# A Mobile Testbed for GPS-Based ITS/IVC and Ad Hoc Routing Experimentation

**Erik Welsh, Patrick Murphy, J. Patrick Frantz**
Department of Electrical and Computer Engineering
Rice University, Houston, TX, USA
{welsh,murphpo,jpfrantz}@rice.edu, http://www.cmc.rice.edu/

## Abstract

Past investigations into the formation of ad hoc networks and ad hoc routing have focused on computer simulations of mobile traffic. However, the proliferation of mobile electronic devices (mobile phones, PDAs, and laptop computers) combined with the commoditization of GPS chipsets has made realizable the construction of a large-scale testbed for both GPS and non-GPS aware ad hoc network applications. In this paper we present the Rice University Shuttle Bus Project (RUSH)[1] as such a testbed in its first stages of development, in which we have outfitted the shuttle bus system at Rice University with custom wireless and GPS hardware.

## Keywords

Wireless ad hoc networks, Global Positioning System (GPS), Bluetooth.

## I. INTRODUCTION

Imagine if, while getting off a shuttle bus on the way to work, a passenger makes a voice over ip telephone call using her wireless enabled Personal Digital Assistant. Packets from this device are then seamlessly routed between the fixed base stations of the local infrastructure and other mobile wireless devices in the area enabling the call to be completed. With the proliferation of wireless devices, there is an ever increasing demand for wireless connectivity, anywhere and everywhere. With this demand, both the local fixed infrastructure and other mobile nodes in the area need to be utilized through ad hoc routing protocols in order to provide complete coverage.

Previously, in order to evaluate ad hoc network applications such as GPS and GPS-free routing protocols, researchers have primarily used simulation. Simulation as an evaluation method has both pros and cons. On the plus side, it is easy to construct a system and test it. It is also easy to make modifications to a proposed system. On the minus side, simulators can be constrained because of complexity. For example, most simulators tend to work in a fairly limited area, about 1 $km^2$, with a small number of hosts, often less than 50. In addition, simulators rarely address the nature of a wireless channel, which can greatly affect performance in a mobile environment. Effects such as Doppler shift and spread, multipath and fading are seldom included in the simulation [11]. At best, the channel may be modelled in an AWGN environment. Furthermore, most simulation models assume a pseudorandom movement within a given space. This does not necessarily reflect a real environment. Few studies have investigated mobile routes which are regular in their patterns [8, 13].

In order to consider many of these factors, a physical testbed is needed to analyze ad hoc network applications. Therefore, we are building the Rice University Shuttle Bus Project (RUSH). RUSH is a hardware and software testbed for an inter vehicle communication (IVC) and intelligent transportation system (ITS) which operates in a peer-to-peer manner with access to a limited infrastructure. Peer-to-peer systems of this type have been studied, but mostly in a simulation environment [10]. RUSH, on the other hand, offers a true testbed which includes both GPS-aware mobile and fixed wireless nodes, since both are becoming inexpensive enough to be conceivably put into any device. RUSH currently operates on the Rice University Campus, a relatively wide area. This allows RUSH to be used to test a variety of applications that have up to this point only been studied via simulation.

This paper will introduce the various components of the RUSH system and discuss possible applications that could use RUSH as a "real-world" test environment. Section 2 will cover the RUSH hardware, while Section 3 will cover the RUSH software. Then, Section 4 will discuss possible applications to be used with RUSH. Finally, Section 5 will offer a summary and future directions of RUSH.

## II. RUSH HARDWARE

In order to create RUSH, we designed a wireless node, Wireless Integrated Networked Device (WIND), which can act as either a GPS-aware fixed basestation or mobile node. The WIND, as seen in Figure 1, combines common off-the-shelf components (COTS) with custom PCB design to provide a platform for ad hoc network applications.

