WIRELESS SOLAR-POWERED ROUTER FOR HEALTH ISOLATED RURAL ENVIRONMENTS

F. J. Simó*, P. Osuna[†], J. Seoane[‡], A. Martínez*

*Universidad Rey Juan Carlos, {javier.simo,andres.martinez}@urjc.es
Camino del Molino s/n, 28943 Fuenlabrada (Madrid) - Spain
Tel: +34914888223 – Fax: +34914887500
[†] Fundación Rafael Escolá & Fundación EHAS, Spain, posuna@ehas.org
[‡] Universidad Politécnica de Madrid, Spain, jsp@dit.upm.es

Keywords: Rural telemedicine, Mesh networks, WiFi, IEEE 802.11, VoIP, Developing countries.

Abstract

Isolated rural areas often lack for any terrestrial telecommunication networks, specially in developing countries, which supposes an important obstacle for offering health assistance of acceptable quality. On the other hand, low density and low concentration of population, lack of electricity in many points and accessibility problems make difficult to propose realistic solutions based on conventional technologies. This work presents the development of an autonomous solar-powered wireless node for low-cost static mesh networks. IEEE 802.11 is used for communications among nodes. The network is QoS-aware at the IP level providing reliable VoIP services, and nodes contain a software PBX so that any two nodes in the network can establish a multihop VoIP communication.

1 Introduction

More than a half of world population lives in isolated rural areas out of the scope of any terrestrial telecommunication networks. This is particularly true in developing countries, where rural areas very often lack of any access to the public telephone network or even to electricity. Low density and low concentration of population make difficult to afford the installation of permanent infrastructures that would be expensive due to typical restrictions in power service, accessibility, maintainability and security. Additionally, in developing countries rural communities are usually extremely poor and can not afford the cost of services if this is too high [14].

In our group – EHAS program [13,14] - we are much concerned about isolated rural environments in developing countries, and specifically with health facilities and their communication to hospitals. Previous advances in rural telemedicine for developing countries proved that providing voice and data communications in small health rural spots gives great benefits such as a drastic reduction in the average evacuation time of critical patients, improve of diagnostics' reliability, and decrease of travels needed by the staff.

In this work we propose to use IEEE 802.11 mesh networks supporting voice and data communications as the most appropiated technology that makes possible to use telemedicine applications and public health information systems in rural areas of developing countries.

Mesh networks do not need any communication infrastructure. Nodes connect to neighbours as they discover them, and can communicate with non-contiguous nodes or with other networks using other nodes as routers. Several aspects must be taken into consideration for applying IEEE 802.11 and the mesh networks paradigm in this project:

- IEEE 802.11 is a very well-known technology and extremely cheap. Nonetheless, existing research can not be applied to long-distance WiFi links because of the universal asumption that a node can listen to another transmiting node within a slot time (20 μs). In a paralel research we are working on a model for long-distance WiFi links up to 100 kms.

- WiFi systems can work in ad-hoc mode, which makes this technology be appropiated for mesh networks. This reduces even more the price of communication infrastructures because user terminals permit themselves to extend the network scope.

- IP autoconfiguration is desirable to avoid the need of network administration. The same reason forces to use multihop ad-hoc dynamic routing protocols, so that nodes can attribute themselves unique IP addresses and then constitute with other nodes an IP network. Routing protocols must use a cross-layer approach in order to use physical level information for taking right decisions in the choice of routes.

- Minimal power consumption is a must. Nodes will be solar powered, so size and cost will be strongly related to

consumption. Hardware must be optimized for low power consumption, and the network must collaborate in order to avoid useless transmissions when users do not need the system to be available.

All these considerations guide our design of an autonomous wireless mesh node; some units of the designed system could constitute a network just by putting them in different places and making sure that each node sees at least one neighbour.

Related projects are developed by a group in the MIT [3], the TIER group at the University of Berkeley [4] and some industrial groups, but none of them offers a complete self-configuring QoS-aware solution.

2 IEEE 802.11 mesh networks for rural telemedicine in developing countries

Isolated rural scenarios in developing countries use to have some common characteristics:

– Long distances of several tens of kilometres among "controlled" points.
– Lack of fast routes that make easy the movement between different points of the network.
– Lack of an electric installation and, if it exists, it is often unstable.
– Shortage and high cost of qualified technical staff.
– Extremely low incomes of rural inhabitants.

