Providing Internet Access in Rural Areas: A Practical Case Based on Wireless Networks

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Abstract
To achieve country-wide Internet access is an important goal to sustain the progress of our societies. Nevertheless, there is an important gap between urban and rural areas in terms of Internet connectivity that is mainly due to a lack of interest from ISPs in deploying a wired infrastructure in these areas; such lack of interest is expected to be maintained since the estimated return on investment (ROI) is not attractive. In this paper we propose a solution to this problem that combines mobile ad-hoc networks and cheap hardware devices to offer low-bandwidth Internet access to isolated rural areas. We present preliminary results obtained on a laboratory testbed, along with results obtained in a real-life setting.

1 Introduction
It is widely accepted that new information and telecommunication technologies are needed to alleviate a wide range of obstacles for economic and social development in rural areas [Her05]. This is particularly true for Internet accessibility, since it offers a global platform for retrieving and sharing information.

During that past few years there has been a remarkable progress in the most developed countries in terms of telecommunication facilities. However, outside the main urban areas, there are still important handicaps that make Internet connectivity a complex and costly task [Lie04].

In rural areas and small towns the Internet Service Providers (ISPs) do not assume the high-cost of technologies designed for the urban market. Moreover, low population density and high deployment costs discourage ISP investments since the estimated return on investment (ROI) is unattractive.

New wireless technologies offer a very effective and inexpensive solution to bring wireless Internet to rural areas. In fact, the promise of wireless Internet technologies has caused the interest of the international development community to increase. This synergy has been driven by wireless standards recently ratified by the IEEE, namely the IEEE 802.11 standard [IEEE99] for wireless local area networking (also known as Wi-Fi), and the IEEE 802.16 standard [IEEE02] for long distance point-to-point connectivity (also known as WiMax) targeting MANs.

Clearly, wireless Internet will offer significant applications such as e-education, e-health, e-business or e-agriculture to remote users. However, additional efforts are required to extend the deployment of wireless infrastructures from urban centers and laboratories to low density population areas.

In this paper, we present an experimental system architecture which combines mobile ad hoc networks [Manet] and commercial off-the-shelf wireless devices to offer low cost wireless Internet connectivity to people living in isolated rural areas.

The overall system architecture is based on the cooperation of a distribution wireless network and a backbone wireless/wired network. The distribution side is solely based on IEEE 802.11 technology, being used to provide subscribers with wireless connectivity. The backbone network is based on the integration of a fixed Ethernet local area network and IEEE 802.11 WLAN technology. The optimum combination of technologies depends on the physical layout of the deployment area. The backbone network connects to the Internet through a server acting as gateway.

We first develop a small test bed in our laboratory to evaluate the feasibility and performance of our proposed architecture. We test the capability of the hardware devices and document all the software packages to tune the system. We then deploy a small-scale solution in a project targeting a rural area in Ontinyent,
which is a small town located in the south side of the Comunidad Valenciana, Spain. We assess the system’s viability to provide Internet connectivity to a set of subscribers, evaluating the overall system behavior.

The rest of this paper is organized as follows. Section 2 describes the system architecture. Section 3 presents the details of the implementation prototype in our laboratory where we validate the overall architecture. Section 4 illustrates our experiences installing the system in a real environment and offers some preliminary performance results. Finally, in Section 5 we present our concluding remarks.

2 System Architecture

The overall system architecture, shown in Figure 1, has been designed to be easily upgraded by including new services, and extended for covering larger areas at low cost. All the subscribers are connected to the Internet through the main server which acts as gateway to Internet, and it also perform management tasks.

Our architecture combines a distribution wireless network and a backbone wireless/wired network. We base our solution on Linksys wireless routers (models WRT54G and WRT54AG [Linksys]), which operate using IEEE 802.11 technology on the 2.4 GHz (both) and 5 GHz (WRT54AG) frequencies.

2.1 Distribution Network

The distribution network is composed by several wireless routers representing neighboring rural areas, which are grouped to form a mesh network. To implement the mesh network each WRT54G router at the distribution level implements the Dynamic Source Routing protocol [Dsr05]. DSR is a simple and efficient routing protocol designed specifically for use in multi-hop mobile wireless ad hoc networks. By using DSR the coverage area can be easily extended since the network is completely self-organizing and self-configuring. Network nodes - including Linksys routers and client devices - can cooperate in the routing and forwarding process to allow multi-hop communication between nodes not directly within wireless transmission range of each other. As nodes move around, join or leave the network, and as wireless transmission conditions such as noise or interference change, all the required routing tasks are automatically performed by the DSR routing agents. Since the route used to reach any destination may change over time, the resulting network topology may be quite rich and frequently changing.

When new subscribers join the system, they will become part of the distribution network. If the number of clients is high enough many alternative paths will be available, allowing the DSR protocol to find the
best path for each client using different routing criteria - number of hops, degree of congestion, delay, etc. - towards the gateway to Internet.

We setup the wireless distribution network by using the DSR implementation from the Uppsala University [udsls]; it offers most of the features specified in version 10 of DSR's draft. We install DSR in WRT54G wireless routers by cross-compiling DSR's code, making it operative under the OpenWRT [Opwrt] Linux distribution used by our routers. We also install a DSR agent in each one of the system clients.