The design for WIND centers around the ETRAX 100LX processor (not visible in the picture) from Axis Communications [3], which is capable of running the full Linux 2.4 kernel. Access to the processor is through a development board, also from Axis Communications [2], which provides 2MB of flash memory, 8MB of SDRAM and a 10/100 wired Ethernet connection. The processor is then connected seri-

[1] http://koala.ece.rice.edu/projects/rush/

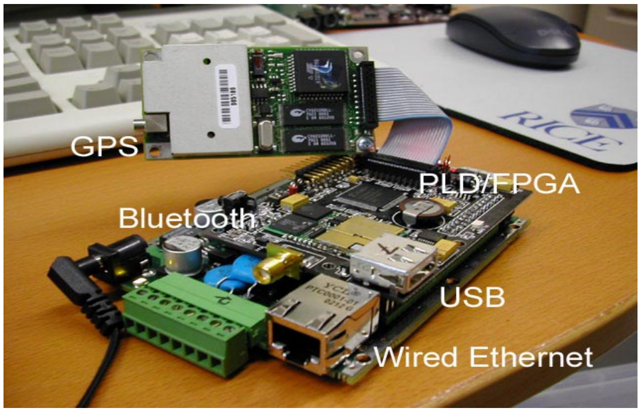


**Figure 1. RUSH Wireless Node (WIND)**

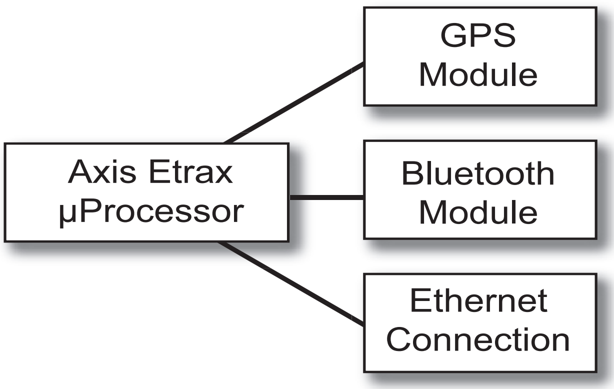


**Figure 2. Block Diagram of RUSH WIND**

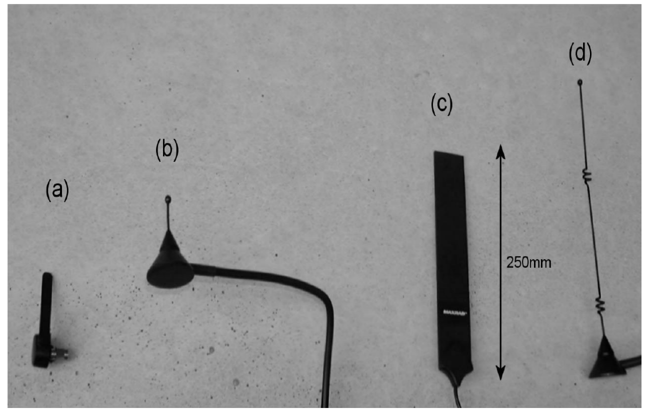


**Figure 3. Antennas Used in Testing**

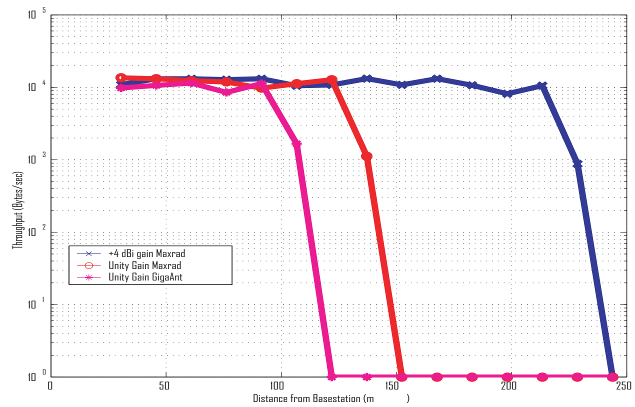


**Figure 4. Throughput vs Distance from Basestation (Fixed Class 1 module and Mobile Class 2 module)**

ally through our custom PCB design to both a GPS module manufactured by Connexant and a class 1 Bluetooth radio from Taiyo Yuden based on the SiliconWave chipset, as seen in the block diagram of Figure 2. Class 1 Bluetooth modules have a broadcast power of 20 dBi and a specified range of approximately 100 meters. However, experiments have shown that even with a 0 dBi gain antenna, the class one radios can have a much farther range [12]. Therefore, we performed further experimentation with various antennas to determine to see the range and throughput of the WINDs within RUSH.