Those environmental characteristics determine the requirements that must be met by any telecommunication technology in order to be successful and sustainable in such scenarios. WiFi mesh networks have many interesting properties that make them a candidate solution:

– The use of WiFi permits the production of very low-cost nodes that can establish long links. There are some important technological problems that must be solve in order to obtain an optimal performance, but that is the subject of another research of our group and will not be developed herein.
– If we are able to obtain a highly self-configurable mesh architecture, nodes can be place at strategical positions by any non-qualified person whose only concern will be to assure the line-of-sight to neighbour nodes.
– Using low power hardware and optimizing the power consumption by several means, it is possible to produce compact autonomous nodes that incorporate a solar power subsystem, thus eliminating any restrictions regarding power sources.
– The fact that all nodes in mesh networks have the same functionality is also very positive for the extension and maintenance of the network.

The EHAS group has developed a mesh architecture as represented in Fig. 1. Actually the three kinds of nodes represented in the figure may have the same functionality, but

they are used differently; so it must be understood that client nodes, core nodes and gateways are mainly the same thing, the only difference is the position and use of the nodes.

One can think at this architecture superposed to rural telemedicine scenarios: core nodes would be deployed in strategical points in the area whose main characteristic is the visibility among them. The gateway node would be placed in the first establishment where we can have access to fix networks (i.e. the reference hospital) and client terminal nodes would be placed in isolated health facilities.

The main concern of the project presented herein is to develop a WiFi mesh node powerful and flexible enough to permit to build this architecture with it. The core idea is that nodes do automatically every thing once they are placed in the right positions. As a node is powered on, it discovers its neighbours, attributes itself a unique IP address, and then establish the most appropriated routes to the rest of the network and to the world, taking into account the quality of the links. Nodes know about the different classes of traffic in the network, and manage the QoS (Quality of Service) at the IP level. Additionally, each node has the necessary elements to make possible partial voice and data connectivity even if part of the network is provisionally not available.

The rest of the paper will describe in detail the design of the WiFi mesh node.
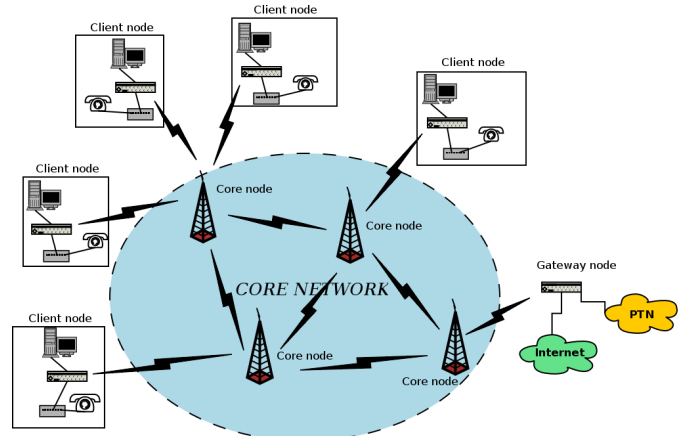

Figure 1: Mesh Network Architecture

3 Components of the wireless solar-powered router

In this section we will study separately the hardware and the software of the wireless solar-power router, enhancing which are the current and future research lines for each component. The design presented in this paper has been partially used in networks already deployed in rural areas of Peru, in the region of Cuzco. References to previous installations regard to that preliminary experience.

3.1 Hardware

The hardware is composed by several subsystems:

– Computer subsystem: It consists of an embedded computer optimized following consumption and size requirements. For the first prototype of the router we have chosen Soekris boards based in x86 architecture. The main advantages of this platform are: low cost design, availability of three wireless interfaces, robustness against bad weather conditions and hardware watchdog. According to measurements performed in our laboratory, Soekris board has an average consumption of 4W, a value still too high for our requirements. A second version of the node is under development, in which the power consumption will be reduced to 1W. For that purpose we are working now in a consumption comparison from different boards: ARM architecture (Peplink, Compulab, Inhand) and MIPS architecture (RouterBoard, MeshCube). Results from this comparison will be available in the short term.

– Wireless subsystem. This subsystem is the responsible of the communication with the rest of the network. It consists of several WiFi interfaces, pigtails, low-attenuation cables and high-power directional antennas. We are currently working with wireless cards using two different chipsets: Intersil Prism II and Atheros. Intersil Prism 2.5 linux driver (Hostap) has good support of ad-hoc mode in linux, whereas Atheros linux driver (Madwifi) allows to tweak some parameters related to timeouts for optimization of long distance links.

