A Prototype Platform for a Multitier Network Interface Card (mNIC)

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ABSTRACT - The Center for Multimedia Communication at Rice University has developed a hardware testbed for multitier wireless environments. These types of environments incorporate many diverse wireless standards, such as 802.11 and WCDMA. The goal of this testbed is to demonstrate seamless switching between various standards. Switching should be automatic, fast and transparent to the user. The current hardware testbed includes the following network devices: wired Ethernet, Bluetooth, 802.11b and 802.11a. Processing is provided by an Axis Communications ETRAX 100LX microprocessor running a Linux kernel. The system has been designed to be used as an embedded system initially, with the ultimate goal of fitting into a small form factor such as PCMCIA or MiniPCI. The testbed is currently being used at Rice to demonstrate the feasibility of multitier systems and to conduct research in the area of multitier systems. It is also being used to implement and demonstrate various ad-hoc routing algorithms. This paper will introduce the need for such a testbed, discuss the current status of the hardware and software, and reveal the future plans and design goals of the testbed.

I. INTRODUCTION

Providing ubiquitous wireless communications has been a research goal of many for years [1-4]. Today, we do live in a world in which wireless Internet access is, indeed, nearly ubiquitous, but it is still not yet a *seamless* user experience. That is, the user experience is still marred by competing standards, clumsy hardware and software, and incompatible services [5]. This paper will give a broad overview of what we call "multitier" systems and present some of the contributions that Rice University[†] has made in this area of research. "Multitier" simply means a wireless environment that is composed of many diverse standards for communications and Internet access. A quick brainstorming session will yield many of the ones that are currently in use: 3G, 802.11a, 802.11b, Bluetooth, GPRS, EGPRS, GSM, WCDMA, Wi-Fi, etc. This is the reality in which we live today – wireless access of some sort is nearly always available, but there does not exist one single device that can seamlessly bridge the gap between the myriad wireless standards that exist in today's marketplace.

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II. Bridging the Gap Between Wireless Systems

Table 1 shows rough estimates of the data rates, range and power for some contemporary wireless systems that are commonly used for Internet access. It is clear from the table why there are so many different standards for wireless access. There is not any one "ideal" technology for wireless access. That is, there are always tradeoffs to be made when choosing a particular mode of access, and each one has advantages in a certain area. For example, WCDMA systems offer excellent range, but at a high power cost, whereas 802.11 offers better data rates at lower power, but with much less range capability. There are clearly benefits to be gained by developing a seamless system for switching between standards. Ideally, any device that could do this would be reconfigurable, such that a single piece of hardware could handle the job of communicating with all of the different standards.

Technology	Data Rate	Range	Power
Bluetooth	Low (100s of kilobytes)	Low (10s of meters)	Low (10s of milliwatts)
802.11b	Medium (megabytes)	Medium (100s of meters)	Medium (100s of milliwatts)
802.11a	High (10s of megabytes)	Low (10s of meters)	Medium (100s of milliwatts)
WCDMA	Low (10s of kilobytes)	High (kilometers)	High (watts)

Table 1 - Characteristics of Some Common Wireless Systems

A typical scenario for ubiquitous wireless access will have a user's personal digital assistant (PDA), laptop or mobile phone switch between available standards in order to achieve the highest possible data rate. This might be because the user is engaged in some multimedia application such as streaming audio or video to a PDA. One could imagine a situation where the user begins at her office where a high-speed wireless LAN connection is available. However, outside the office and in the car there may only be a wide-area cellular connection. In this case, quality may need to temporarily suffer so that the connection can be maintained. Once home, the user could switch back to a wireless LAN and higher quality content could once again be delivered.

It is easy to see, however, that obtaining the highest data rate is not necessarily always the best use of a ubiquitous wireless system. Rather than always seek the highest possible data rate, one might want hardware that would seek a constant connection, but at the lowest possible power consumption. For example, if both Bluetooth and 802.11 are present, one might chose to use Bluetooth to save power, as long as the application permitted the use of lower data rates. Having a system that would give the user both ubiquitous *and* seamless wireless communications would make both of these scenarios a possibility. An additional concern would be billing constraints that may occur in a real world system. A user would also need to be able to set preferences and profiles based on costs. One network might be preferred because the cost is less (or maybe even free) without regard to data rate or other constraints.