## Antenna Experimentation

Since it is critical in most wireless applications to maximize the amount of data that can be sent between two wireless devices, we tested various antennas to determine their throughput at as a function of distances away from a basestation. For our tests, we used four omnidirectional antennas, as seen in Figure 3, whose specifications are given below:

- (a) GigaAnt 2.4 GHz swivel mount antenna with unity gain
- (b) Maxrad BMMG24000 magnetic mount antenna with unity gain
- (c) Maxrad MIG24 tapemount antenna with +4 dBi gain
- (d) Maxrad BMMG24005 magnetic mount antenna with +5 dBi gain

In order to test the throughput of the wireless connection, we first set up a WIND basestation with a class 1 Bluetooth module using a +4 dBi gain antenna. Since mobile node might have power limitations, we used a WIND mobile node with a class 2, 4 dBi, Bluetooth module with a +4 dBi gain antenna. Then in a "real world" environment, with multipath effects from trees, vehicles and buildings, we transferred a 64 KB file multiple times from the mobile node to the basestation using FTP across a TCP/IP link and observed the throughput. We then repeated the tests with the two unity gain antennas to show the performance increase of gain antennas. The gain antennas give almost the same range as using two class 1 Bluetooth modules [12]. Again, we observed ranges that far exceeded those specified in the Bluetooth Spec. The results of these throughput tests can be seen in Figure 4.

From the test, we can see that throughput remains relatively constant over most of the range of the antenna and then

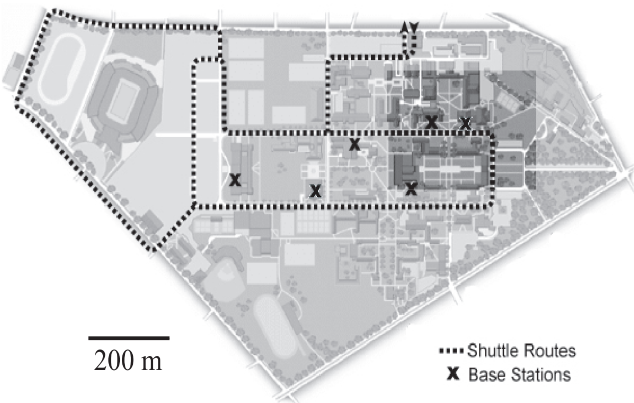


**Figure 5. Map of RUSH testbed on Rice Campus**

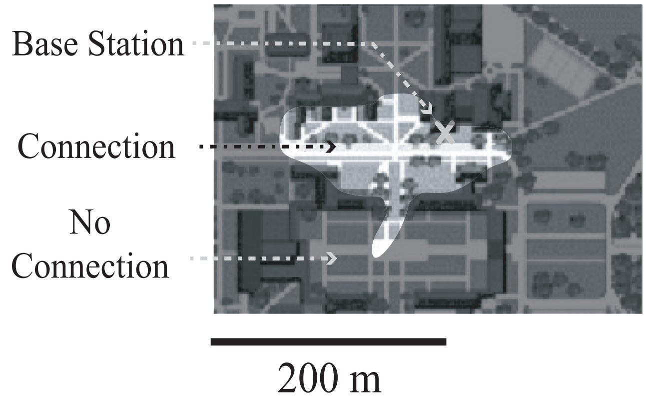


**Figure 6. Coverage of Single WIND Basestation on the Rice Campus**

falls off sharply as the range continues to increase. The throughput bitrates are not as high as one might expect give the Bluetooth standard has a maximum raw data rate of 1 Mbps. This can be attributed to many factors. First, the internal serial transfer of the files within the node itself was capped at 460800 bps. Then, there was overhead due to error correction with the Bluetooth standard [6] as well as the FTP protocol itself. In addition, it is well known that the TCP/IP protocol is not well suited for a wireless link and can cause additional loss of throughput, and many suggestions have been made to improve its performance [7]. The +5 dBi antenna was used as well in this test, but we could not form a reliable connection. However, the +5 dBi antenna was used successfully in other tests.

### Fixed WIND Locations

Based on our tests of throughput, we have currently placed six WIND basestations around the Rice University campus, as shown in Figure 5. There are also mobile WIND nodes in six of the Rice University shuttle busses. This not only forms the basis of the RUSH testbed, but also allows the Rice University Transportation Office to monitor the movements of the shuttles in real-time.

