Deploying and Experimenting Wireless Ad Hoc Networks in Mountainous Regions for Broadband Access

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Abstract

The multi-hop wireless networks developed by the FP6 IST ADHOCSYS project provide a cost-effective solution for providing broadband access in mountainous regions. The solution is based on ad hoc networking technologies, created using cheap off-the-shelf hardware equipment, open source software, and an enhanced version of the OLSR routing protocol. This paper describes the implementation, installation and deployment aspects of the project, focusing on current deployment of a pilot network.

I   Introduction

Broadband Internet connections in many rural and mountainous areas are still not a reality, and for this reason these areas are still experiencing the digital divide in terms of the types of services that they can receive and how fast these services can be accessed.

Based on multi-hop ad hoc wireless networking and IEEE 802.11 Wireless Local Area Networks (WLANs) technologies, the ADHOCSYS project aims at building a cost effective solution for broadband Internet access in these regions, by connecting these areas to the Internet through available gateway(s) in the nearby towns or villages. In particular, the developed solution is based on an extended version of the Optimized Link State Routing (OLSR) routing protocol [1], to create a multi-hop ad hoc wireless network.

Briefly, an ADHOCSYS network is a multi-hop wireless network, composed of two tiers - a few access networks and a backbone network which inter-connects these access networks. The Internet connectivity is provided by one or more gateways located at the edges of these networks. In this paper, we focus on the descriptions of a few practical aspects of the project, including implementation, configuration, deployment of the pilot network etc [2] [3]. For a general description of the ADHOCSYS networks, application scenarios, algorithms and mechanisms, please refer to an accompanying paper [4] and reference [5].

The rest of this paper is organized as follows. Sections II and III describe the hardware equipment used for building ADHOCSYS nodes and the Linux software image that has been built in this project respectively. Section IV deals with OLSR enhancement implementation, and Sections V and VI describe the pilot network that has been built and the testing activities that have been performed. Finally, the paper is concluded in VII.

II.   ADHOCSYS Hardware Equipment

The hardware equipment used in ADHOCSYS network mainly consists of Linux boxes. The exact configuration of each of these Linux boxes depends on the roles each node has within the network.

More specifically, different hardware configurations are foreseen for wireless devices used for the backbone and wireless devices used for mesh access networks. Table I compares hardware features of different node types.

Hardware	Backbone	Access network
Antennas	Directional (up to 28 dBi gain) or Omni-directional (6/8 dBi gain)	Omni-directional (6/8 dBi gain)
Location	Outdoor	Outdoor
Power supply	Battery powered. Some Type-1 nodes may have 220 V power supply	220 V power supply (usually installed at customer place). Some nodes may need battery power supply
Radio channel	5.4 GHz (IEEE 802.11h) 3.5 GHz (WiMAX)	5.4 GHz (IEEE 802.11h) 2.4 GHz (IEEE 802.11b/g)
Radio card slot	at least 2 x MiniPCI	at least 2 x MiniPCI
Storage Media	Flash Memory Disk	Flash Memory Disk

Table 1. Hardware features of ADHOCSYS nodes.

Additionally, the hardware equipment to be used must have some common characteristics, regardless which type a node is configured as. In the following a brief list of the characteristics each node should have is presented:

1) It should use Reduced Instruction Set Computer (RISC) Central Processing Unit (CPU), since these architectures exhibit in general lower power consumption.

2) It shall be equipped with at least one serial interface that may serve for monitoring purposes.

3) It shall resist to extreme climatic situations. For this reason it must be enclosed in a box with ingress protection IP66 or even IP67.

4) It shall resist to severe variations of temperature. Experimentations have shown that in these devices the inner temperature is normally 10° C higher than the external one. This means that in the summer the inner temperature may be very high, for instance up to 50° C. In the winter, besides, there may be the problem of internal humidity.

