Providing Low Cost Wireless Connectivity to Rural Communities

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Abstract—
Recent advances in communication technologies, as well as the proliferation of computing devices, are shaping our environments towards an ubiquitous Internet. However, even in the most developed countries, the majority of rural areas are still without any basic communication infrastructure. In this paper we evaluate the use of Wireless Local Area Network (WLAN) technologies to offer Internet support in rural environments. With this purpose we present RuralNet, an experimental wireless testbed based on Captive Portal technology that provides Internet access to rural subscribers and offers a wide range of telecommunication services and applications. The solution developed for RuralNet is able to reach distant areas at a low cost. Moreover, it can be easily deployed and extended both in terms of coverage area and services offered.

I. Introduction

Recent advances in Information and Communication Technologies (ICTs) have resulted in the development of powerful solutions. These technologic improvements can alleviate the wide range of obstacles that rural areas face for their economic and social development [1]. Such obstacles are particularly evident in terms of Internet reachability.

Besides universal connectivity, the Internet offers a global platform for accessing a wide range of telecommunication services such as e-mail, e-commerce, teleeducation, telehealth, and telemedicine at a low cost. However, the majority of rural areas are still without any basic communication facilities, which makes Internet connectivity a complex and sometimes costly handicap for people and businesses in these areas. This problem is emphasised by the study of Bright [2], who shows the Digital Divide between urban areas and rural areas. Others works [3], [4], [5] also focus on this problem, emphasising on how serious and difficult to handle it is.

Recently, the development of wireless local area network technologies has made it possible to consider non-traditional approaches to deploy an infrastructure in rural areas. Such solutions were not possible some years ago because the costs were too high. The newly available technologies are much cheaper to use, making the infrastructure required to connect a village to a big city affordable at a low-cost [6], [4].

Any solution based on a wireless infrastructure has to solve problems related to signal propagation, security, channel utilization, etc. Moreover, we want everyone with an adequate wireless interface to be capable of connecting and accessing the public WLAN deployed. We create a new user control system based on a specially-designed web portal. This special type of portals are known as Captive Portals. A Captive Portal is a web-based solution that allows a client to subscribe with the system and, in this way, connect to the different services the system offers.

In this paper, we describe RuralNet, a captive portal based system providing Internet connection to distant areas where deploying a wired-based infrastructure is too expensive. Such an infrastructure can provide the different services required, besides avoiding the problems referred before. RuralNet has an user-registration control system to allow subscribers to access the Internet. It can also provide a group of free services to all the people within a certain area.

We have built a prototype composed by multiple Wi-Fi access points connected to a main server. Every client within the coverage area of one of these access points deployed can access all the services offered. The client authorization problem is solved with the implementation of a Captive Portal. Therefore, a client only needs an Internet navigator to access to the system; further knowledge about wireless networks is not required, neither is it necessary to use special software.

The paper is organized as follows. Section II describes the overall system architecture. Section III presents the details of the implementation prototype and describes the end application. Section IV evaluates our proposal and, finally, in Section V we make our concluding remarks.

II. The RuralNet System Architecture

The system is designed to cover a wide area, connecting all the clients with a main server that has full control of the system. The overall system architecture for our RuralNet telecommunication network is shown in Figure 1. The system is composed by different Access Points connected to each other, forming a mesh network. This approach allows creating a scalable net which is able to cover a vast area, connecting the main server with all the clients within range of any of the APs deployed. The RuralNet platform has been created using open-source software, and it can be downloaded for free at: *http://www.grc.upv.es/software/index.html.*