We also performed tests to see the coverage of one of our WIND basestations in it's real environment, as seen in Figure 6. In order to see the maximum range of the WIND basestation, we equipped the basestation with the +5 dBi gain antenna, and a mobile WIND node with a +4 dBi gain antenna. From the figure, we note that the main limitation to the coverage of the basestation is the presence of buildings. Fortunately, due to the nature of the Rice campus, this still provides good coverage over the paths travelled by the mobile WIND. However, the wireless node is only the first step towards making this an easy-to-used testbed for application designers. In addition, we noticed an interesting effect that is not shown in the figure. The coverage shown in Figure 6 represents successful device inquiry and connection establishment. We did notice that once we established a connection to the basestation, we were able to travel well beyond the boundary shown in the figure, while keeping the connection active (usually around an extra 50 meters). Therefore, the useful range is greater than what is indicated in Figure 6.

## III. RUSH SOFTWARE

In order to streamline application development for the RUSH testbed, we created a flexible set of software libraries to integrate our hardware, performing common functions, such as parsing GPS data or providing network services. The code design was structured from our assessment that the software portion of the device should provide three main categories of service: network, sensory input, and control logic. By generalizing the categories of service, we hope to end up with a more adaptable device, reducing time needed for new feature implementation, and create a potentially highly reusable code base for future projects.

As seen in Figure 7, network and sensory services are integrated by control code. The control logic takes in command line arguments specifying which type of network and sensory devices will be used, desired routing protocol, data collection interval, and time period for accessing routing decisions. Control then initializes the specified hardware and begins looping over data collection and data routing at the specified intervals.

Our current network library is setup to utilize the onboard Bluetooth network. Driver code is based on the open source implementation of the Axis OpenBT Stack [4]. The Axis OpenBT libraries abstract away hardware specific operations associated with device discovery, establishing a connection and transferring data. Our changes to the Axis stack were primarily to add another layer of abstraction and convert the OpenBT library from a set off command line applications to a structure more suitable to use by other programs.

Sensory input is provided by a custom implementation of a GPS device driver. The GPS libraries offer the ability to parse

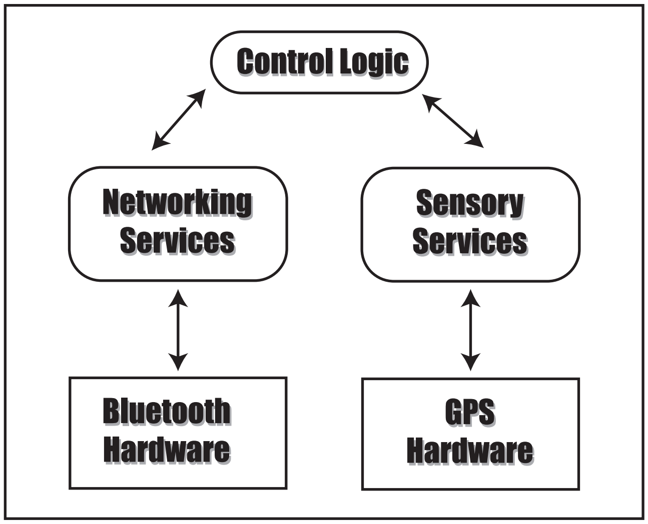


**Figure 7. RUSH Software Abstraction Layers**

GPS streams of NMEA formatted data into well-defined data structures that can be easily accessed.

Finally, we provide documentation on creating applications for the testbed. Therefore, users do not need to know every detail of the hardware, merely the strengths and limitations of the testbed.

## IV. POSSIBLE RUSH APPLICATIONS

In developing RUSH, we have tried to provide a "real-world" test environment that targets many applications and future areas of research. The primary use of RUSH is to provide real-time tracking information on the shuttle busses for the Rice University Transportation Office. However, the testbed was designed to suit many research applications, as well.

Since RUSH combines fixed WINDs with mobile WINDs, we can use GPS data in novel ways. Mobile WINDs can have knowledge of where fixed nodes are and use this to their advantage by determining when they are "in range" of a known basestation. The distance, $D$, between points $(x_1, y_1)$ and $(x_2, y_2)$ on a globe is given by:

$$D = R * \arccos(\cos x_1 * \cos x_2 * \cos(y_2 - y_1) + \sin x_1 * \sin x_2)$$

where R is the radius of the Earth, approximately 6366.7 km. By computing this distance and combining it with knowledge about a WIND's antenna, any node, mobile or fixed, can determine whether it is "in range" of another node. This type of location aware routing could enhance device discovery in protocols like Bluetooth [14] and possibly in future wireless standards.