To fulfill these requirements, the selected hardware for ADHOCSYS backbone nodes is the Routerboard 532 produced by Mikrotik [6], which has the following features:

- MIPS CPU
- 64 MB DDR RAM
- 128 MB NAND storage
- Up to 4 miniPCI slots for wireless cards (2 miniPCI slot embedded on board, 2 more miniPCI available on daughterboard 502)
- 3 Ethernet Ports

For ADHOCSYS access network nodes, a similar but less expensive hardware can be used, with the following characteristics:

- MIPS CPU
- 16 MB RAM
- 164 MB NAND storage
- 2 miniPCI slots for wireless cards (1 card for IEEE 802.1a access network and 1 card for IEEE 802.11b hot-spot)
- 1 Ethernet Port1

Figure 1 shows an example of an ADHOCSYS node (Linux box) which has been configured as an access point. In fact, the cost of these devices is quite low, ranging from 300 to 600 euros, including the cost of antennas and enclosing boxes.

Figure 1. ADHOCSYS node illustration.

III. ADHOCSYS Software Image

The hardware equipment described in the previous section has been equipped with an optimized software image based on the Linux operating system.

The software image has been derived from the OpenWRT distribution, and has been developed in order to be deployed over MIPSEL little Endian architectures, i.e. RouterBoard 500 and RouterBoard 100, which have been selected as the working motherboards for ADHOCSYS nodes.

The software image has been designed to be small in memory size, and with remote diagnostic and troubleshooting features. In order to keep the memory size of the image small, the Squashfs highly-compressed, read-only file system for Linux has been used.

All the software implementations that have been developed in this project, together the OLSR enhancements which are described in the next section, have been deployed over this software image, using a cross-compiler for MIPSEL architectures.

IV. ADHOCSYS Enhancements to OLSR

The choice of the routing protocol is a crucial element in ad hoc networks. Within ADHOCSYS, the standard OLSR protocol has been chosen as the basis for our extensions to the OLSR protocol, as listed below. These already implemented extensions in the context of the project result in an enhancement to the current state of the art.

A. Multi-homing

With our multi-homing enhancement, a node uses a metric-based policy to select the best gateway. The adopted metric is based on the traffic load of each gateway. This metric can be used in combination with other metrics, as described in "metric-based routing", later in this section. Figure 2 illustrates a simple example of the implemented multi-homing function where a node is able to choose the default gateway based on advertised metrics, instead of on the number of hops.
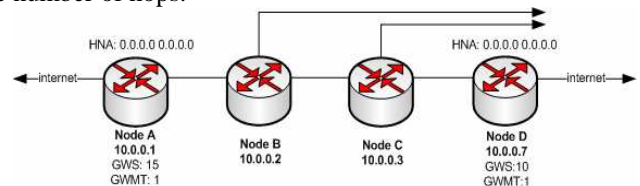

Figure 2. An example of multi-homing.

This feature allows the network to exhibit an intelligent behaviour, in which each node selects the best gateway, considering both its load status, and its distance.

Furthermore, when used in combination with the "link-break detection" enhancement, described later in this section, the ADHOCSYS multi-homing implementation forces the second gateway to be immediately available once the first gateway is down.

B. Load-balancing

If a given path becomes saturated, the ADHOCSYS load balancing implementation will re-calculate a new path. E.g. if a path A-B-C is over-loaded, a new path like A-D-E-C will be established. This type of load balancing assumes that topology redundancy among network nodes is provided

Information about the load status of each link is calculated by parsing the output of IPTraf commands, and considering the total amount and size of packets that each

node sends to each of its neighbors in a given time interval. This information is included in a custom LINKINFO message that each node sends and receives.

Each node maintains a data base of link load information, which can then be used as a metric for route calculation (which is described later in this section).

C. Power awareness

The ADHOCSYS nodes in both backbone and access networks may be installed in open environments without Alternating Current (AC) power supply. These nodes could be battery-powered, and equipped with solar panels.

For this reason, the routing protocol should be power-aware, in order to avoid routes involving nodes with nearly drained batteries. As an enhancement to OLSR, a power-aware plug-in which disseminates the battery level throughout the network, has been implemented. Each node maintains a data base of this information, which is also used as a metric for route calculation.

Additionally, an alarm message function has been implemented, to send a message to the system administrator for possible human intervention when the battery level is lower than a given threshold.

D. Link quality

Link quality is not defined in the 802.11 standard. Wireless network engineers and wireless product vendors usually refer to "Link Quality" as the overall performances of a wireless link. In ADHOCSYS, these measures are acquired from the MADWiFi drivers.

MADWiFi computes the signal quality with function *set_quality*, and provides two tools to retrieve PHY and MAC layer statistics: *athstats* and *80211stats*.

