, we have successfully demonstrated the effectiveness of these algorithms in exploiting the full advantages of CDMA technology and their robustness to the characteristics of wireless channels [12]. Our current projects include (i) joint source and channel coding for transmission of images and video over wireless channels, (ii) space-time coding and modulation for users with different quality of service requirements, (iii) temporal, spatial and spectral diversities to combat fading, (iv) multiuser signal processing algorithms for interference mitigation and improved performance. Ongoing work is focused on the real-time implementation of the above algorithms on state of the art programmable DSP chips and reconfigurable FPGA hardware. Once again we are exploring ultimate system capacity tradeoffs for various proposed WCDMA implementations.

2.3. Home/Desk Area WLAN

Wireless desk area networking (DAN) which is often referred to as wireless home area networking is a technology with a fast growing market. These desk area networks will provide wire-free networking and Internet access to various devices including laptops, desktops, printers, and PDAs in a small geographical area. The data links provided by these networks should have rates much higher than traditional personal computer I/O port connectors and be comparable to typical ethernets. Since these networks eliminate the need for expensive wiring they are very attractive alternatives. In the RENÉ multitier wireless system, desk area networks will be considered as one possible tier of services. Such integration involves developing the reconfigurable wireless modem to support the physical layer standards of DANs and building proxy servers that allow seamless handoffs to and from DANs.

We recently began a research collaboration with Texas Instruments on the development of low cost, low power and very short range wireless modems for home and desk area network applications. Within the home or desk area the basestation will be connected to the Internet via a traditional wireline service, such as ADSL or cable modem. The home/desk area WLAN may use a lower cost physical layer RF device, such as the proposed "Bluetooth" wireless transceiver operating at 2.4 GHz. In this project, the home/desk area WLAN will be our third tier of service and require a modified baseband network receiver to deal with both the low- power and interference issues within the home. The necessary baseband processing will also be done within a DSP processor.

3. Implementation Challenges for a Multitier Network Interface Card (mNIC)

In the above discussion, we have focused on each of the three interfaces in isolation. However, to create a truly integrated multitier mobile interface, the baseband processing and network control must be integrated for efficient handoff [8, 13]. In the RENÉ project, we will leverage on the RF expertise of Nokia and Texas Instruments and concentrate on baseband processor integration. Several key issues will need to be addressed within the baseband processor to ensure that signal strength is monitored on the three RF interfaces, and handoff occurs to the lowest cost, highest speed interface. Control pilot channel protocols will be important to guarantee that connections are maintained through the handoff transition. In order to conserve RF power and system resources, the handoff algorithms will transfer all services for a given "user" during a vertical handoff. This initial transition scheme will ensure that only one RF interface will be active at a time, although an enhanced mNIC may eventually be capable of transferring selected component services and maintaining multiple RF connections. A general-purpose microcontroller (MCU) cooperating with the DSP baseband processors will coordinate the processing of handoffs. It will be important to allow for reprogrammability and reconfiguration at this level so that the resulting network interface can be modified to reflect different cellular and wireless standards supported by various service providers. The multitier network interface card (mNIC) will also interface with the mobile host's general-purpose processor to provide current wireless data rate and current wireless bit error rate information. This status information will be critical to the performance of the proxy servers to allow for seamless

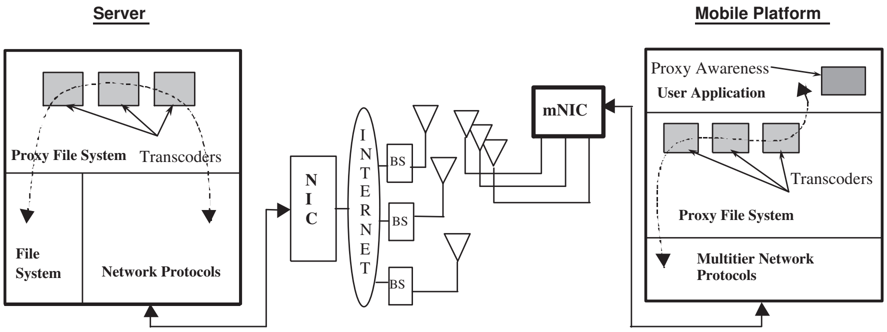

Figure 4. RENÉ Multitier Network Software and Hardware Configuration.

multitier communication in a heterogeneous wireless network as shown in Figure 4.

In order to enable the development of an advanced multitier wireless physical layer prototype, simulation and algorithm mapping must proceed through several design stages. Initial algorithm design and simulation will occur with high level environments such as Simulink/Real Time Workshop from the Mathworks and Signal Processing Workstation (SPW) from Cadence. From the high level simulations, insights will be gained on appropriate approximations and algorithm mappings suitable for DSP processors. A major goal is to study the commonality among the functional blocks in both the OFDM and WCDMA baseband transceiver units to reduce implementation complexity through module reuse. Further refinement of the algorithms and study of the fixed point wordlength will highlight the cycle time and real-time bottlenecks and lead to the identification of candidate modules for FPGA or ASIC implementation. This process will lead to a reconfigurable baseband processor for both the mobile unit uplink and downlink [5]. We will also study the corresponding uplink and downlink algorithms at the various basestation transceivers. For the mobile unit, we will additionally study potential power savings through the use of design optimizations at the VHDL to ASIC or FPGA mapping process. Finally, the integration with the multiple RF signal sources for WLAN, WCDMA, and Bluetooth radios will require complex multi-domain simulation.

Acknowledgements

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is a collaboration among Profs. Behnaam Aazhang, Richard Baraniuk, Joseph Cavallaro, Edward Knightly, and Dan Wallach.

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Authors' Vitae

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Behnaam Aazhang received his B.S. (with highest honors), M.S., and Ph.D. degrees in Electrical and Computer Engineering from University of Illinois at Urbana-Champaign in 1981, 1983, and 1986, respectively.

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