– Solar subsystem. Our router will be installed in isolated rural areas, typically high mountain or jungle, where often there are no power sources at all. So nodes need to have a solar power subsystem to provide enough power in a continuous way. This subsystem will consist of all necessary elements to feed in DC our communication system: solar panel, batteries, charger/regulator and cables. A typical system will consist of a 22Wp solar panel, a 3A regulator and a 17Ah battery, calculated for powering a system consuming about 3W 24 hours a day in the worst weather conditions that we can find in EHAS networks, which are deployed in tropical regions. The cost and size of the solar sub-system will be proportional to its power consumption, so it will be essential to design a very low-powered system. As mentioned before a first approach to reduce the consumption will be to migrate the hardware platform to a less-consuming one. Another approach has to be with the wireless cards. According to measurements performed in our laboratory wireless cards are the most power-demanding elements. IEEE 802.11 specifications include a power-saving mode (PS). Linux drivers are using that mode, but it is more efficient in centralized networks than mesh ones. To improve this power-saving scheme our group is considering the design of a protocol which wakes the wireless interfaces up and sleeps them in period cycles while the network is idle. During certain periods, for example in the night, it could be allowed a delay of up to several minutes in the establishment of the communication in order to reduce power consumption while the solar subsystem is not supplying power.

– Structural subsystem. In the installations made until now, hardware components have been installed separately. Thus, antennas and solar panels are installed on the communication mast, whereas the embedded computer is installed inside the facilities. For the second version of the router, we are designing a unique compact system in a NEMA-4 waterproof box, on which the solar panel will be easily mounted. There will also be some fixation elements to the tower or mast. Inside the prototype we will locate the hardware board with its corresponding wireless cards and pigtails. Besides to be waterproof, this kind of box also includes a suitable protection system for extreme temperature and humidity conditions.

3.2 Software

The software part of the node is composed by an operating system and several applications that provide all the functionality needed. In this subsection the main problems to be handled will be analysed one by one.

– Autoconfiguration. To be part of an IP network, each node needs to be set up with an IP address, whether it be manually or automatically through a DHCP server. In fact, this has been the approach taken in the first prototype. However, the dynamic and self-configuring character of a mesh network makes these procedures be an unsuitable solution. In IPv6 there are several solutions [9,10,11] to obtain automatically an IP address in the scope of an unique multicast domain. This local character makes them useless for the nodes of a Mesh network whose addresses do not keep a fixed relation and therefore do not share the same domain. In IPv4 ZEROCONF workgroup has implemented a similar solution to IPv6 one. Using this implementation (zcip in Linux) a node is automatically set up with a 169.254/16 IPv4 address. As the case of IPv6 these addresses are just valid for the communication with nodes in the same physical link (or logical). The draft [2] shows an overview of the proposed solutions for autoconfiguration issue in MANETS. These solutions are being studied by AUTOCONF group, responsible of the standardization process of autoconfiguration. However, it will take a long time to have an implementation which complies with the standard. In the short-term these are some of the solutions studied and proposed by our group:

- In IPv4, although a node has a unique 48 bits MAC address, there is no mean to obtain a unique 32 bits IPv4 address from it. One partial solution in order to get this uniqueness could be the use of wireless cards from the same manufacturer.
- PACMAN [19], NOA-OLSR[15], LUNARng[18] are multihop adhoc dynamic routing protocols offering a solution for the autoconfiguration issue. However, they

suffer from other limitations: no QoS-aware, limited number of interfaces per node, inestability.

- A DHCP centralized server would permit that a node could get its IP address making use of several DHCP relays or sending DHCP requests through routing packets.

– Multihop Adhoc Dynamic Routing Protocol. For the first version of the router we have chosen a static routing design. This solution is stable and does not add any routing control traffic among the nodes that compose the network. However this is not a self-configuring solution that does not serve to our purposes. In mesh networks, multihop ad-hoc dynamic routing protocols have been developed for routing packets among contiguous nodes or not contiguous of the network, or between any node of the network and the exterior through a gateway node. In these protocols the only requirement for an IP address in the network is its uniqueness. A lot of research articles analyse and compare the performance of different protocols, among them the most famous is [5]. A traditional classification of these protocols divides them in: 1) Reactives, a one node only exchanges control information when it wants to begin a communication with another node. AODV [16] y DSR [12] are the most extended in this category. 2) Proactives, nodes exchange information in a periodical way to learn the typology of the network. OLSR [6] and TBRFP [6] are the most popular.