Using this information, we have implemented a LINKINFO extension to OLSR, which diffuses information about the quality of links. This information is then used by the routing table calculation enhancement described later in this section, to consider link quality in routing table computation.

E. Link-break detection

When a link break happens, traditional OLSR will react to this change by exchanging HELLO and Topology Control (TC) messages, for establishing a new route. This process normally takes up to a few seconds.

With our link-break detection enhancement, a new path, if exists, will be available immediately (e.g. in the order of milliseconds) after a link break. With this enhancement, we are able to provide the end-users with non-interrupted access.

The basis for this enhancement is to utilize link quality information gathered at the MAC layer to impose OLSR routing table re-calculation. More specifically, the MAC layer detects the link break and sends an indication to the protocol layer, and upon receiving such an indication which is treated as a topology or neighbor change, OLSR shall conduct routing table re-calculation immediately.

F. Channel selection

When nodes are equipped with multiple wireless cards (typically 2~4 cards), two or more channels may co-exist between a pair of nodes. If one channel is close to congestion, and an alternative channel exists, this second channel should be used.

The ADHOCSYS channel selection algorithm provides both channel redundancy and higher per-hop throughput when installed. This algorithm considers both the case of channel selection for point-to-point connections between ADHOCSYS nodes, and the case of channel selection for point-to-multipoint connections between ADHOCSYS nodes and clients.

Since there are 3 and 11 non-overlapping channels for 802.11b/g and 802.11a respectively, the problem for channel selection becomes how to select a channel which leads to least interference when both intra-system and inter-system interference is considered.

The proposed algorithm is based on a central-controlled solution, where each node measures and reports the interference level in its neighborhood, and based on this information, a channel manager decides the most suitable channel for each pair of nodes.

G. Hierarchical structure

There are two levels of hierarchy in ADHOCSYS networks. Level-1 hierarchy corresponds to connection among backbone network nodes, while Level-2 hierarchy corresponds to connection among access network nodes.

An access sub-network which is connected to other access sub-networks is referred to as a cluster. A backbone node serves as the cluster head and advertises its reachability to other clusters periodically.

In this architecture, the cluster heads are predefined, thus there is no need to develop an algorithm for cluster head selection. The cluster heads are aware of each other, and are connected to each other, either directly or via multi-hop relays. The cluster heads aggregate IP addresses in each cluster and are responsible for communications between clusters.

Host and Network Association (HNA) messages are used for disseminating both the Internet gateway information and the connectivity information among different network clusters. More specifically, inter-cluster HNA messages advertise a cluster head's connectivity of all nodes, including also Internet gateway nodes inside the same cluster, to other clusters. Intra-cluster HNA messages, instead, which are sent to all nodes inside the same cluster, advertise a cluster head's connectivity to other clusters, including also Internet gateways from another cluster.

Every node in a cluster is considered as a special type of "gateway", in which it acts as an AP for its clients, and therefore it generates HNA messages. The cluster head, upon receiving this information, establishes an HNA Information Base, which is then used to build the inter-cluster HNA messages which are forwarded to other cluster heads.

H. Multiple interfaces

Multiple wireless interfaces installed on the same node are supported by standard OLSR via Multiple Interface

Declaration (MID) messages. In this implementation, however, only one interface is used as the main address for path establishment.

The idea behind our multiple interface extension is to treat each interface independently, so that higher path reliability and higher throughput can be achieved when two or more interfaces co-exist between two routers. With two interfaces between a pair of nodes, the link between these two nodes is still available even if one of the two channels is broken.

In our implementation, we consider every individual interface as a main address. Each interface advertises other interfaces located on the same node as its neighbors. To other nodes in the network, the two interfaces look like two distinct nodes.

K.   Metric-based routing

Many of the enhancements described so far, including multi-homing, load balancing and power awareness, are based on an enhanced routing calculation algorithm, which we have developed based on the Dijkstra algorithm, and allow use metrics for route computation.

This algorithm, in particular, allows to use multiple metrics at the same time, and to assign a relative weight at each of these metrics. As the input of this algorithm, the 'cost' of all links and nodes within the network is advertised throughout the whole network, so that each router has the topology information needed for its routing calculation.