2.2 Backbone Network

The top level of the mesh network is connected to the backbone network to provide subscribers with wireless connectivity. The WRT54AG routers conforming the backbone include important features such as firewall and QoS capabilities. We use TC [Ber03] and IPtables [Pel03], both tools provided with the OpenWRT distribution, to control the system's firewall and to regulate the bandwidth offered to different subscribers.

The backbone network is linked through wireless trunks to the central server which acts as a gateway to the Internet. Wireless connections using directional antennas are preferred at this level since they allow covering a long distance at a low cost. For the backbone network we prefer using IEEE 802.11a technology, which operates at the 5GHz band instead of the 2.4 GHz band (used for the distribution network). The IEEE 802.11a standard provides a higher performance since it offers more independent channels and suffers from less interference due to multipath fading.

The "adequacy" of the selected technologies used for the backbone network will depend on the physical layout of the deployment area. So, we have to determine an ad hoc solution based on parameters such as line of sight, signal interference, and channel overlapping.

3 Experimental Test Bed

We evaluated our system architecture using a small testbed in our laboratory. We studied the system performance and also acquired experimental data, allowing us to evaluate the capabilities of the Linksys routers. We first evaluate the performance of the WRT54AG Linksys router conforming the backbone network. We then studied the behavior of the WRT54G, part of the distribution network. Our testbed uses one Linksys router for the backbone network and 3 Linksys routers for the distribution network. The main gateway server is a PC with a 3 GHz Pentium IV processor and 512 MBs of RAM. It has two Fast-Ethernet NICs that interconnect our experimental system with Internet by doing NAT; the operating system used is Debian 3.1. Finally, to simulate network subscribers, we used three Pentium IV based laptops with 1 GB of RAM memory and a 802.11g embedded card.

3.1 Evaluation of the Backbone Network

We first evaluate the performance of the backbone network. We evaluate the performance of Linksys routers using three different configurations: (a) the Linksys original firmware, (b) the OpenWRT Linux distribution, and (c) the Click modular router [Koh00]. The Linksys original firmware is the one with less features - it has neither firewall nor QoS support. The OpenWRT firmware offers a complete Linux distribution with all the features required to tune the system in a very flexible way. Finally, the Click modular router is a new software architecture for building flexible and configurable routers. It uses a special programming language to implement powerful features using different building blocks. However, the version used offers a few features only.

The strategy followed to make long-run measurements consisted of developing a series of scripts that allowed making the evaluation process automatic. For each configuration we evaluate the latency of ICMP packets traveling over the backbone wireless network. Figure 2 shows the results obtained for each configuration, which include the minimum, maximum and average round-trip time, along with the mean deviation values.

Despite that the Click configuration exhibits the best performance, it is actually a stripped-down version that does not implement the NAT function, which explains the best performance results obtained. When comparing the performance obtained with the Linksys standard firmware to the one achieved with the OpenWRT Linux distribution we found that, despite the software capabilities of the latter are much more powerful and complete, and despite it is not vendor-specific software, the performance penalty is relatively small. So, due to the extra functionality required (firewall, QoS, SNMP, etc.) we will use the OpenWRT
kernel. Nevertheless, we plan to continue looking into research on Click-based routers due to their flexibility and to the good results here reported.

3.2 Evaluation of the Distribution Network

We now proceed to evaluate the performance of the distribution network in our laboratory. The Wireless WRT54G Router comes with the standard Linksys operating system, which offers only basic functionality. So, we have to update each node of the distribution network for it to support DSR. Table 1 shows the main steps we should follow to setup each Linksys node conforming the distribution network. We now proceed to detail each of these steps.

- Install the OpenWRT Linux distribution firmware.
- Compile the DSR-UU protocol for the WRT54G MIPS processor.
- Configure the distribution network nodes using the ad hoc mode.
- Start the DSR daemon.

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<th>Table 1: Steps for preparing a Linksys router to integrate the distribution network.</th>
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<tr>
<td>1. <strong>Install the OpenWRT firmware.</strong> The OpenWRT distribution provides the functionality and flexibility of a Linux distribution. That means that it can be easily altered or updated with additional modules to provide new functionality.</td>
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<td>2. <strong>Compile the DSR-UU protocol.</strong> The next step is to compile the DSR-UU daemon for the MIPS processor used by WRT54G routers. Since we can not compile the code on the WRT54G itself - it does not have enough memory to install the compiler - we compile the MIPS executable code on a i386 GNU/Linux system using the <em>mips-gcc</em> cross-compiler. After the code is correctly compiled we merely need to copy it into the router’s flash memory.</td>
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<td>3. <strong>Configure the ad hoc mode.</strong> Nodes in the distribution network will be configured to operate under a same Independent Basic Set Services (IBSS), using the ad hoc mode and allowing peer to peer communication among nodes. To do that all the nodes must share the same configuration - SSID, channel, and wireless technology used (802.11b, 802.11g, or 802.11a).</td>
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| 4. **Start the DSR routing protocol.** Finally, we must start the DSR routing agent at each node. Once we start it, each DSR agent creates a new virtual network interface in the Linksys router which intercepts all the traffic, redirecting it to the DSR agent. The new virtual interface will take the
IP address of the Linksys router, while a new IP address in network 192.168.45.0/24 is assigned to the Linksys interface. From that moment on DSR's interface will have full control over the system, intercepting all the packets without modifying the IP address the router was working with before starting the DSR daemon.