At present, there are very few, if any, products on the market that offer the user this kind of seamless experience. At best, to switch connections, the user would have to fumble with multiple cards and cables, and perhaps be forced to change some software settings on their portable device. Of course, this is unacceptable if the user is in the middle of using an application and doesn't want her connection to be disrupted. Some of the available products that this author is aware of include PROSet software form Intel that allows PCs to switch between available networks such as wired Ethernet and 802.11 wireless LANs [6]. In addition, Nokia makes a multimode PC card, the D211, which can operate on both GPRS and 802.11b wireless networks [7]. These products are definitely a step in the right direction. However, more work still needs to be done to offer the user a true seamless multitier experience.

III. THE RICE EVERYWHERE NÉTWORK

To aid in achieving the goal of ubiquitous and seamless wireless communications, The Rice University Center for Multimedia Communication (CMC) established the Rice Everywhere NÉtwork (RENÉ) project. The main goal of this project was to explore the integration of wideband CDMA (WCDMA) cellular systems, high-speed wireless local area networks (WLANs), and personal area networks (PANs). This cross-disciplinary project was first established in 1997 through a grant funded by the National Science Foundation, and researchers affiliated with the CMC have been actively working in the area since that time. Components of this project span all the layers of the OSI reference model - from the physical to the application layers – and include such topics as: physical layer algorithms for WCDMA and WLAN systems, QoS for wireless networks, network modeling, applications for multitier networks.

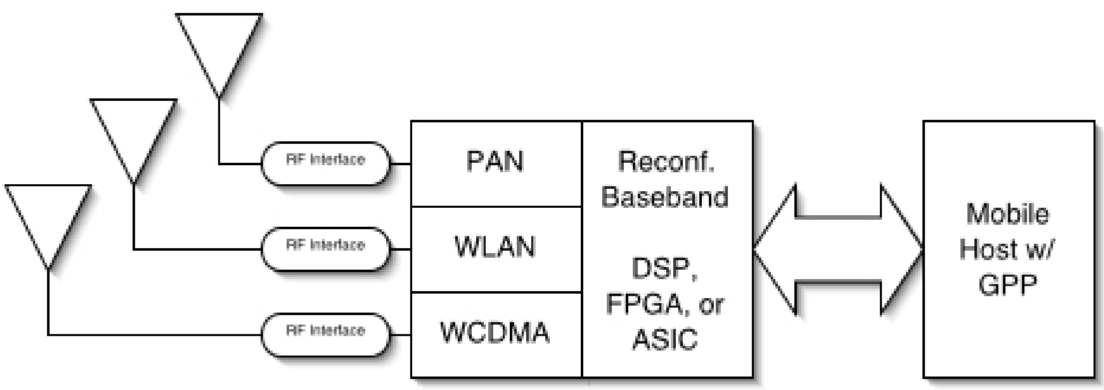

Figure 1 - A Block Diagram of the mNIC Architecture

A major component of the RENÉ project, and the topic of this paper, is the development of a novel piece of hardware called an mNIC (multitier Network Interface Card) and the accompanying software [8-9]. This hardware is dubbed "multitier" because it is capable of operating with multiple wireless standards. It achieves this through reconfigurable hardware that exploits common features of the baseband in each standard.

A basic block diagram for the mNIC architecture is shown in Figure 1. It is useful to point out that Rice University is an academic institution and not a company that sells products. As such, it is helpful to think of the mNIC not so much as a finished product, but rather as a group of components (hardware, software and algorithms) that will achieve the goal of seamless and ubiquitous wireless access. One of these components happens to be an actual prototype system for multitier wireless access.

