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Planning a Wireless Mesh Network which Takes Advantage of the Urban Geography of the City

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***Abstract*—The Metropolitan Area of Caracas, Venezuela, has a geographical distribution such that almost every middle-class and wealthy neighborhood is located next to at least one *barrio*—informal squatter settlements. We propose a *Wireless Mesh Network (WMN)* that exploits the urban geography of the city, so some poor families could gain access to the Internet via one or more Internet Service Providers contracted by some neighbors living in surrounding middle-class or wealthy neighborhoods. We present the design of the intended WMN, according to some deployment strategy issues: provisioning, node locations, interference, node associations, connectivity, coverage and types of antennas. Then we describe the results of the simulation study in terms of throughput and packet loss rate for three routing protocols: *Optimized Link State Routing Protocol* (OLSR); *Hybrid Wireless Mesh Protocol* (HWMP) (reactive and proactive). In order to implement the WMN, some kind of agreement must be established between the person who pays for the Internet connection service in the neighborhood and the members of the community in the barrio. Also, given the policies of the government in matter of laptop provisioning for the low-income families, we expect to have enough mesh nodes in the barrios so connectivity along the mesh network could be guaranteed.**

Keywords—Wireless Mesh Network (WMN); Metropolitan Area of Caracas; Urban Geography; Optimized Link State Routing Protocol (OLSR); Hybrid Wireless Mesh Protocol (HWMP)

I. INTRODUCTION

One of the Millennium Development Goals is to increase the number of Internet users in developing countries, with the aim that most people enjoy the benefits of information and communications technologies (ICTs). Venezuela's population is about 29 million people and according to the *National Telecommunications Commission (CONATEL)* [10], about 13 million people have Internet access—about 48 percent of the population uses the Internet compared to 77 percent in developed countries. Moreover, 28 people per 100 inhabitants have Internet access from home and 44 users per 100 inhabitants enjoy a stable and frequent Internet service [10]. Many families do not have Internet access due to several factors, such as digital illiteracy, lack of computers and nonexistence of Internet access. This research is focused on the latter problem.

The Metropolitan Area of Caracas (AMC) is a political-administrative unit that coordinates the functions of the city of Caracas, the capital of Venezuela. The population of the AMC is about 3,220,540 inhabitants (about 11 percent of the total population), and the region concentrates the families with highest incomes in Venezuela and the greatest number of Internet users. The AMC has a geographical distribution such as almost every *neighborhood*—in this paper, we define a neighborhood as a community where middle-class and wealthy families live— is located next to at least one *barrio*— informal squatter settlements. People living in the neighborhoods often pay for the Internet access service, which is usually provided the whole day and every day of the year. However, this service is underused during the hours when the users are away from home, working or studying. Most people who live in barrios can not afford this service because of their low annual incomes.

A *Wireless Mesh Network (WMN)* is a type of *Mobile Ad-Hoc Network (MANET)*—a collection of self-configured and self-organized mobile nodes connected into a temporary and arbitrary topology without a preexisting infrastructure— which arises as a response to the limitations of the MANETs, such as restricted covered area. A WMN, which can be seen as an extension of a wired network, includes fixed and mobile nodes interconnected via a wireless network and connected to other networks via a wired or wireless infrastructure. The WMNs can sometimes provide a more affordable solution than the wired networks, such as in places difficult to wire (e.g. highway and buildings considered world heritage sites by UNESCO) and in a town that has been devastated by an earthquake or another natural disaster.

This paper proposes a way to provide Internet access to persons living in barrios close to neighborhoods using WMNs. The idea is that each family living in a barrio gains access to the Internet via an ISP contracted by a neighbor living in a surrounding neighborhood. This could be achieved through the use of one or more Wi-Fi networks in the neighborhood next to the barrio. The devices (computers, tablets) located in the houses in the barrio and the wireless routers in the neighborhood will be connected to the mesh network using Wi-Fi or any other data link layer technology. Thus, user information data will travel from the mesh network to the

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Internet and from the Internet to the mesh network via the intended wireless routers.