We evaluated the behavior of the distribution network by setting up several random "ping" sessions over the distribution area and evaluating the impact on round-trip time with varying channel conditions. We evaluated the performance on a clean environment - i.e., all the wireless equipments in our laboratory not participating in the measurement session have been disabled - and on a very noisy environment - we have interference from additional wireless devices in the laboratory. Figure 3 shows the cumulative distribution function for the round-trip time where the measurement session lasted 24 hours; sources probe the network at a rate of 1 "ping" packet per second. The results show that, in our testbed, 90% of the total ICMP interchanges are successfully completed for a round-trip time in the interval from 0.1 to 0.8 seconds, independently of the noise level in the environment. These round-trip times are normally acceptable to a subscriber without causing annoyance. However, when operating under a noisy environment, we verify that 10% of the traffic suffers from poor performance. More specifically, 4% of the traffic experiences too high delays, being considered lost in practice.

Finally, from our experiments we also observe that, when a new route is being established, the routing protocol delays packets until the route discovery process completes. After this initial phase the round-trip times become quite stable.

4 Deployment of the Proposed System

We now describe the deployment of our proposed system. We built a small-scale project on a rural area in Ontinyent, which is a small town located on the south of the Comunidad Valenciana, Spain. We selected this rural area since there is an increasing demand for Internet connectivity to support the emerging industrial activity and the populational increase. Moreover, high deployment costs required to reach that area discourage traditional ISPs' investments in the zone. Figure 4 shows a map of the deployment area.

The backbone network is composed by five Linksys routers which have been strategically positioned to assure line of sight. The distances between the backbone nodes and the gateway server vary from 1 kilometer to 5 kilometers. Concerning the distribution network, we have studied the most appropriate location of the nodes to reduce channel interference while increasing the network coverage. Initially we have a distribution network composed by ten Linksys routers running the DSR protocol. As for subscribers, a DHCP server
located on the gateway provides them a valid IP address, making the configuration process almost automatic. Once they register and join the network they will become part of the distribution system, acting not only as clients but also as DSR-based routing elements. Currently, the system provides wireless connectivity to about forty subscribers.

We evaluated the performance of the deployed system to study its behavior and acquire experimental data to tune it for optimum performance. Our experiments focused on evaluating the throughput and the CPU overhead on the Linksys routers over time. To perform the study we enhanced each node with an SNMP [Cas89] agent to collect the data required.

Figure 5 shows the throughput values obtained at a distribution node over a 24 hour period; the number of connected subscribers varies from 15 to 30. We observe that the throughput values are below the maximum theoretical throughput stated in the 802.11g standard, i.e., around 17 Mbps, though they approach the maximum theoretical throughput when the source and destination are three hops away (close to 7 Mbps). Figure 5 shows that this maximum data rate was only achieved for a short period of time, and so the current distribution network can still accept new subscribers before becoming congested.

We now study how well Linksys routers at the backbone network support our proposed architecture. We evaluate a router's overload in terms of the number of processes waiting at the run queue. Figure 6 shows the results for a full day, where again the number of connected subscribers varies from 15 to 30. Results show that at peak hours the CPU congestion increases up to a maximum of 4 processes enqueued. These processes perform a variety of tasks including (a) routing, (b) firewall analysis, (c) traffic prioritization of real time traffic (e.g., VoIP and games) and (d) packet dropping for forbidden traffic (e.g., P2P packets). Finally, further experiments show that each of the Linksys routers at the backbone network can support up to 50 concurrent connections. From that point on, increasing the number of simultaneous connections will cause performance to decay.
Figure 5: Measured throughput over a 24-hour period.

Figure 6: CPU load over a 24-hour period.

5 Conclusions

In this paper we study the viability of using the most recently developed wireless technologies to deploy a low-cost infrastructure offering Internet connectivity to rural areas. We argue that traditional wire-based solutions are inappropriate, and yet universal Internet connectivity is fundamental to drive progress in those areas. The proposed system combines the flexibility of mobile ad hoc networks with low costs on infrastructure by using commercial off-the-shelf wireless devices.

We firstly develop a small test bed in our laboratory to do a preliminary evaluation of the feasibility and performance of our architecture. This includes testing the capability of the hardware devices used and documenting all the software packages required to tune system. We then deploy our solution in a small-scale project over a rural area of the Comunidad Valenciana in Spain. We assess the viability of our system by providing a set of subscribers with Internet connectivity. A performance evaluation was made focusing on the throughput achieved and on the overhead imposed on the Linksys routers used. Results show that the current system is able to support up to 50 subscribers. Moreover, the system can be gradually scaled up as the number of subscribers increases.

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References


