A multi-hop MANET demonstrator tested on real-time applications

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ABSTRACT

In this paper we illustrate the implementation of an actual MANET demonstrator, based on off-the-shelf PDA devices with IEEE 802.11b wireless connectivity, tested on real-time applications.

The most critical aspect affecting performances, in our opinion, is related to create a network where connectivity among nodes is as stable as possible.

We implemented an enhanced version of the AODV protocol by embedding routing policies in order to choose routes based on link stability evaluation and show the effectiveness of this approach by means of simulations.

Finally we describe the demonstration phases in a mixed indoor/outdoor environment.

Keywords: MANET, VoIP, demonstrator

1 INTRODUCTION

Routing in mobile ad hoc networks (MANETs) has been widely studied by means of simulations, often hypotizing the use of IEEE 802.11b technology for the physical and MAC layers. Several protocols and various optimizations have been proposed, but only a few works describe how the implementation of these protocols impacts on real testbeds (see e.g. [1]).

MANETs are characterized by dynamic and unpredictable topology and it has been shown in [2][3] that reactive routing protocols like popular AODV [4] and DSR [5] are well suited to this kind of environment where nodes move (almost) randomly. They cope with topology changes by requesting routes only when needed and, as a consequence, they limit the number of transmissions of control packets saving powerlife of battery-constrained nodes.

One of the most popular approaches to optimize performances and reduce power consumption at the same time, is make the nodes, that act as routers, aware of the neighbours positional attributes (i.e. relative position and speed) [6].

The basic idea is to relate link stability to the relative distance between nodes: the nearer the nodes the stabler the hop. In our opinion, although this approach may lead to significant simulation results, it is not easily implementable in the real world. The location-awareness founding hypothesis, in fact, is severely limited by the extremely variable nature of the wireless channel (especially indoors). Besides obstacles that modify the propagation environment are usually not taken into account in simulations.

However, inspired by a GPS-less location-aware mechanisms, we propose a different approach and try to evaluate the link stability through continuous channel conditions monitoring in order to provide effectively reliable routes. The choice of the best route should be done trying to optimize the power consumption and simultaneously trying to enhance the network performances (e.g. minimizing end-to-end - E2E - delay and/or maximizing the throughput).

Scope of this work is evaluating how these critical parameters are influenced by the route choice; in particular we develop and explore a method that considers link stability in order to provide more reliable routes instead of using the usual shortest path approach.

The work has been carried out on two tracks: first, the algorithm proposed has been tested on a network simulator in order to compare the results with pure AODV and validate the performance enhancements; second, the algorithm has been implemented on a real demonstrator based on PDA devices in order to highlight limits and problems that are not visible in simulations.

The paper is organized as follows: next Section describes the proposed approach and the modifications needed on the routing protocol; simulation results are shown in Section III. Demonstration phases and related hardware equipment and installed software are presented in Section IV and conclusions and future work are drawn in Section V.

2 LINK STABILITY APPROACH

In our research project, we focused on the Ad hoc On demand Distance Vector (AODV) protocol [4]. AODV is a routing protocol based on the mechanisms of “Route Discovery” and “Route Maintenance” to reach arbitrary destinations in the ad hoc network. Route discovery is performed by iteratively broadcasting a Route Request (RREQ) packet, while Route Reply (RREP) packets are waited to establish a path. When a link break is detected by a node a Route Error (RERR) packet is used to notify other nodes.

In order to limit the number of control messages, thus increasing throughput and decreasing end-to-end delay, it is necessary to choose routes that are stable. In our implementation, derived from the AODV-UU (Uppsala University) implementation [7], we introduce a scheduling algorithm where RREP transmission delay is inversely proportional to the “stability” (or lifetime) perceived from that link thus favoring the creation of stable routes.

Prediction of the link lifetime, that is the time during which the wireless communication channel between two mobile nodes stays up, is performed by measuring the signal level when receiving data or control packets from neighbours. We exploited the Wireless Extensions APIs of the installed Linux distribution that allows the driver to expose to the user space statistics and configuration parameters of the specific WLAN card device.

The algorithm works as follows: after monitoring the signal levels received from the last three packets, said P_x the power registered at time t_x (where $x = 1, 2, 3$ and $t_1 < t_2 < t_3$), if $P_3 < P_2 < P_1$ we assume that the link is becoming more and more unstable and we calculate the mean link lifetime T according to the formula shown in [1]:

$$T = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{1}$$

where:

$$\begin{aligned}
a &= t^2 \sqrt{P_2 P_s} \beta \\
b &= \sqrt{P_s} \left(\left(\sqrt{P_1} - \sqrt{P_2} \right) - t_2 \sqrt{P_2} \beta \right) \\
c &= t_2 \sqrt{P_2 \left(P_s - P_1 \right)} \\
\beta &= \frac{\sqrt{P_1 P_2} t_2 + \sqrt{P_2 P_3} t_3 - \sqrt{P_1 P_3} t_3 - \sqrt{P_2 P_3} t_2}{\left(t^2 t_3^2 - t_3 t_2^2 \right) \sqrt{P_2 P_3}}
\end{aligned}$$

and P_s is the sensibility threshold, that is the power level under which the signal cannot be detected.