The deployments of WMNs in urban areas for providing community services are not new. Vural et al. [22] performed a survey of city-wide mesh networks deployed in several metropolitan areas according to some issues related with the network deployment and architecture. They evaluated the following networks: Google Wi-Fi [2], MadMesh [6], Roofnet [5], TFA Houston [19], Metricom Ricochet [11] and Dartmouth [12]. We also propose a WMN for an urban area—Metropolitan Area of Caracas —but unlike the following WMNs: Google Wi-Fi, MadMesh, TFA Houston, Metricom Ricochet and Dartmouth, the proposed network is unplanned, uses omnidirectional antennas and utilizes the routing protocol for the IEEE 802.11s mesh networks [13], *Hybrid Wireless Mesh Protocol (HWMP)*. Our proposal is somehow similar to Roofnet, however unlike this network, we do not require that any user in the neighborhood installs any additional infrastructure, and the network is deployed taking the advantage of the urban geography of the city.

The paper is divided in the following sections. In Section II, the WMNs are reviewed including a description of the routing protocols considered in this study. In Section III, the issues related to the network design and deployment are described. The simulation model is detailed in Section IV, while the simulation results are presented in Section V. Some implementation considerations of the WMN are presented in Section VI. Finally, in Section VII, we describe the main findings of the research; the limitations found, and further works, which may be carried out in the future.

II. WIRELESS MESH NETWORKS

A. *Overview*

The MANETs have some limitations which arise from the fact that they are isolated networks— "the network is made of users devices only and no infrastructure exists" [7]. The WMNs emerge as a solution to the limitations of the MANETs, so they include a combination of fixed and mobile nodes interconnected by wireless links to form a multi hop network, which is an extension of a wired network.

A mesh network includes two kinds of nodes: *mesh routers* and *mesh clients*. The mesh routers are connected to the existing wired network and have routing capabilities to support mesh networking. The mesh clients have simpler functionalities, however, they can still route packets through the network.

B. *Routing*

Routing protocols developed for MANET have been improved taking into account the new features of the WMNs, such as scalability—capability to work on very large wireless networks— and robustness—ability to continue operating despite links failures or network congestion. The routing protocol can be much simpler than those for MANETS due to the lower mobility of nodes and no constraints on power consumption in mesh networks.

In this work, we evaluated three routing protocols: *Optimized Link State Routing Protocol* (OLSR) and *Hybrid Wireless Mesh Protocol* (HWMP) (reactive and proactive). OLSR is a protocol optimized for MANETs that has been also used on WMNs [15]. HWMP is the routing protocol to be supported by default by IEEE 802.11s. The IEEE 802.11s standard [13] is an amendment for the IEEE 802.11 standard, and it has been designed to meet the requirements of the WMNs.

1) *OLSR*

OLSR [9] is a proactive routing protocol that uses the classic link state algorithm improved to work more efficiently on wireless networks. The protocol utilizes the concept of *flooding using multipoint relays* —only some nodes retransmit the data as shown in Fig. 1. The functions of OLSR are as follows: neighbor discovery, transmission of control information and transmission of network topology. A node discovers its neighbors by sending *Hello messages* periodically. The Hello messages are utilized to know the quality of the channel and the type of links (i.e., symmetric or asymmetric links). Each node chooses a set of its neighbor nodes as *Multipoint Relays* (MPRs), which retransmit control information, such as the topology information, to other nodes. Each node knows the set of neighbors for which it is a MPR. Thus, the information about the topology of the network broadcasted by the MPRs is used to build and to maintain their routing tables.

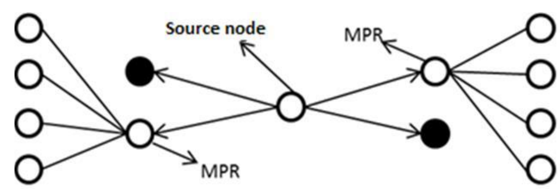

Fig. 1. Multipoint Relays (MPRs) nodes in a OLSR network.

2) *HWMP*

HWMP [3] is a hybrid routing protocol, based on the *Ad-Hoc On-Demand Distance Vector* (AODV) protocol [18], so it can operate in either on demand (reactive) mode or proactive mode (see Fig. 2). In the on demand mode, each node can discover the path between a source and a destination when required. Otherwise, in the proactive mode, also known as proactive tree-based mode, a root node (root mesh) establishes the path between the nodes in the mesh network. If the path is not known, the nodes will send the traffic through the root. The paths are established a priori.

HWMP uses four types of messages: Path REQuest (PREQ), Path REPlies (PREP), Path ERRor (PERR) and Root ANNouncement (RANN). When a node has a message to a destination for which it does not have a route, it sends PREQ messages to all nodes in the proximity. If the node either knows the route to the destination or is the destination, it sends a PREP back to the source. Otherwise, it sends the PREQ to its neighbors. A node that does not know the path to the destination may send a PERR message back to the source.