The algorithm works independently, regardless of the number and type of metrics that are adopted. The metrics that have been considered in this project are the ones that have been mentioned earlier in this section, i.e. load status, battery level, link quality, etc.

The metrics that should be used for a particular network, and their relative weight, can be established by the network administrator though a configuration file. Based upon this information, each router is able to build its routing table according to the minimal path cost criterion.

V.   ADHOCSYS Pilot Network

All mechanisms and algorithms described in the previous sections have been implemented, and the implemented functionalities have been deployed over the software image described in Section III, and finally installed on ADHOCSYS nodes.

The ADHOCSYS nodes have been used to deploy a pilot network in Coggiola, a small town located in mountain region in Northern Italy which still suffers from digital divide, the "Comunità Montana Biellese". Figures 3-5 illustrate the region, the whole network and the access network alone respectively.

The ADHOCSYS mesh pilot network, consisting of 10 nodes which act as access points for end-users, covers almost all Coggiola territory, about 1.2 Kilo square meter. This network is connected to an Internet Gateway through a multi-hop wireless backbone, as shown in Figure 4.

The nodes are mostly concentrated on the south east part of the village, in order to create a well connected mesh

network, suitable for realistic situations, and are mainly installed on top of house roofs.

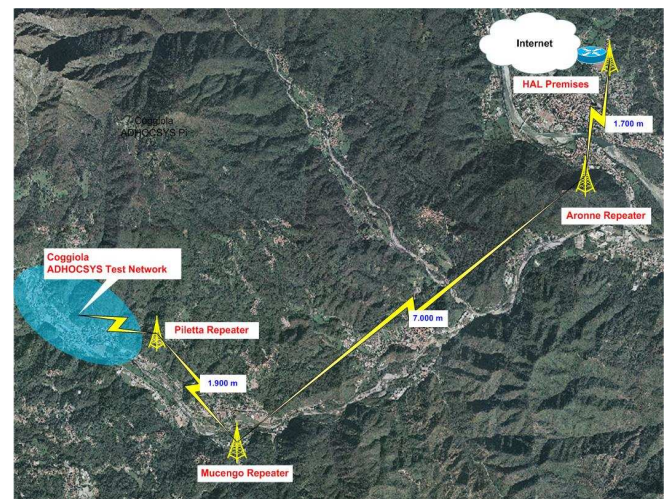**Figure 3. Geographic location of the pilot network (Coggiola, Piemonte)**

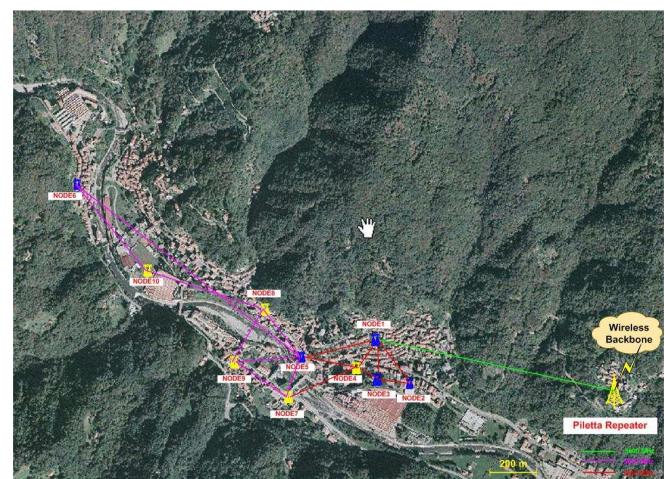**Figure 4. ADHOCSYS: the whole pilot network.**

Figure 5. ADHOCSYS pilot access network.

Any end-user covered by an access point on the roof will connect his/her PC or home network to the Ethernet port of the ADHOCSYS node and is connected to the Internet through the gateway.

Figure 6 depicts the pilot network layout and major configuration parameters.

Figure 6. ADHOCSYS pilot network layout.

The pilot network architecture is depicted in Figure 7. It is composed of the access network, a server farm, a backbone, and a Virtual Private Network (VPN).

Figure 7. ADHOCSYS pilot network architecture.

The server farm is used to run certain basic services, which include the RADIUS server for user authentication, the ZABBIX server for network monitoring, Domain Name System (DNS), Dynamic Host Configuration Protocol (DHCP) and Network Time Protocol (NTP) servers, and a centralized configurator, used for remotely configuring the network nodes.