Some of the critical aspects that make some of these protocols better than others are the quick convergence faced with changes in the network topology, the mechanisms to avoid loops, the right establishment of routes to the gateways and the efficiency to avoid loading the network with unnecessary control traffic. Most of these problems disappear in static networks and most of the protocols mentioned before are suitable from a stability point of view. Our work [17] mentions some lab tests that allowed us to use with success the AODV (implementation of the Upsala University) as well as OLSR (Qolyster version) in static ad-hoc chains.

Furthermore, there is a specific problem that only recently has been tackled by some research groups: a QoS-aware routing protocol. As a MIT group proved in [8], the protocols mentioned before stablish routes that are not always optimum because they use number of hops as metric, not taking into account the relative quality of the links. AODV is in this sense somehow better than the rest, because it defines a signal threshold to considerate a link as valid. De Couto et al. have suggested a metric called ETX [8] that considers the average number of retransmitions in every link. This breaks the independence rule between layers since it uses the information of the MAC layer to influence on IP level. The QOLSR [1] project has introduced QoS in OLSR. Its implementation, Qolyester, still finds itself on a first stage of development but it deserves to be followed closely in the future.

Our team has selected *olsrd*, Andreas Tonnesen's OLSR implementation, as the best current solution for our network. In contrast to other projects, it has achieved a remarkable maturity and stability and nowadays it keeps being supported by an extensive community. Recently this protocol has incorporated a ETX metric to its core. "olsrd" is a protocol structured in a modular way by plugins that easily allow to add external functionalities to the code. We could mention the following: Dynamic Internet Gateway, to add gateways to Internet dynamically; Security, to add signature messages to OLSR traffic; HTTP info, a small HTTP server that displays various information about the running olsrd daemon; and Dot Topology information, to generate graphics of the current net topology.

– QoS. IEEE 802.11 networks can offer a strong, suitable and low-price solution to distribute voice and data communication. But if we want to propose real-time communications it is necessary to ensure a quality of service in certain conditions. In our case telephony communications are essential, voice is the most demanded service to communicate isolated rural areas as it has been proved in the long-term evaluation of previous demonstrative projects of the EHAS group [14]. Additionally if we could propose other real-time services as video-conference, it could be also interesting to telemedicine and e-learning applications, among others. The QoS (Quality of Service) can be defined as a guarantee assured by the network of respecting certain maximal or minimal values to certain parameters when switching a packet throughout the network. The main problem associated to the QoS in a protocol stack is that all protocols must be QoS aware, which is not the case of 802.11b; any wireless network using this technology will never support QoS completely. However, the use of certain technical procedures at the IP level will permit at least that different kinds of traffic could be differentiated and treated as needed. Typical IP QoS architectures are IntServ and DiffServ. Both are standardized by the IETF, but the second one is preferred generally because it is simpler and it scales better. None of them can be directly applied to ad hoc networks because they make some important functional differences between edge nodes and core nodes while in ad hoc networks all nodes have the same functionality; so any of these solutions will have to be adapted.

The QoS at the IP level implies that different communications (in IntServ) or different traffic classes (in DiffServ) can be identified in each router and be treated separately, with different priorities. An important handicap will be that the throughput of wireless links must be estimated in order to perform bandwidth sharing in a fair way, though the throughput may be variable due to the distance between nodes or to the presence of

interferences. We have also mentioned that the WiFi technology is not QoS-aware. However, a partial support for QoS may be obtained at the IP level applying QoS aware IP switching, what permits to give different priorities to different traffic classes. The parameters that can be adjusted for each traffic class are mainly the following ones: throughput, delay and packet-dropping probability. Additionally, traffic shaping functions give us a way to avoid network overload, what permits us to guarantee that the network performance will approach what is expected.

Some experiments made by our group with mesh nodes chains have permitted to demonstrate that a differentiated quality of service of voice, video and elastic data could be guaranteed if it is possible to delimit the performance of the link [17]. It would also be very interesting to future works the dynamic estimation of the available resources so that they could be adapted according to changes, presenting even control adaptive admission.