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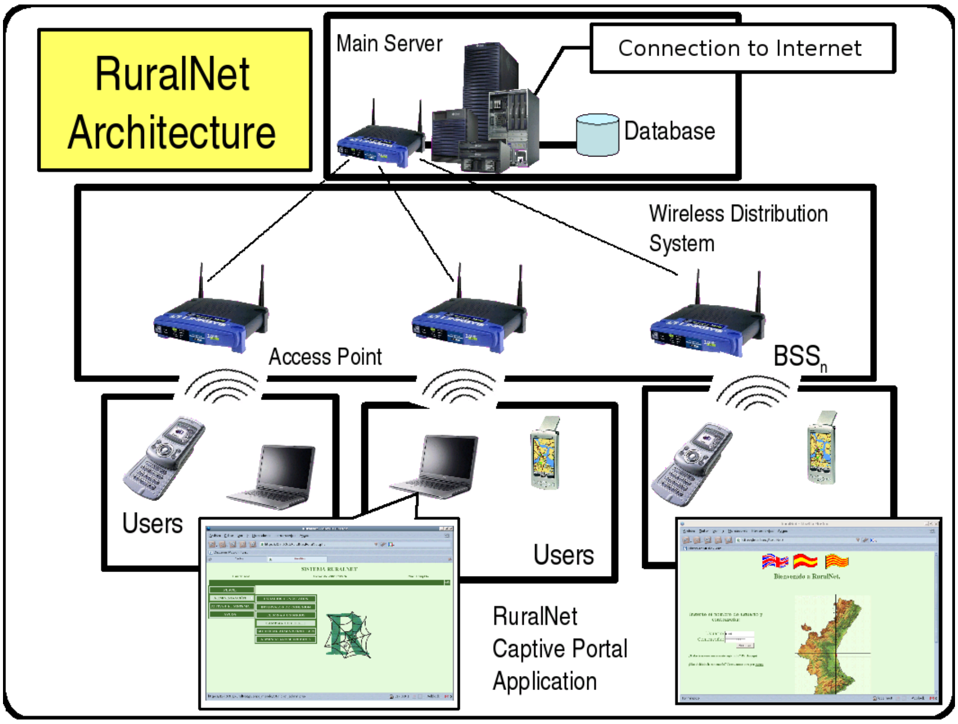

Fig. 1. The RuralNet System Architecture.

Our architecture is conceptually organized into three levels, which are: the management level (main server), the network connection level (called Backbone Net), and the user level.

- **Management level**. The top level of the system is composed by a server that controls user authentication. This level is based on a web server to interact with the subscribers, a database used to store system information, and a control unit that converts management decisions into traffic rules. Besides, the server has also a high-speed connection to the Internet, along with a wireless or an Ethernet connection to link it with the Backbone Net level.
- **Backbone Net level**. This second level is composed by a group of nodes distributed in a wide area, composing a mesh network. These nodes are connected to the main server and to other nodes through either Ethernet or IEEE 802.11 technology. Wireless connections are preferred since they can benefit of antennas to achieve increased range at little cost. The main purpose of this level is to work as a bridge, connecting subscribers to the main server.
- **User level**. At the lowest level we have the actual subscribers. These can connect directly to the wireless infrastructure using their own Wi-Fi enabled computing devices. Such devices can quite heterogeneous e.g., cell phones, PDAs, laptops, etc. The only restrictions are that these devices must include both a Wi-Fi interface and a web browser.

The system interacts with clients through Captive Portal technology. When a client first connects to the system and opens a web browser, he is automatically redirected to the main page of the portal; this process is completely transparent to the user. The main server controls client access depending on whether he is a register user or not. Depending on the client's access level, different services will be provided.

The first time a client accesses the system he is asked to register himself with the Captive Portal. After a login process the user can use any of the freely available services or purchase others, like Internet access. Concerning the Internet access service, RuralNet allows each client to choose among multiple connection speeds, making the price vary accordingly.

III. Implementation Details

The RuralNet system was developed using several programming languages and tools. We split it into three conceptual areas: web interface, system interface and database interface.

The implementation of the web interface makes use of different programming languages, i.e., PHP, Javascript, HTML and XML. The combination of these languages allows achieving complex solutions, and yet compose the user interface in a simple and straightforward manner.

The system interface uses PHP to access TC [7] and IPtables [8], both tools are provided by default on a GNU/Linux system. These tools offers the functionality to control the system's firewall and to regulate the bandwidth for the different user connections.

