Experiences Deploying an Ad-hoc Network in an Urban Environment

Peter Barron, Stefan Weber, Siobhán Clarke, and Vinny Cahill
Distributed Systems Group,
Department of Computer Science,
Trinity College,
Dublin 2, Ireland.
email: {Peter.Barron, Stefan.Weber, Siobhan.Clarke, Vinny.Cahill}@cs.tcd.ie

Abstract

Studies of mobile ad-hoc networks are in the most part restricted to simulations and theory. They have, to this point, rarely ventured into the real world on a large enough scale to make significant statements about their behavior or performance. The lack of evaluations is largely due to the practicable implications of deploying and evaluating such networks in a real environment. In order to analyse the problems we have built a Wireless Ad-hoc Network for Dublin (WAND). The network provides a large-scale testbed for applications and protocols for mobile ad-hoc networks. It offers the opportunity to explore the behavior and performance of a variety of routing protocols in a real-life environment and an ideal platform for investigating the use of mobile applications in an urban environment. In this paper we present WAND and the experiences gained in building such a network.

1. Introduction

Much of the research in ad-hoc networks has been restricted to the evaluation of solutions through simulation. The simulators used typically aim to represent the different software and hardware components within the system as well as the physical environment in which they operate. While this provides a useful method of validation the simplified assumptions made of the physical environment limit the scope of what can be achieve from them [4, 8]. For instance, the phenomena of gray-zones were only discovered through experiments conducted real world environment. It is therefore necessary to complemented simulation studies with real-world experiments to identify phenomena that would otherwise go unnoticed within a simulator. For these reasons, we have built WAND - the Wireless Ad-hoc Network for Dublin - a large-scale testbed for ad-hoc network protocols and applications.

The network covers the centre of Dublin along a 2km route from Trinity College Dublin to Christ Church Cathedral. The area is seeded with a number embedded devices with wireless connectivity. These devices have been custom-built to meet the needs of the WAND network. They are housed in 3x3x6inch containers that accommodate a stack of PC/104 boards, IEEE 802.11b PCMCIA cards, and two patch antennae. The embedded devices are hosted on traffic lights and cameras along the route to provide a minimum level of connectivity. The embedded devices form a sparse population of wireless network nodes. This sparse coverage is constantly available and the embedded devices can be configured to create a variety of network models. The testbed can be further populated through the introduction of mobile nodes such as laptops, PDAs, and other mobile devices with wireless connectivity. The network provides researchers with a flexible platform for developing and investigating different protocols and applications for ad-hoc networks.

In designing the WAND network, the goal has been to provide a platform that would allow basic research on the behavior and performance of ad-hoc routing protocols in a real-life environment. The choice of an urban setting, while also providing a fertile environment for mobile applications, exposes the network to the problems and challenges of operating in an environment that is inherently unpredictable. The changes in weather, movement of people, and that of cars, trucks, and buses, while the presence of buildings all have an effect. Rather than avoiding these issues we aim to include and measure their effect on the behaviour of the network and its components. The WAND testbed also offers a unique opportunity to explore the different aspects of building applications for wireless ad-hoc networks in an urban setting. The goal has also been to use the WAND network to build integrated traffic systems, pervasive computing applications, and location-based services, and as such, it provides an excellent testbed for investigating these areas of research.

In this paper we discuss the technology employed in the test-bed and the experiences gained in deploying the WAND network. We then present some initial results of the throughput over a series of nodes using AODV [14].

2. Description of WAND

The section provides details of the WAND testbed. Describing the environment that it is operates in, the hardware that is used to form the initial sparse population of fixed nodes for the network, and the software that is installed on each of these nodes.

The testbed is locate at the heart of the shopping and business districts of Dublin along a 2km route. It is seeded with a number of custom-build wireless-enabled embedded PCs. The nodes are distributed along the route in the form of a line at a distance of about 200m apart. Each pair of neighbouring nodes is installed within line of sight of each other. There are currently eleven of these nodes located along the route. The nodes are mounted on traffic lights and camera positions at a height of about 3m. Figure 1 provides an overview of the area covered and the distribution of the nodes. The *GK* node is used as gateway from the WAND network to the college network.