In addition, scatternet formation and routing in ad hoc networks Bluetooth networks is currently and active area of research [5] and RUSH could be used by researchers at Rice and elsewhere to verify these organization and routing algorithms in a real environment. Furthermore, as mentioned in other studies [8], GPS may not always be available for accurate location information (e.g. in an indoor environment), so other methods need to be considered. In a hybrid environment, with fixed nodes as well as mobile nodes, RSSI plus a digital compass could be used to determine crude location information with respect to a fixed node. This could be used to facilitate route discovery and handoffs in a hybrid environment. The RUSH project testbed can be used to evaluate these GPS-free methods, as well.

## V. DISCUSSION AND FUTURE WORK

RUSH is still in its initial stages of development as a testbed for ad hoc network applications. Currently, RUSH uses Bluetooth to wirelessly transmit data. However, we would like to expanded this to include other wireless technologies such as 802.11a, 802.11b and wide-area W-CDMA cellular technology. We envision that future WIND devices will operate in a multitier environment in which connections can be made across different wireless media [1]. The hardware for such a multitier system is currently under development at Rice [9]. Also, we would like to expand RUSH to include many more WINDs than are currently in the network. For example, we would like to include the maintenance carts used on campus, as well as the cars of students and staff. Finally, we would like to work with other research groups to help port existing ad hoc network applications over to RUSH.


## ACKNOWLEDGEMENTS

We would like to thank Randy Holman, Rob Gaddi, and Ricky Hardy for their hard work and dedication to this project. Also, we would like to thank the Rice Digital Library, Rice Information Technology, and George R. Brown School of Engineering for providing seed funding for this project.


## REFERENCES


[1] Aazhang, B., and Cavallaro, J. R. Multi-tier Wireless Communications. Kluwer Wireless Personal Communications, Special Issue on Future Strategy for the New Millennium Wireless World 17 (June 2001), 323–330.

[2] Axis Communications Developer Board LX. http://developer.axis.com/products/devboard/index.html.

[3] Axis Communications ETRAX 100LX. http://developer.axis.com.

[4] Axis OpenBT Stack. http://developer.axis.com/software/bluetooth/.

[5] Basangi, S., and Petrioli, C. Multihop Scatternet Formation for Bluetooth Networks. In *Proceedings of the Vehicular Technology Conference* (Spring 2002), vol. 1, pp. 424–428.

[6] Bluetooth Specification version 1.1. http://www.bluetooth.com/.

[7] Chaskar, H., Lakshman, T. V., and Madhow, U. TCP Over Wireless with Link Level Error Control: Analysis and Design Methodology. In *IEEE/ACM Transactions on Networking* (Oct 1999), vol. 7, pp. 605–615.

[8] D. Kim, C. T., and Choi, Y. Location Aware Long-Life route Selection in Wireless Ad Hoc Networks. In *Electronics Letters* (Aug 2000), vol. 36, pp. 1584–1586.

[9] Frantz, P. A Prototype Platform for a Multitier Network Interface Card (mNIC). In *Communications Design Conference* (September 2002).

[10] Joa-Ng, M., and Lu, I. A GPS-Based Peer-to-Peer Hierarchical Link State Routing for Mobile Ad Hoc Networks. In *Proceedings of the Vehicular Technology Conference* (Spring 2000), vol. 3, pp. 1752–1756.

[11] Karimi, H., and Krishnamurthy, P. Real-time routing in mobile networks using gps and gis techniques. In *Proceedings of the 34th Annual Hawaii International Conference on System Sciences* (2001), pp. 3470–3480.

[12] Murphy, P., Welsh, E., and Frantz, P. Using Bluetooth for short-term ad hoc connections between moving vehicles: a feasibility study. In *Proceedings of the 55th IEEE Vehicular Technology Conference* (Spring 2002), vol. 1, pp. 414–418.

[13] W. Su, S. L., and Gerla, M. Mobility prediction in wireless networks. In *MILCOM 2000, 21st Century Military Communications Conference Proceedings* (2000), vol. 1, pp. 491–495.

[14] Welsh, E., Murphy, P., and Frantz, P. Improving connection times for Bluetooth devices in mobile environments. In *Int. Conf. Fundamentals of Electronics, Communications and Computer Science (ICFS)* (March 2002).