The database interface uses the PHP technology to access data stored by a MySQL database engine. Figure 3 shows the relation among the software components. We can see that the main server also offers

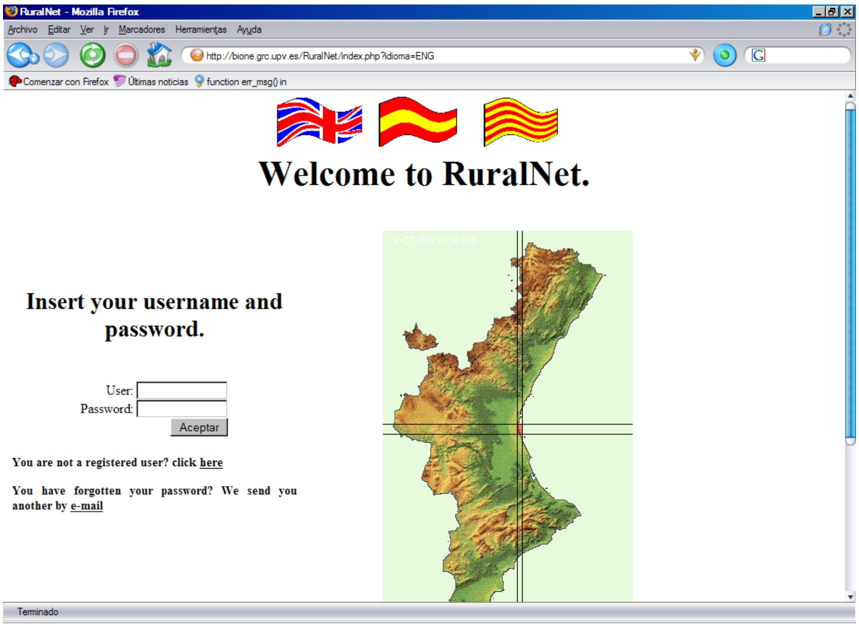

Fig. 2. RuralNet presentation screen.

a centralized DHCP service, making it possible for subscribers to be configured automatically.

Figure 3 also evidences the different support files created and the tools that use them. A single arrow line represents a reading action and a double arrow line represents a read/write or execute action. This design provides the required flexibility, allowing to make changes or add new modules in a straightforward manner.

We will now proceed by detailing some of the core elements of RuralNet's system.

A. RuralNet's Core Elements

When a client connects to RuralNet he usually does not know any connection information, namely RuralNet's URL. Our system re-directs all the unregistered clients accesses to RuralNet's identification page by typing any URL and trying to access it. The most appropriate solution for this task is developing a Captive Portal. The enhancements required to make RuralNet a Captive Portal-enabled platform are the followings.

- **Capture the subscribers who try to access the Internet through the system**. When an unregistered client tries to access a web page, the system must re-direct him to the registration page instead. Once a client introduces his user name and a password, he can access the web page he originally requested (if he has credit to do so). In a GNU/Linux system this capture process is possible thanks to IPtables [8].
- **Control the connection speed of each client**. When subscribers access the Internet using a system as described above, they could, in theory, use all the available bandwidth. This is a undesirable situation, especially if this system belongs to an Internet Service Provider. So, it would be desirable to have a full control of the connection speed for each user. In RuralNet this control has been named Cityticket. Depending on the Cityticket bought by a client, he acquires the corresponding connection speed. RuralNet implements the Cityticket functionality by using the Traffic Control (TC) [7] linux tool. Using TC the main server can regulate the bandwidth of each user, since it can control both download and upload packets passing through the interface that gives access to Internet.
- **Offer free access for specific web servers**. For different reasons, it could be necessary for all clients to have access to a selected group of external web servers. This includes those clients that do not purchase an Internet connection. RuralNet has the option for an administrator to choose a group of servers that can be accessed by everyone, regardless of the Internet privileges granted. For example, if RuralNet is installed in a certain town, a free web server could be the city-hall's web server, which has news addressed to every citizen. RuralNet has two ways to add a free web server: by IP address and by connection port.