The streets the network is deployed on are approximately 16-22 m wide and are lined by buildings of 4-6 stores high. The majority of these buildings have thick stone-walls that block the propagation of radio signals onto the neighbouring streets running in parallel.

Figure 2. Hardware used to WAND node.

The streets in the area are open to public traffic which run on either one- or two-way streets. The vehicular traffic on these streets consists of a mixture of cars and buses; articulated trucks do not enter this area of the city centre. Most of the vehicles have a height between 1.5m and 2.5m except for double-decker buses which have a height of 4.40m.

2.1. Hardware

The hardware for the nodes that form the initial sparse population for the WAND network are custom-build embedded PCs. Each node consists of a stack of PC104 boards [13, 12], a number of 2.4GHz PCMCIA wireless cards, an enclosure, and a set of antennae. The stack of PC104 boards comprises of a motherboard and two PCMCIA PCI-boards (see Figure 2).

These boards are mounted inside an enclosure together with a 30GB hard-drive. The motherboard employed in the system is a 400-700 MHz EEPD C3VE board featuring a Pentium-class processor, 128MB of memory, a video and an Ethernet adapter as well as an IDE controller. Each of the PCMCIA boards have two PCMCIA slots. These slots are filled by three CISCO Aironet 350 cards which provided 802.11b connectivity. The cards have two sockets that connect to external antennae instead of an internal antennae which is more commonly used. The sockets are connected via 10cm cables to RP-TNC connectors that are mounted on top of the enclosure. The setup allows a variety of antennae to be used by the nodes. At the time of writing, each of the fixed nodes is equipped with two patch-panel antennae with a gain of 8.5 dBi. The radiation pattern of these antennae is in the shape of a

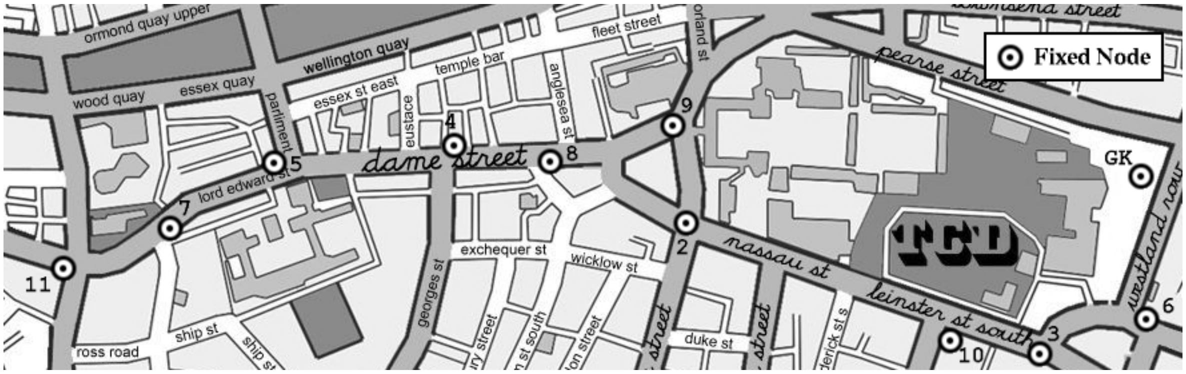

Figure 1. Map of the area covered by WAND.

hemisphere in front of the antennae. The patch-panel antennae of neighbouring nodes are directed towards each other.

2.2. Software

The platform provided by the nodes is similar to what your might find on a Pentium based PC with a number of extra wireless network cards connected. At present, the nodes have been installed with RedHat Linux 9. The installation includes packages such as web-server, a JDK installation (version 1.4.2), a secure-shell daemon, plus the majority of the other packages that typically come with this distribution.