Each node that receives a PREQ message checks the sequence number in the message, if the sequence is new or exists but the node has a better metric, the node reduces the *Time To Live* (TTL) and updates both the hop counter and the value of the metric. Unlike AODV, HWMP uses a metric called Airtime Link that measures the amount of resources taken when a frame is transmitted over a determined link. When a node detects that a path is broken, it sends a PERR message to the source. In addition, in the proactive tree-based mode, a root node uses a RANN message to announce its existence.

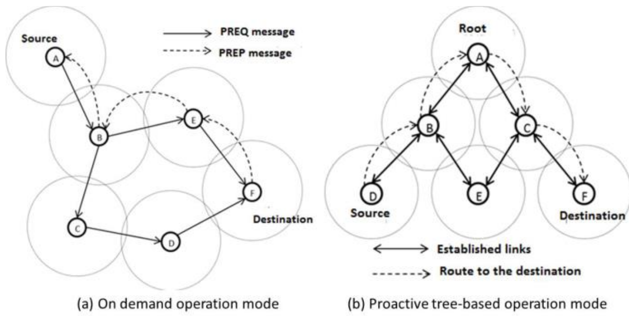

Fig. 2. HWMP operation modes.

III. Design of the Proposed WMN

A. Actual Situation

Caracas is a valley with high-rise buildings scattered unevenly throughout the city. In the low-lying mountains, we can see most of the barrios. Thus, almost every neighborhood in the city is next to a barrio. In Fig. 3, we can see the Petare barrio; on the left is the "formal (planned) city", while on the right we can see the informal area or barrio.

Fig. 3. "Map of the Petare barrio of Caracas,Venezuela, illustrating dual nature of city. On left is the open spacing of the planned,"formal" city. On right is the densely packed squatter barrios of the "informal" city…"[20].

Giving the urban geography of the city, we carried out a study which demonstrated that the range of some wireless networks in several neighborhoods of the city can extend to the barrios in the proximity (see Fig. 6). Most of the Internet users live in the neighborhoods, where people can afford for the service. Although the number of Internet users has increased in the last years, we can see that most of Venezuelans do not have Internet access at home (as mentioned before, only 28 Internet users per 100 inhabitants of Venezuela have Internet access from home).

In the following paragraphs, we present the design of the proposed WMN, according to the deployment strategy issues described in [22]: provisioning, node locations, interference, node associations, connectivity, coverage and types of antennas. We initially present the network architecture before tackling the deployment phases.

B. Network Architecture

Fig. 4 shows the two-tier architecture for the proposed WMN. The user devices—laptops, desktops—will be located in some houses in the barrios. Each user device within the neighborhood wireless network coverage is connected to a wireless router using the WMN. The Internet access is provided by the ISP contracted by the owner/tenant of the residence in the neighborhood.

C. Provisionning

We propose an unplanned mesh network, where the nodes will be located in the houses in the barrios and the Internet gateways will be located in the buildings closest to the barrios. So this is a low cost and time saving solution.

D. Nodes Locations

The mesh network will be built in a random way. The nodes will be randomly located in several houses in each barrio. This can have some effects on the performance of the networks as shown in our simulation results.

E. Interference

The informal houses located in the barrios are usually built from bricks, concrete blocks and metal foils [14]. These houses are scattered unevenly in the area, one house very close to the other. Most of the houses have one floor but we can find buildings that have up to three floors. So the many sources of interference can be found.

F. Node Associations

Balderrama and Colombo [4] explain that more than one wireless network in a neighborhood may be available in a barrio. As mentioned, we propose that poor families in the barrio gain access to the Internet via one or more ISPs contracted by some neighbors living in the neighborhood. Thus, some kind of agreement must be established between the community representatives of the barrio and the owner of the wireless network, so the users in the barrio can gain access to the Internet through his network. In order to not downgrade the performance of the shared Internet connection, a limit on the use of the network resources must be established. For example, the user who pays for the Internet access service may want to share only 50% of the total bandwidth (as proposed in [4] and [21]). Today, several low cost wireless routers may be configured to share the Internet connection. In order to implement more complex sharing restrictions, devices with more configuration options must be located between the wireless router and the mesh clients.