B. The RuralNet Interface Implementation.

The RuralNet Interface is designed to be maintained mostly unaltered regardless of which web browser, operative system or device is used. This means that RuralNet must be designed with extended languages such a HTML and XML. Other specialised languages like ActionScript (Flash) and DHTML (a mix of Javascript and HTML) are able to offer a higher programming level for the design and implementation of the visual interface. Notice that all these programming languages are available for every client regardless of the system architecture used. By ma-

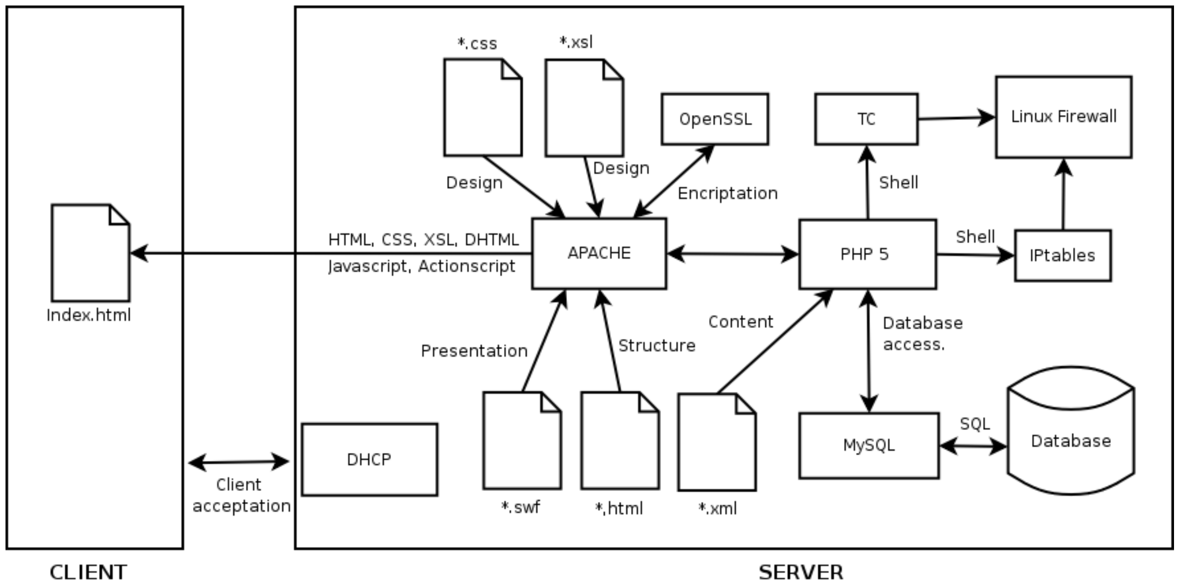

Fig. 3. Relationship among RuralNet's software components.

king use of PHP technology we are able to adapt the web pages to interact with the RuralNet Core, hence allowing every device with web browsing capabilities to access the Internet and connect to RuralNet system.

Figure 2 shows the RuralNet presentation screen.

Once inside the system the interface is rather intuitive. A left-hand menu provides the user access to all the options made available to him. There are three types of users defined in the system: regular user, user with Internet access, and system administrator. The differences among them are reflected in terms of options appearing in the menu. For a regular user only the most basic options appear, i.e., user profile, Internet access, allowed servers and help. An administrator has all the options available, including the system administration options, i.e., users managements, connection properties, and Cityticket administration. By selecting a menu option the user is able to navigate through the system, thereby accessing to the desired service.

RuralNet has been implemented to support multiple languages. To implement this functionality, we choose to separate the web structure from the text. This means that web pages have two components: a basic structure written in HTML language and text in the XML format on a separate file. This separation allows an administrator to easily update the system with a new language. It merely requires editing the appropiate XML files and adding to every paragraph the appropriate translation for the new language to be supported. The current prototype version of RuralNet supports both English, Spanish, and Valencian.

IV. Evaluation

In this section we present some experimental results where the purpose is to assess the correct operation of our RuralNet system. Also, we will study how the bandwidth is divided among different subscribers when these have homogeneous or heterogeneous types of Internet connections.

The Main Server was an AMD XP 2000+ PC with 512 MBs of DDR RAM. It has a Fast-Ethernet connection to the Internet, and a similar connection to a root Access Point. The operative system used is Debian 3.1.

Concerning the clients, these are simulated using four laptops with different capabilities. The best performing one has an Intel Pentium 4 processor at 1700 MHz, and the worst one has was an Intel Celeron processor at 150 MHz. All of them are dotted with IEEE 802.11b PCMCIA Wireless Cards (maximum data rate of 11 Mb/s). We also used another machine as an FTP server for experimental purposes.