The kernel, that by default comes with the RedHat Linux 9 installation, has been replaced with the kernel from the RedHat Linux 7.3 distribution. This is due to the RedHat 9, kernel version 2.4.20, using PCI-hotplug which conflicts with the current configuration of the PC104 stack. The kernel that comes with the distribution of RedHat Linux 7.3, kernel version 2.4.18-3 was developed prior to the introduction of PCI-hotplug support in the kernel and operates without problems on the PC104 stack.

Currently, the OLSR [7], and AODV [14] routing protocols have been installed on the nodes. The AODV implementation - Kernel AODV (version 2.1) - is from the National Institute of Standards and Technology and the OLSR implementation is from [3]. It is possible to install other protocols though at this stage we have not done so.

2.3. Configuration scenarios

The aim has been to provide a flexible platform that can support various network topologies and installation of different routing protocols. It is possible to configure the sparse network of nodes, that make up the WAND network, to provide a backbone and serve as regular access points to mobile nodes. Alternatively, they can also be configured to use the wireless cards and antennae they have to resemble a network of ad-hoc nodes. Mobile nodes can then be connected to form larger ad hoc networks.

The fixed nodes also provide a excellent platform for running different pervasive computing, mobile applications, or integrated traffic systems scenarios. The embedded devices used are ideally placed in the middle of the shopping, tourist, and business districts of Dublin and have enough power to support applications that require quality-of-service support or extra processing power. The fixed installation of nodes also ensures that a permanent presence can be maintained for example for location-aware services.

3. Description of Experiences

This section describes some the experiences gained during the installation and preliminary evaluation and use of the testbed. The issues listed are broken into two categories. Those that occurred during the initial installation and those that subsequently arose from the day-to-day use of the network as a testbed for ad-hoc routing protocols, and for application development and testing.

3.1. Installation issues

The installation of the testbed involved an initial design phase followed by the deployment of the nodes between Trinity College Dublin and Christ Church Cathedral. The choice of hardware and software used was based on an initial set of requirements for providing a flexible testbed for basic research into protocols and applications is a wireless ad-hoc network. The deployment of the nodes was achieved in collaboration with the local authority who provided access to the traffic lights and camera positions along the length of the route. The experiences gained from building WAND have shown to us many of the difficulties facing those looking to develop these types of networks. In this we wish to highlight a number of them.

Hardware is difficult. During the initial design of the testbed a number of hardware configurations were considered. One of the major factors that influenced the design was the availability of off-the-shelf hardware for IEEE 802.11a/b/g network cards. Most of the wireless network cards either available in either PCMCIA or cardbus format. Thus the hardware of a fixed node had to support the PCMCIA format.

A number of community wireless projects use PCBs with one PCMCIA slot. One of the intend use for the testbed is the development and evaluation of multimedia applications and quality-of-service (QoS) protocols. The specifications for these uses required more processing power and storage capacity than the available PCB could provide.

We finally choose the current hardware configuration because of its compatibility to desktop PCs, availability of off-the-shelf components and the ability to configure it to suit the required number of network cards. However, the lack of previous experience with this hardware platform and the lack of maturity of the hardware at the time lead to a number of problems: Motherboards that comply with the PC104 standard and are based on Intel 80386 processors are relatively mature and stable. High-end motherboards that comply with the PC104+ standard and feature Pentium-level processors are more complex. The PCI-bus that was introduced with the PC104+standard requires components in a PC104+ stack to accurately synchronize the timing of signals on the bus. This requirement makes the use of PC104+ stacks more complex and difficult compared to PC104 stacks.