Initial development of the mNIC was started on several simultaneous paths. One research group pursued the development of physical layer baseband and scheduling algorithms that could be used in a multitier environment, an example of which can be found in [10]. A second group pursued the implementation of these algorithms in reconfigurable hardware such as digital signal processors (DSPs), field-programmable gate arrays (FPGAs), and custom application-specific integrated circuits (ASICs). An example of this is the work done at Rice on a dynamically reconfigurable Viterbi decoder [11] that was implemented in a Xilinx Virtex FPGA. A third group focused on the development of applications that benefited from multitier environments. This sub-project of RENÉ, called Puppeteer [12], made modifications to the Microsoft Office suite of applications so that they could adapt in real-time to varying network connections and congestion. A fourth group pursued the development of a proof-of-concept testbed for the mNIC. The rest of this paper will describe this system.

IV. THE INITIAL mNIC PROTOTYPE

The initial mNIC prototype and testbed were conceived as a way to demonstrate the effectiveness of hardware that has been designed for a multitier environment, and to do so in a real-world environment. While the ultimate goal is to build reconfigurable hardware that can be used in multiple wireless settings, the goal of the first-pass prototype was to build a quick proof-of-concept device that would demonstrate the core principles of the RENÉ project. That is that it would present the user with seamless access to multiple wireless standards. This prototype would also give researchers at Rice – those who are working on higher layers of the OSI model – access to a functional device. This prototype can be used immediately, for example, in conducting experiments in ad hoc routing in multitier environments, without having to wait for actual reconfigurable hardware.

Figure 2 shows the prototype system that is currently being tested in the lab. Rather than designing our own PC card or PCI device, we chose to make this version of mNIC a completely self-contained embedded system. To speed development, common off-the-shelf components (COTS) were used where possible, as were complete wireless chipsets from major semiconductor vendors. The device is based on the ETRAX 100LX processor (not visible in the picture) from Axis Communications [13], which is capable of running the full Linux 2.4 kernel. Attached to the processor bus are 2MB of flash memory and 8MB of SDRAM. Included in this design are: a 10/100 wired Ethernet connection, USB for peripheral expansion, a class 1 Bluetooth transceiver, and a GPS module for locationaware computing applications. Not shown in this picture is an additional plug-in card that contains a PCMCIA slot for use with an 802.11b or 802.11a card. We are currently using an 802.11 b driver implementation for the ETRAX from Balnetos Komunikacijos [14], which uses the processor's high-speed parallel port to connect to the wireless LAN card. By adding this card, our prototype becomes a true multitier device that is ready for deployment.