The strategy followed to make several long-run measurements consisted of developing a series of scripts that allowed automatizing the evaluation process. Every client has a script that starts a FTP connection to our FTP server, which is accessed only through the RuralNet system. We control the throughput of the FTP server so that we can model different connection speeds with the RuralNet's main server.

We run the *tcpdump* [9] tool at the Main Server in order to trace all the incoming and outgoing packets. We begin our tests by using only one client, and measuring the accuracy of the bandwidth management system offered by the TC tool. So, our client downloads data ininterruptedly from the FTP server, allowing us to compare the requested data rate with the actual throughput received. Figure 4 shows the obtained results.

Figure 4 shows different intervals, where each interval represents the actual range of throughput values experienced by the client; the mean value is also represented. By observing these results we confirm that the requested bandwidth value is close to the

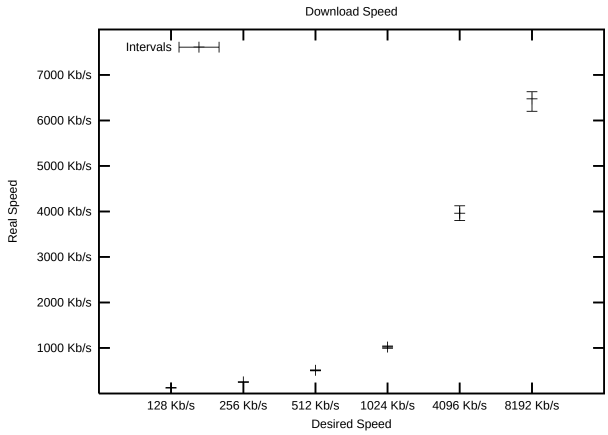

Fig. 4. Connection speed for one client.

throughput provided by the system except for the last value where 8 Mbit/s are requested and only around 6Mbit/s are finally delivered. When the requested bandwidth surpasses the maximum value achievable when using IEEE 802.11b technology the Wi-fi link becomes the bottleneck.

We now proceed with a set of tests where we have all four clients active. We will study the interactions among them when limiting both their bandwidth and the bandwidth towards the FTP server.

We begin by experimenting with different bandwidth values for each client. We set the bandwidth of the four users to 128, 256, 512 and 1024 Kb/s, respectively. Our purpose is to check if the system can indeed make effective the different user privileges. Figure 6 shows the obtained results. As it can be observed, the RuralNet system can offer the requested bandwidth according to the user configuration. We also observed that the throughput values sometimes suffer from variations that deviate them from the requested ones. We consider that these small discrepancies are due to wireless media noise and not the bandwidth control algorithms used.

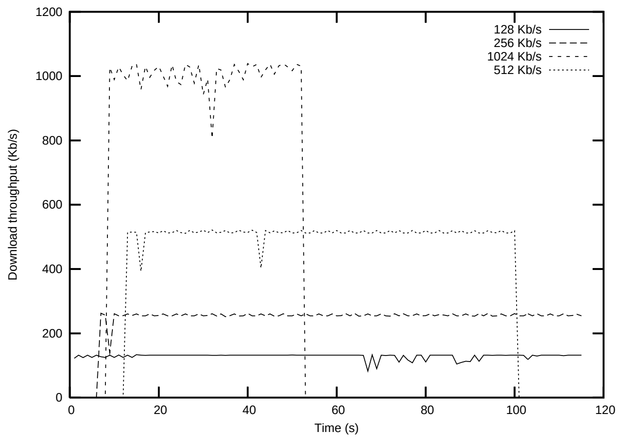

Fig. 6. Download speed for the 4 clients under analysis.

We now extend the previous example by acting upon the link speed between RuralNet's server and the FTP server so as to assess the impact on client's performance. We experiment with two different speeds for this link: 1024 kbit/s and 256 kbit/s. In neither case is there enough bandwidth to serve the four clients at their requested data rate.

Figure 5 shows that when the maximum aggregated data rate is limited to 1024 kbit/s the two slowest connections use their requested bandwidth of 128 and 256 Kb/s. However the other two higher speed connections tend to reach an equilibrium at a similar data rate value during the period when both are active.