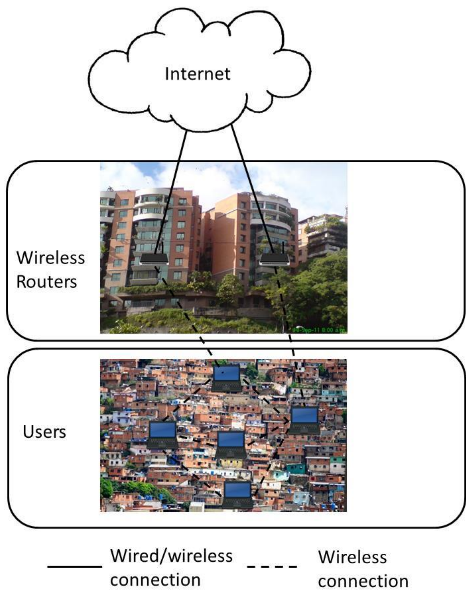

Fig. 4. Wireless Mesh Network architecture in the Metropolitan Area of Caracas.

The wireless routers that will be part of the WMN may be established in advanced. So the mesh clients within the wireless network coverage area can be associated with a predetermined set of routers.

G. Connectivity

To have Internet access, at least a path should be available between the user and the Internet gateway (wireless router). In the proposed WMN, not all mesh nodes have direct connection to the Internet gateway, so network density is a fundamental factor to have high connectivity. We studied the urban geography of the city, and we determined that the distance between each mesh client may be around 30 m, and the distance between the each mesh border client—any mesh node within the wireless network coverage associated with the wireless gateway—and the wireless router may be around 50 m. The network degree—"the number of neighbors a mesh node has" [22]—will be determined by the distribution of the devices in the houses in the barrio. Another key factor that may affect the connectivity is the throughput. The throughput of the WMN is evaluated in this work.

High connectivity can be limited by the sharing of the broadband Internet connection. In [21], we evaluated the performance of the network for several sharing bandwidth values—several values of Internet bandwidth available for the mesh clients. In Fig. 5, we show the throughput results for 25 users and a total Internet bandwidth of 1024 Kbps. The outcomes show how we improve the network performance when we relax the bandwidth constraints.

H. Coverage

As indicated in [20], in the city of Caracas exists a mixture of suburbs and barrios, so almost every barrio is next to a neighborhood. Although we could not obtain the total number of Wi-Fi networks in the city, we have an estimate of the number of Internet residential subscribers, which could give us an idea of how many mesh gateways we could have. The population of the AMC is about 3 million people, it has around 500,000 residential Internet subscribers [10], located in an area of 297.3 Km^2 (urban area) [1], around 1681 subscribers/Km^2. We also carried out a site survey in some areas of the AMC to know how many Wi-Fi networks in some neighborhoods are in the proximity of some barrios. The results are shown in Fig. 6. In each barrio we can find three or more Wi-Fi networks.

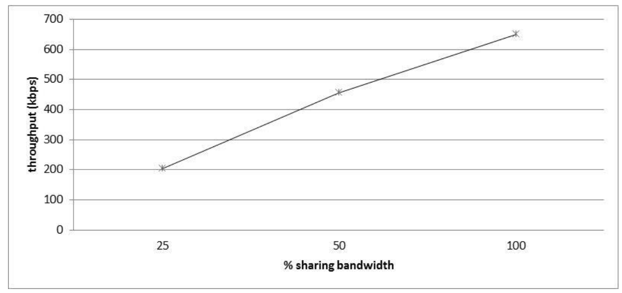

Fig. 5. Throughput of the network for several percentage of sharing bandwidth.

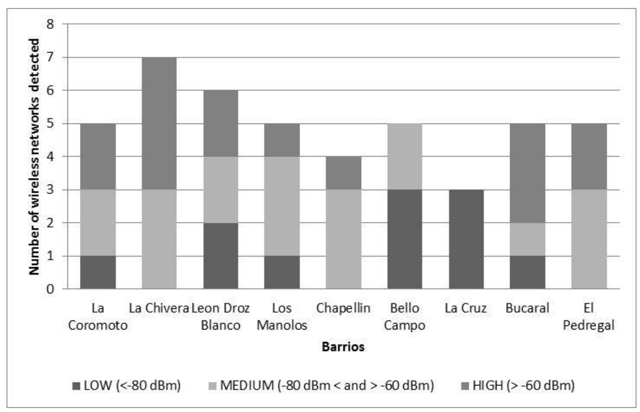

Fig. 6. Number of wireless networks in the neighbourhoods in the proximity of some barrios of the AMC distributed according to the signal power.