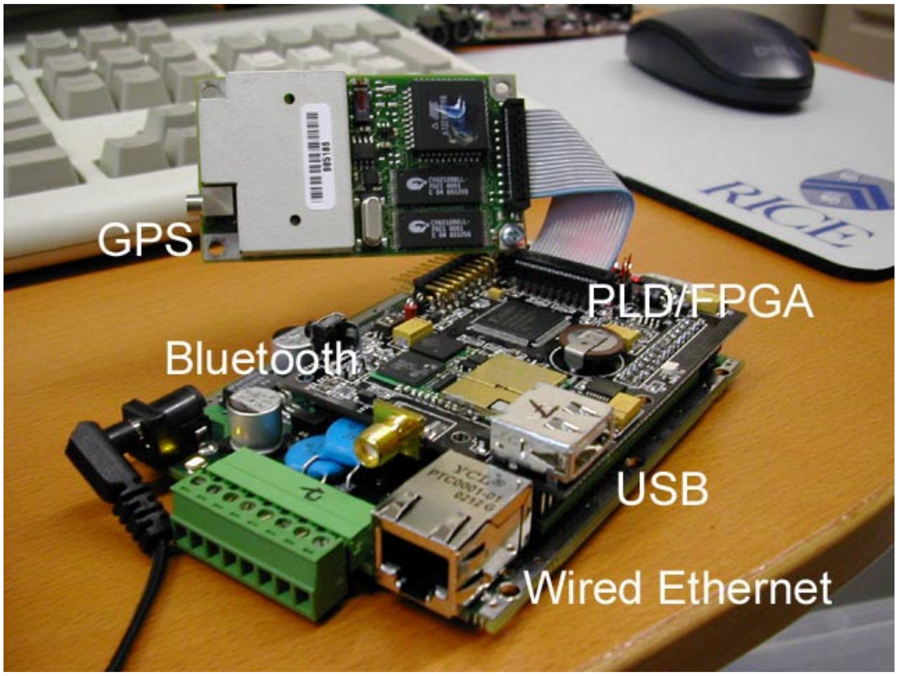

Figure 2 - Prototype mNIC Developed at Rice University

V. System Deployment - The Rice University Shuttle Bus Project (RUSH)

Testing and deployment of our device is occurring through the Rice University Shuttle Bus Project (RUSH). The university administration has been supportive of the RENÉ project and has given us permission to install our custom hardware in the shuttle busses that circle the campus. This provides an ideal test platform by mixing devices that are constantly mobile with several fixed basestations. We are using this as a demonstration platform and as a tool for conducting networking experiments in a multitier environment [15]. Figure 3 shows a map of the Rice University campus with the shuttle bus routes and the locations of the initial fixed basestations. Expansion of the system is currently taking place.

To demonstrate the multitier concept, each mobile device (i.e. the shuttle busses) will be equipped with a complete mNIC. It contains at least Bluetooth and 802.11b wireless transceivers. Basestations, however, may contain only one standard, and no one standard provides blanket coverage to the campus at this point in time. Therefore, as the shuttle busses move across campus, they will move in and out of range of the two technologies and must switch between them in order to maintain a constant connection. Our initial test application involves providing GPS tracking data to the Rice University Transportation Office. We also use this GPS data to route data in an ad hoc manner when no basestation is reachable and also to help determine when switched between technologies should be made.

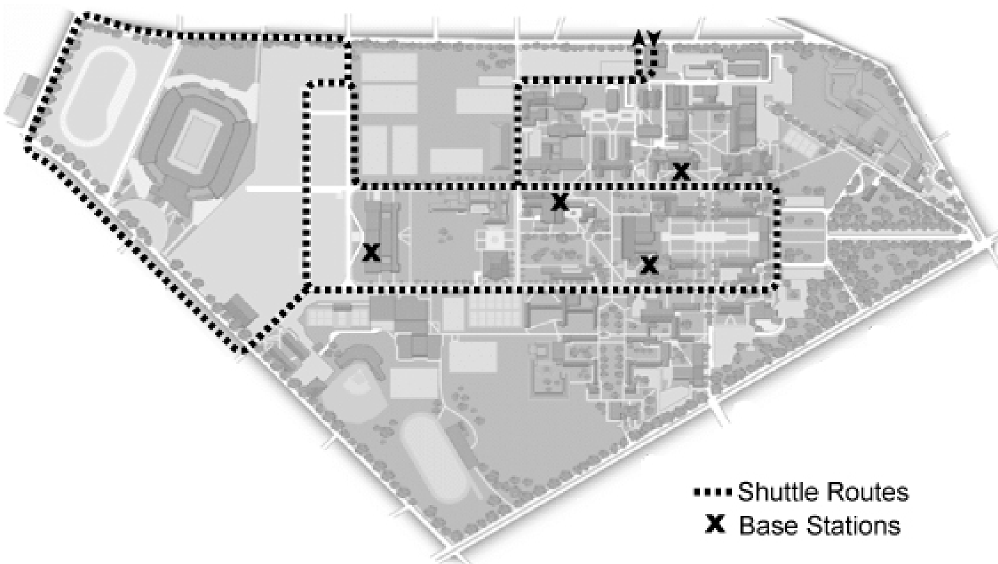

Figure 3 - Rice University Campus Map with Shuttle Bus Routes and Basestation Locations

VI. FUTURE DIRECTIONS

The mNIC and corresponding testbed are ongoing research projects. There are several improvements that we are actively pursuing at the time of this writing. First, as previously mentioned, we are expanding the current testbed system to include more mobile test stations and fixed basestations. Second, we are working on a new design of mNIC that will offer some level of reconfigurability between standards. It is likely that this will occur as an FPGA-based solution with the use of partial chipsets (most likely the radio elements) of several standards. Third, we are adding wide area WCDMA coverage through the use of custom radios that operate in the 2.4Ghz ISM band. This feature will provide a low data rate, but wide area complement to the existing 802.11 and Bluetooth standards. Finally, we will eventually implement the mNIC in a smaller form factor, such as a PCMCIA or Cardbus card that can be installed in a laptop or PDA.

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