Positioning of nodes. When deploying the network between Trinity College Dublin and Christ Church Cathedral it was necessary to find the best positions along the route for the nodes. However, we found that there where a number of issues that restricted where we positioned the nodes. First, was the actual range that could be obtained from the nodes and the patch antennae being used. It was found that the distance could vary considerably depending on the buildings, density of vegetation, road congestion, and interference from existing networks in the area. However, the biggest influence was the actual route taken by the network in combination with height of the buildings in the surrounding area. In many cases the line of sight between nodes was lost as the network weaved it way through the city centre. The combination of factors significantly decrease what could normally be achieved when line of sight could be maintained. Sources of power for the nodes also provided to be an issue that restricted where we could place the nodes. The only power sources available to us were the traffic lights and some of the camera positions locate along the route. This provided us with 17 possible locations for 11 WAND nodes along a 2km route. However, we found a number of issues that limited the number of possible positions/locations for the nodes. The use of other sources such as telephone kiosks, apartments, shops would have enabled a better distribution of the nodes and provided better connectivity; unfortunately these locations were not available to us at the time of the installation.

Interference from other sources. The location chosen for the network, while providing an excellent testbed for mobile and pervasive computing research, is in the middle Dublin City Centre at the heart of the business and shopping districts. A wireless survey, using kismet, showed a large number of networks, approximately 35, already existing in the area. The majority were infrastructural based but there were also a couple ad-hoc networks. To annoyed interference with these networks it was necessary to choose a channel not being use by these networks. Unfortunately, due the size of the WAND network the survey showed that the majority of channels were already in use. It was therefore necessary to pick a frequency that would cause the lease amount of interference with the existing networks to ensure the WAND network could operate successfully.

Because of the unlicensed nature of the 2.4GHz band this will increasingly become a problem for deploying these types of networks in urban environments. There is also number of other sources of interference that can cause problems and which are not so easily detected. An example for one such source is the coordination of traffic cameras that are installed at various points along the route. These cameras are controlled generally through a wired connection but sometimes the last 100m to a camera pole is based on wireless communication in the 2.4GHz.

Height of installation The height of the installation of the fixed nodes is a compromise between security of the hardware installation, the quality of the RF signal and the accessibility of the hardware for maintenance. One of the initial concerns regarding the height of the installation was the clearance of the Fresnel zone. A rule of thumb determines that 60% of the 1st Fresnel zone should be free of obstacles. This meant that the nodes needed to be installed at least 1.5m above every obstacle given that the fixed nodes were to be installed every 200m along the route. An installation height of 4m would have been ideal to locate the direct line of sight in sufficient space over the heads of pedestrians and to protect the nodes against possible vandalism. However, this height was deemed to be inaccessible for maintenance purposes. It was predicted that due to the exploratory nature of the installation the nodes needed to be accessible without great difficulty and so a compromise was made to install the nodes at a height of 3m. This height allows access to the nodes by ladders and gives enough clearance of the Fresnel zone to provide a good signal. One of the main obstacles due to the height of the installation is the interference of buses. Double-decker buses have a height of 4.20m and tend to block the line of sight between two fixed nodes completely.

3.2. Maintenance issues

A number of projects and experiments were run following the deployment of the testbed. The experiences gained from running them on the WAND network are described within the following sections.

Configuration of services The wide distribution of the WAND nodes along with the dynamic state of the network has lead to difficulties in maintaining the configuration of the network in a sustainable way. Currently, access to the nodes is achieved either from a gateway node located at one end of the network, or via other wireless devices - laptops, PDAs - within the WAND network itself. Maintenance and the continuing configuration of the WAND nodes can only be accomplished through either of these routes. However, the preferred route of administration has to be through the gateway node as updating nodes from mobile devices within the network itself is impracticable over a sustained period. The problem we have found is that all the nodes are not always accessible from the gateway node due to a variety issues. Therefore, configuring or updating services or the network configuration is difficult to achieve throughout the network without it failing. So far, we have not been able to find a satisfactory mechanism that would allow updates to be propagated through the network and be applied unilaterally.