The VPN is used to let ADHOCSYS partners securely access the pilot network from remote locations.

The centralized configurator is a software application that has been developed in the context of this project. It is a web-based application that can be used with any Internet web browser. The tool user interface, displayed in Figure 8, shows a list of the locations where the wireless nodes are installed. After selecting one of these locations, the list of the nodes belonging to the selected network will be displayed in the right frame.

Using the centralized configurator, it is possible to edit a node configuration, and specify values for network

parameters, OLSR settings, and wireless interfaces. Figure 9 depicts how OLSR parameters can be configured to a specific node.

Figure 8. ADHOCSYS centralized configurator.

Figure 9. ADHOCSYS configuration of OLSR.

After having specified the configuration parameters it is possible to send the configuration to each node in the network, and force each node to reboot. The configuration is packed into an XML file, which is received by each node and then parsed and applied when the node is rebooted.

VI.   Testing Activities

The pilot network is continuously monitored through a Zabbix [7] server which gives statistics about network availability and latency between the Zabbix server and each node belonging to the pilot network.

The testing activities in the pilot network are being performed at the time of writing. These tests include

measurements of the network performance, and verifications for all the software implementations performed within this project. The experiments will be conducted both under light traffic load and under saturation status, for different types of services.

The measurements scenarios include performance between pairs of directly connected nodes, performance between pairs of nodes over a multi-hop connection, and performance between the Internet gateway and final users.

To perform performance measurements like packet loss, throughput, jitter and delay, we are using the open source tool – Distributed Internet Traffic Generator (D-ITG) [8]. This is a tool to produce traffic at packet level, by accurately replicating appropriate stochastic processes for both Inter Departure Time (IDT) and Packet Size (PS) random variables.

A few testing activities have been performed immediately after network installation, to verify the pilot network correct behavior. First of all, an inventory of main links has been performed, indicating the pair of nodes forming the link, the link distance and the operating frequency. After that, for all links, latency and packet loss have been measured by transmitting a set of 50 ping (size 56 bytes) packets over links from both ends of the links, at different times.

The results that we have obtained through this test show that most links have a good or acceptable performance. For instance, the link between two nodes SCHOOL (10.16.0.2) and TOWNHALL (10.16.0.3) in Figure 6, at a distance of 120 m, reports a 0% packet loss. A few links, however, have poorer performance and are not very stable, for example, the link that connects two nodes SCHOOL (10.16.0.2) and KINDERGARTEN (10.16.1.7) reports a 26% packet loss. In fact, this is caused by some trees that are in between the two nodes. Similar situations could also happen in other practical installations of ADHOCSYS networks, and may the standard OLSR may meet problems in these cases.

Our tests, for instance, have experienced that standard OLSR considers this link as available for short periods of time and unavailable for other periods. This depends on the number of HELLO packets that are correctly exchanged among nodes. Because OLSR normally considers only the hop count for routing table computation, the route from KINDERGARTEN to SCHOOL is not stable.

This observation shows that this pilot network provides a good test case for the project implementation, as it is a task of this project to overcome this type of problems. Thanks to our routing protocol enhancements, we expect that we will be able to exclude links with poor performance from the routes, resulting in a more stable and performing network. The tests to be performed in the next months are aimed at giving a proof for this enhancement.

VII.   Conclusions and Further Work

In this paper a solution for broadband Internet access especially suitable for rural and mountainous regions has been presented. Various key factors have been considered such as implementation, configuration and deployment aspects. The ADHOCSYS solution is based on ad hoc wireless multi-hop networks, and adopts cheap off-the-shelf hardware equipment and open source software. The solution features an enhanced version of the OLSR routing protocol, which allows use routers installed at the premises of end users ad active nodes that take part in routing.

We have described how ADHOCSYS nodes are built, and have presented our enhancements to the OLSR routing protocol, that increase the efficiency and functionality of the network. ADHOCSYS nodes have been used for building a real-life pilot network, suitable for tests and measurements, as well as for providing Internet access services.

Some of the tests that are being performed have been described in this paper while others will be performed in the next months. The implementation codes described in this article have been released as free software, already downloadable at [9], under the GPL.

Acknowledgments

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