– Network management. A management system is advisable in our mesh networks for informing about the availability and state of the nodes. We can also prevent future problems or failures in advance. EHAS has developed a management system based on electronic email and Zabbix, an open source software which supports both polling and trapping techniques to collect data from monitored hosts or execute remotely some control tasks. A flexible notification mechanism allows easy and quickly configure different types of notifications for pre-defined events.

– Security. Unlike a cabled network, it is not necessary the physical access to a wireless network to violate the security in different aspects. So the search of security systems which guarantee the authenticity and confidentiality of data is a critical aspect. These are some of the mechanisms proposed to enforce the security aspect in WiFi:
- Static WEP (Wireless Encryption key). A unique key is used to encode the communications between two nodes. It is still the most used method although this mecanism has been proved to be very easy to break.
- Dynamic WEP. It improves static WEP since the key is refreshed periodically though 802.1X protocol.
- TKIP y CCMP. Created from 802.11i, working group responsible of Wi-Fi security. TKIP has a encryption system similar to WEP with significant improvements. Thanks to WPA standard from WiFi Alliance, it is completely compatible with wireless cards backwards. However CCMP is only valid for new wireless cards due to its encoding mechanism.

All of these security protocols, with the exception of WEP, have been developed focused on a centralized architecture. Because of that, we can only implement layer-2 security using WEP and not WPA without compromising the partial connectivity requirement. Therefore it will be feasible to find additional mechanisms to improve security at higher levels as IPSec - VPN (layer 3), SSL (layer 4), SSH, NoCat (layer 7).

– Software distribution. We have developed an operating system, Pebble-EHAS, based in the Pebble minidistro. The total size of this version is around 77MB. It has all the networking tools necessary for routing (static in the first prototype), as well as DHCP, DNS and NTP servers, and a watchdog software. We have added a software PBX named Asterisk that supports VoIP-to-PSTN switching. All VoIP components in our networks use SIP, though Asterisk PBX communicates with peers using the propietary IAX protocol. The size mentioned before, 77MB, was not a critical aspect in the first prototype since the storage device used, a Compact Flash card, could be easily extended up to 512MB without important cost differences. However for the second prototype we are working with embedded computers whose storage device is based in Flash Memory. Due to the high cost of this kind of memory, the size of the operating system becomes more critical than in the case of CF storage and so it should be kept under 32MB. We are working now in the design of this system, building it from scratch with applications like busybox and tinylogin. It is also important to remark that in case we work with architectures different from x86 (p.e ARM or MIPS), we will have to cross-compile the software using a cross-compiling tool-chain.
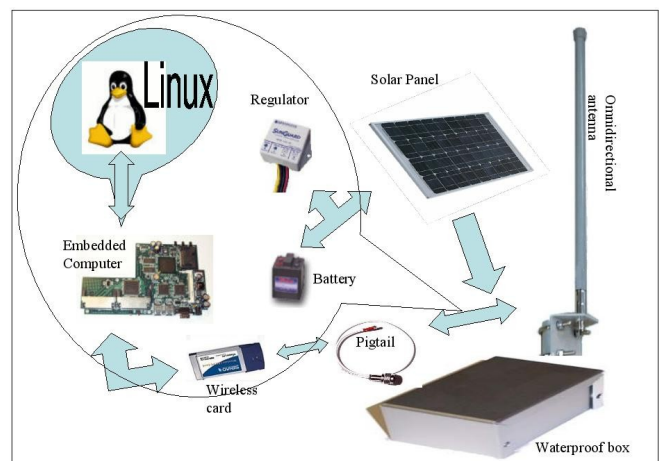

Figure 2: Design of the wireless solar-powered router

In Fig. 2 we show the scheme of the wireless router.

4 Results

The project is still under development in its second phase. However, partial results have been obtained already. The

network deployed in Peru has 15 nodes with point to point links up to 42Km long and point to multipoint links up to 20Km long for the farthest client. In this networks our first version has been successfully evaluated. It has been demonstrated that VoIP services are possible and compatible with data traffic in such a network if the network is not saturated. VoIP calls using SIP phones are possible from any point of the wireless network to the Internet or the PSTN, even through 7 wireless hops covering a total of 130Kms. However, as soon as the network gets saturated, VoIP calls are affected, specially in point to multipoint links. The results of QoS management in this second phase will permit eventually to guarantee the QoS to VoIP calls in all cases.