Development of applications A number of projects have been based on the testbed. Cocoa [2], Visualisation, Multimedia between mobile devices using OLSR. The use of the WAND network has proven to be a valuable resource in understanding how to build these types of applications. The sparse network of nodes provides a stable level of connectivity for these projects that could not otherwise be achieved without a greater population of mobile nodes within the environment. However, the deployment of these experiments and the retrieval of results from the nodes has proven to be challenging. Again, the accessibility to all the nodes from one location has proven to be the main problem. To provide a usable testbed it is necessary to be able to coordinate and configure the network from one set of experiments to another. To be able to

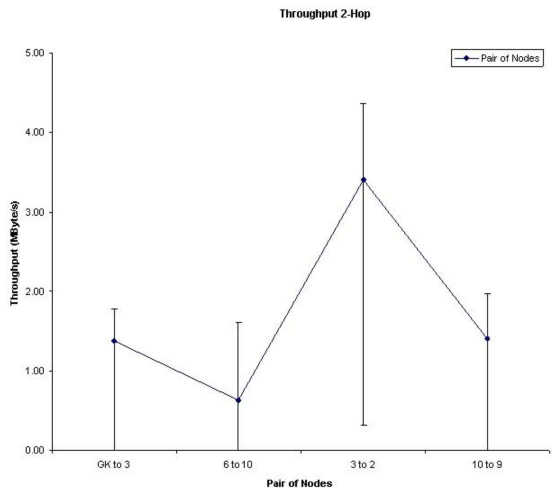

Figure 3. Throughput over two hops.

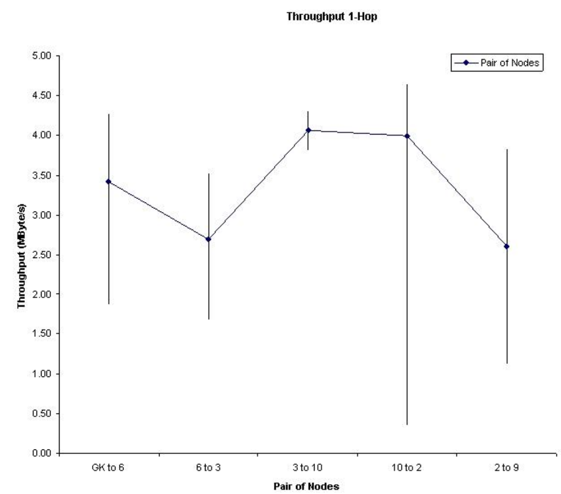

Figure 4. Throughput between individual pairs of nodes.

deploy, configure, and retrieve the results in an effective manner. For the WAND network this has proven to difficult to achieve due to the unpredictable nature of the network itself.

4. Evaluation

This section describes a number of preliminary experiments used to examine the throughput of the WAND network using the AODV implementation from the National Institute of Standards and Technology over a multi-hop network.

4.1. Throughput

The graph in figure 4 shows the throughput between individual pairs of nodes. In order to understand this output correctly it is necessary to consider at the location of the individual nodes. The first pair of nodes has direct line of sight which results in good throughput of around 3.5 MB/s. However, the nodes are installed on different sides of the streets and the traffic on the street causes interference and leads to a variation in the throughput. The line of sight between the next pair of nodes is interrupted by a bend in the road. This causes a slight drop in the throughput between the two nodes; additionally the traffic on this street causes the throughput to fluctuate as well. The third pair of nodes is located on the same side of a straight street. This setup with no interference through traffic or obstacles in the line of sight results in high throughput with little variance. The next set of nodes is located on the same road, slightly further apart. The throughput between these two nodes is equally good to the previous pair despite the increased distance; however, a junction before node 3 where a large number of buses turn off from the main road leads to large variation in the throughput. The line of sight of last pair of nodes is again disrupted by a bend in the road and the throughput shows a similar pattern to the throughput of the second pair.