When we further reduce the bandwidth at the bottleneck link to 256 kbit/s we find that the throughput value for all the connections becomes stable at a value close to 64 kbit/s, as expected (fair resource sharing).

Though currently we apply this solution of evenly sharing available resources when they become much lower than the aggregated bandwidth requested, we could instead apply a different policy. To accomplish that we would require a solution based on a weighted fair queueing policy. That way, when the available bandwidth becomes too low, users would receive a share of the channel's bandwidth that is proportional to the bandwidth they have paid for. However, this enhanced solution is outside the scope of this paper.

V. Conclusions

In this paper we proposed RuralNet, a Captive Portal based architecture especially designed to provide Internet access in rural areas.

We first analyzed the architecture of the system, putting into evidence the most important elements that conform RuralNet's infrastructure. We then describe three core elements of the system, which allow us to capture clients, perform a per-user regulation of bandwidth and offer access to an administrator-defined group of free external web servers. We conclude with a set of experiments were we validate the traffic-shaping tools used by the system, finding that the service offered to clients is the one we expect. The RuralNet application here described is free software, and it can be donwloaded for free at *http://www.grc.upv.es/software/index.html.*

Overall, this paper made evident that by combining both wireless and web technologies we are able to offer a cheap and efficient solution to provide Internet services to rural areas where users are sparsely located.

As future work we pretend to make an in-depth study of mesh networks to find the most appropiate strategy to deploy the Backbone network element, an important part of RuralNet's infrastructure.

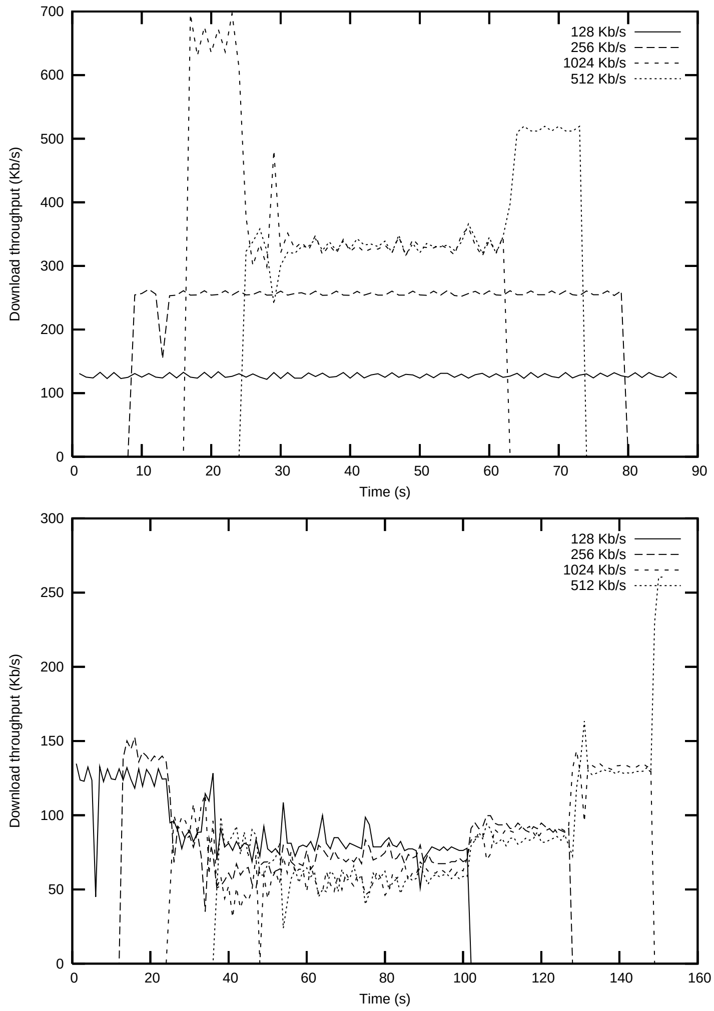

Fig. 5. Download speed when the bandwidth towards the FTP server is limited to 1024 kbit/s (up) and 256 kbit/s (down).

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