The power solar subsystem has been tested entirely but not in tropical climate. The routing using OLSR with ETX metrics has also be tested in laboratory with a few nodes (up to 6) and in shows a correct behaviour.

5   Discussion and future work

This work presents a wireless mesh network design using IEEE 802.11 for providing a voice and data communication infrastructure adapted to the requirements of isolated rural areas in developing countries.

A prototype of the design presented herein is still under development, but several aspects have already been successfully tested. It has been seen that the provision of VoIP telephony and access to public health information systems and e-learning in this scenarios has a very possitive impact in the quality of health assistance in deprived areas. However, most of aspects related with autoconfiguration have not been tested yet and their impact on the installation and maintenance of networks has not been evaluated yet.

Our future work will permit to complete the solution for IP autoconfiguration and an IP adaptative QoS management system.

References

[1] H. Badis and K. Al Agha. "QOLSR, QoS routing for Ad Hoc Wireless Networks Using OLSR". *European Transactions on Telecommunications*, Vol. 15, No. 4, 2005.

[2] C. J. Bernardos and M. Calderón. "Survey of IP address autoconfiguration mechanisms for MANETs", *draft-bernardos-manet-autoconf-survey-00* (Work-in-progress), July 2005.

[3] J. Bicket, D. Aguayo, S. Biswas and R. Morris. "Architecture and Evaluation of an Unplanned 802.11b Mesh Network". *In Proc. of Mobicom 2005*, August 2005.

[4] E. Brewer, M. Demmer, B. Du, K. Fall, M. Ho, M. Kam, S. Nedevschi, J. Pal, R. Patra, and S. Surana. "The Case for Technology for Developing Regions". *IEEE Computer,* Vol. 38, N. 6, pp. 25-38, June 2004.

[5] J. Broch et al. "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols". *In Proc. Mobicom'98*, 1998.

[6] T. Clausen, P. Jacquet. "Optimized Link State Routing Protocol (OLSR)". *IETF-RFC3626*, October 2003.

[7] D. S. J. de Couto et al. « Performance of Multihop Wireless Networks: Shortest Path is Not Enough". *ACM SIGCOMM Computer Communication Review*, Vol. 33, N. 1, January 2003.

[8] D. S. J. De Couto, D. Aguayo, J. Bicket, R. Morris. "A high-throughput path metric for multi-hop wireless routing". *In Proc. of ACM/IEEE Mobicom '03,* September 2003.

[9] IETF. "RFC 2461: Neighbor Discovery for IP Version 6 (Ipv6)".

[10] IETF. "RFC 2462: IPv6 Stateless Address Autoconfiguration".

[11] IETF. "RFC 3315: Dynamic Host Configuration Protocol for IPv6 (DHCPv6)".

[12] D. B. Johnson, D. A. Maltz and Y.C. Hu. "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)". *Internet-Draft manetdsr-10.txt*, July 2004.

[13] A. Martínez, V. Villarroel, J. Seoane, F. del Pozo, "Rural Telemedicine for Primary Healthcare in Developing Countries"*, IEEE Technology and Society Magazine*, Vol. 23, N. 2, Summer 2004.

[14] A. Martínez, V. Villarroel, J. Seoane, F. del Pozo, "Analysis of information and communication needs in rural primary healthcare in developing countries", *IEEE transactions on Information Technology in Biomedicine*, Vol. 9, N. 1, March 2005.

[15] K. Mase. "NOA OLSR specifications", *draft-mase-manet-autoconf-noaolsr*.

[16] C. Perkins. E. Belding-Royer and S. Das. "Ad hoc On-Demand Distance Vector (AODV) Routing". *IETF-RFC3561*, July 2003.

[17] J. Simó, J. Seoane, R. Salazar, "A QoS-aware Ad-Hoc Wireless Network for Isolated Rural Environements", *In Proc. of EUNICE 2005*, July 2005.

[18] C. Tschudin, R. Gold, O. Rensfelt and O. Wibling. "LUNAR: a Lightweight Underlay Network Ad-hoc Routing Protocol and Implementation". *In Proc of NEW2AN'04*, St. Petersburg, February 2004.

[19] K. Weniger. "PACMAN: Passive Autoconfiguration for Mobile Ad hoc Networks". *IEEE JSAC,* Special Issue 'Wireless Ad hoc Networks', March 2005.