The second graph (figure 3) shows the throughput over a 2-hop chain. The first chain involves a pair of nodes with a clear line of sight and a pair of nodes that a separated by a bend in the road. This results in relatively low throughput with great variance. The next chain has the pair of nodes separated by a bend as first pair followed by a pair that has a clear line of sight. This results in less throughput than in the first case with similar variance. The third chain has two pairs of nodes with a clear line of sight; however one of the pairs is separated by the junction with a high amount of bus traffic that was mentioned earlier. This setup results in high throughput but with great variance due to the bus traffic. The fourth chain is similar to the first chain in that the first pair in this chain has a clear line of sight - sometimes interrupted by traffic and the second pair is separated by a bend in the road. This again results in low throughput with great variance.

From these two experiments we can see first indications of the influence of the traffic on the roads on the throughput. Also, these measurements show the effect of the obstructions in the line of sight and its influence on the throughput in 2-hop chains.

The influence of the number of environmental factors such as weather, time of day, etc has not yet been investigated and requires further measurements.

4.2. Related Work

The work related to the experience reported here can be categorized into 3 general areas: reports on community networks, reports on testbeds targeting research in mobile ad hoc network (MANET) protocols and reports on testbeds targeting the investigation of sensor networks.

Community networks such as MIT's Roofnet [1] employ similar hardware to the one used for WAND nodes. Roofnet provides an experimental 802.11b/g mesh network which offers broadband Internet access to participants. The nodes in this network are fixed in a place and consist of small PCs with a wireless and a wired interface. The wireless interface is generally connected to a roof-mounted omni-directional antenna. The nodes provide routing between mobile nodes and the internet. Roofnet provides a platform for experiments to understand the nature of large-scale wireless networks. The research focus of this network is the study of link-level characteristics of 802.11 and the development of high-throughput routes.

A number of research projects have proposed setups of testbeds in order to evaluate protocols for MANETs [5]. Maltz et al [10, 11] report their experiences during an experimental evaluation of Dynamic Source Routing (DSR) protocol under the influence of a high-rate of topology changes. The testbed for this evaluation consisted of 8 nodes that comprised IBM Thinkpads 560X notebooks, a 900 MHz WaveLAN-I radio with a 6db omni-directional antenna and a Trimble 7400 GPS receiver. The nodes were mounted in cars that were driven in a set course at an urban road. By evaluating the routing protocol in a testbed the researchers developed a number of new ideas for the improvement of the protocol.

Tschudin et al [16] developed the Ad hoc Protocol Evaluation (APE) testbed. This testbed is based on a software package in form of a Linux distribution. Laptops can be booted from a CD using this package. Tschudin et al report on experiments with up to 37 nodes and 3 routing protocols [9]. The evaluation of their implementation of the Ad hoc On-Demand Distance Vector (AODV) routing protocol in a real-world environment led to the discovery of gray-zones. In these gray-zones a routing protocol would report a valid route to a destination but almost no data would be delivered to the destination. This phenomenon was not encountered in simulations of the same routing protocol and provides one of the many motivations for evaluations of protocols in real-world scenarios.

The third area that is related to the experience reported here is the area of sensor networks. Ganesan et al [6] describe the experience they gained while evaluating a sensor network of 185 nodes in an open park area. The nodes are based on a 4MHz ATMEL ATmega with a 900MHz low power radio. They found that while current RF-propagation models can be used to model certain behaviour such as that of sparse wireless networks; they need to be extended for dense deployments such as dense sensor networks. Ritter et al [15] describe a similar network based on a combination of a microcontroller and a number of wireless interfaces such as 433MHz RF and Bluetooth modules. This envisioned application domains for this network are ad hoc gaming and home automation.

5. Conclusion

In this paper we have presented a testbed for the development and evaluation of ad hoc network protocols and applications within an urban environment. The experiences that we have gathered through the development and deployment of this testbed are various. It is extremely difficult to design a complex and flexible testbed that delivers reproduceable yet realistic results.

However, we believe that no simulation is able to reflect the inherent uncertainties and erratic nature of real-world environments. The behavior predicted by simulation may vary dramatically from that observed in real networks such as WAND. Thus the measurements done in such a testbed will complement our understanding of the behavior and performance of protocols in realistic environments and the appropriate design and implementation of applications for such areas as pervasive computing.

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