The proposed WMN will cover great part of the city, however, we need that sufficient houses in the barrio have mesh nodes (a laptop, PC or any other mobile device) to have the maximum coverage. Nevertheless, given the high density housing of each barrio area, we do not need that every house to have a mesh node—a mesh node may find a path to the destination through other neighbor nodes.

I. Use of Antennas

The mesh nodes in our WMN use omnidirectional antennas with an average gain of 2.5 dBi, which is the gain of most commercial wireless routers. We do not need the users in the neighborhood to install any further infrastructure.

IV. SIMULATION MODEL

To validate the proposed WMN, we conducted simulation experiments using NS-3 [17]. In our study, we used three routing protocols: OLSR and HWMP (reactive and proactive).

A. Network Topology

We defined several full-connected mesh networks consisting of 3x3 grid (9 nodes), 4x4 grid (16 nodes), 5x5 grid (25 nodes) and 6x6 (36 nodes). We chose this distribution of nodes because it supports a variety of topologies. Fig. 7 shows an example of the topology used in the simulation; it displays the components of the WMN: Internet, mesh gateway, and mesh nodes. Internet represents the Internet connection provided by the ISP contracted by the user in the neighborhood. The mesh gateway represents the wireless router of the user. The mesh nodes are the devices located in several houses in the barrio.

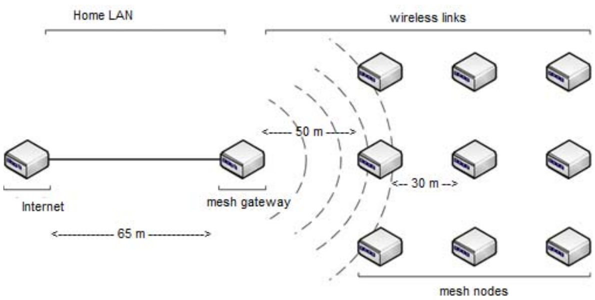

Fig. 7. One of the network topologies considered in our simulation study.

As mentioned before, we carried out some measurements of several distances between some buildings in the neighborhoods and the houses in the closest barrios obtaining an average of 50 m, so we fixed the distance between the mesh gateways and the closest mesh nodes to 50 m. We also set a distance of 30 m between each mesh node (see Fig. 7).

B. Network parameters

In this study, we assume that the mesh nodes are connected by IEEE 802.11g links working at 6 Mbps. The Internet connection has a bandwidth of 1 and 2 Mbps, which are according to the Internet connection speed provided by the ISPs in Venezuela, and we assume no restriction on the use of this resource (100 % sharing bandwidth). The upload bandwidth is equal to the download bandwidth. Also, we generate TCP traffic.

V. SIMULATION RESULTS

In Fig. 8, we show the results of the throughput of the WMN according to the number of the nodes for the Internet connection bandwidth of 1 and 2 Mbps. We can see that the throughput of the network decays as the number of nodes in the WMN increases. Also, the throughput is increased when the Internet connection bandwidth is greater. Each user will get a maximum throughput of 150 Kbps when the network has 10 nodes and the Internet connection is 2 Mbps.

In Fig. 9, we can observe that lower Internet connection bandwidth provides higher percentage of packet loss. For a restricted bandwidth of 1 Mbps, as the number of nodes increases, the performance of the routing protocols affect the packet loss. On the other hand, with a connection of 2 Mbps, the percentage of packet loss almost does not vary when the number of mesh nodes is increased. Also, we can see that the percentage of packet loss is kept below 4% when OLSR routing protocol is used.

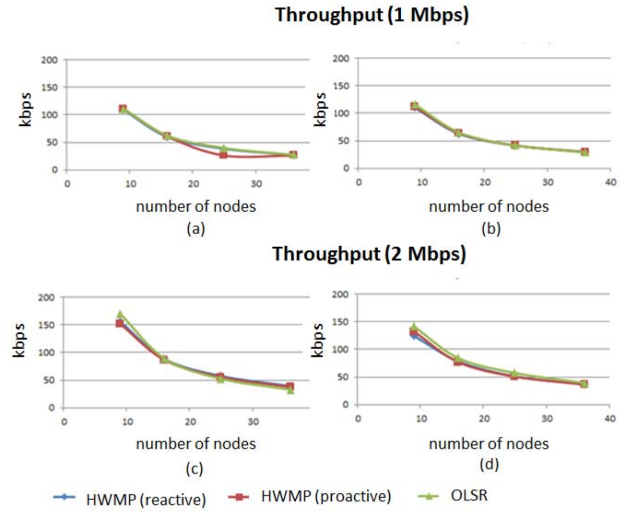

Fig. 8. Throughput of the proposed WMN for an Internet connection of 1 and 2 Mbps respectively: (a) (c) download traffic and (b) (d) upload traffic.

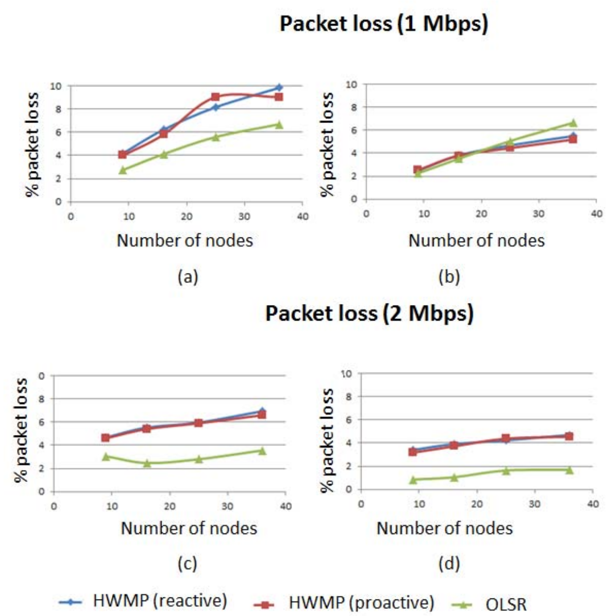

Fig. 9. Packet loss as a function of the number of nodes per each routing protocol for an Internet connection of 1 Mbps and 2 Mbps respectively: (a) (c) dowload traffic and (b) (d) upload traffic.

VI. IMPLEMENTATION CONSIDERATIONS

In this section, we detail some issues that have to be taken into account in order to implement the proposed WMN.

A. *Bandwith sharing*

The speed of the Internet is still low in Venezuela. However, in the next years it should be increased in order to meet the growing Internet traffic demand of the users. As the bandwidth of the Internet connection is higher, the throughput of the WMN should improve as shown in the above results.

On the other hand, a sort of agreement must be signed between the owner of the wireless network and the barrio community representatives in order to share the Internet connection of the owner. The agreement must establish: the time when the Internet connection could be shared, the percentage of sharing allowed, security policies that must be followed by the WMN users, etc.

B. *Mesh nodes*

The Venezuelan government [16] has given more than 1 million laptops ("Canaimitas") to children in low-income families in Venezuela, who usually live in barrios. Other people living in the barrios can get computers through the plans offered by the *National Company of Telephony (CANTV)* [8]. Thus, we expect to have sufficient mesh nodes in the barrios so connectivity along the mesh network could be guaranteed.

C. *Network Architecture*

Given the performance of the WMN in terms of the throughput and the number of neighborhood wireless networks available in each barrio (more than two according to Fig. 6), we propose that each mesh border client be associated with a different wireless network. According to the results, it is not desirable to have more than ten nodes per mesh network.

VII. Conclusions

In this paper we have detailed a WMN that exploits the urban geography of a city such as the Metropolitan Area of Caracas—almost each barrio is next to a middle-class or wealthy neighborhood. The proposed network can be used to provide Internet access to low-income families that live in barrios. We have performed site surveys in some areas of the city, which show that more than two wireless networks in each neighborhood cover part of the closest barrio. Thus we described in detail the issues related with the deployment of the network and carried out some simulation studies. The results show that with the current Internet connection bandwidth provided by the Venezuelan ISPs, the maximum throughput of the WMN is about 150 Kbps. Thus, in order to avoid a strong degradation of the network performance we can group the mesh nodes to access the Internet through different mesh gateways (i.e. wireless routers in the neighborhoods). In addition, we observed that the packet loss rate rises as the Internet connection bandwidth increases, being OLSR the routing protocol that offers the least percentage of packet losses.

So far we have not carried out any test bed in the barrios given that they are not safe. In the future this study must be performed. Meanwhile we would like to carry out more experimental results using different wireless technologies, such as IEEE 802.11n and 802.11ac. We would like to improve the current routing protocols to take into account the bandwidth restrictions in the ingress/egress node—the wireless router through which the client gains access to the Internet.

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