In every other case we assume the link stable and, in order to reduce the computational load on PDA devices, we predict the link stability (i.e. T) according to an heuristic threshold-based algorithm (shown below).

```
If     P > -46 dBm then T = 120 s
Elseif P > -56 dBm then T = 60 s
Elseif P > -66 dBm then T = 40 s
Elseif P > -76 dBm then T = 10 s
Else T = 0
```

It considers only the last signal level received, P, and the reference power level thesholds have been extrapolated from several measurements we made in the office environment shown in Figure 2(b).

Once the link lifetime T is calculated, the RREQ delay is set according to the following algorithm.

```
T = LIFETIME = f(SNR)
If T > T1 # very-stable-link
Delay = U(0,t1)
elseif T > T2 # stable-link
Delay = t1 + U(0,t1)
elseif T > T3 # weak-link
Delay = 2 x t1 + U(0,t1)
elseif T > T4 # very-weak-link
Delay = 3 x t1 + U(0,t1)
else drop(RREQ) # unstable-link
```

Where $t_1 = 1ms$, is the base time of delay and a uniform random delay has been added to prevent the broadcast storming problem [8].

Table 1: Simulation parameters

Parameter	**Value**		
Node speed	Uniform distributed: $0 - 10\frac{m}{s}$		
Transmission range	$R = 250m$		
Time thresholds	$T_1 = 160s$	$T_2 = 80s$	$T_3 = 60s$
N^o of nodes	10		
N^o of traffic sources	5		
Packet size	512 Bytes		
Packet rate	$8\frac{packet}{s}$		
Actual simulation time	$900s$		
Simulation area	$1000 \times 800 (m \times m)$		

3 SIMULATION RESULTS

In order to verify the effectiveness of our approach, we tested it on several simulations using the NS-2 network simulator [9] performing comparisons between the standard AODV behaviour and our modified protocol that we called L-AODV.

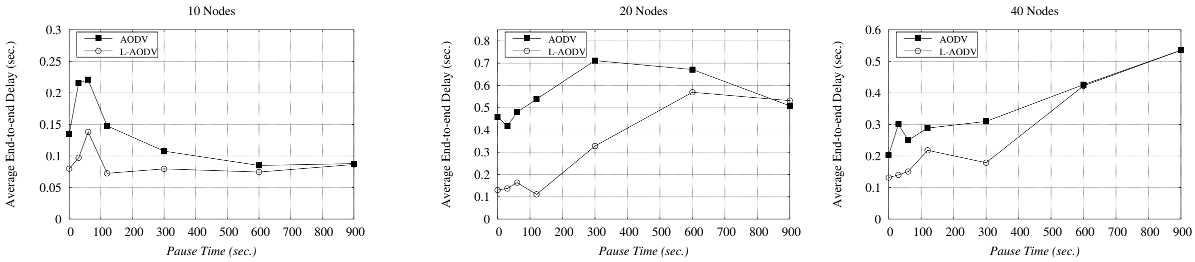
The following three metrics have been considered:

- Packet Delivery Ratio (PDR)
- Average End-to-End (E2E) Delay: it takes into account the delay in the send buffer, the delay in the interface queue, the bandwidth contention delay at the data link layer and the propagation delay.
- Normalized Routing Overhead (NRO): number of routing control messages (RREQ, RREP, RERR) transmitted with respect to the number of data packets delivered.

Simulation parameters are shown in Table 1; a rectangular area has been chosen in order to force the use of longer routes between nodes than would occur in a square area with equal node density. Besides, in order to remove the so called “initialization problem” [10], before starting the real simulation a transitory initial phase of 3600 seconds has been cut off.

We experienced that one of the most critical factors influencing simulation results, in particular when small number of nodes are considered, is the mobility model. In order to create a simulation environment with similar characteristics to those of the demonstration described in next sections, we developed a mixed model using Random Waypoint for nodes moving inside a square area (smaller than the simulation area) representing a building and a Manhattan model [10] for nodes moving outside.

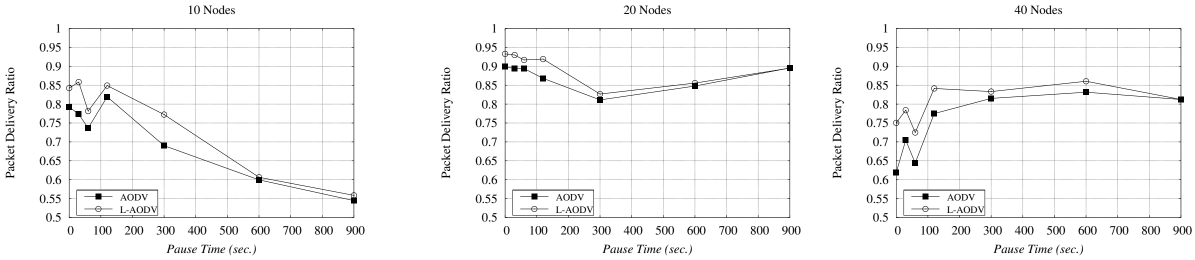
Results are shown in Figure 1 as a function of the pause time of the mobility model. Pause time is an index of the dynamicity of the network topology: the higher the pause time the more static the topology. Figure 1(a)(b)(c) shows the variation of the average E2E delay, Figure 1(d)(e)(f) shows the variation of the PDR and Figure 1(g)(h)(i) shows the variation of the NRO increasing node density. It can be seen that the modified protocol offers superior performances compared



(a) Average E2E delay (10 nodes)

(b) Average E2E delay (20 nodes)

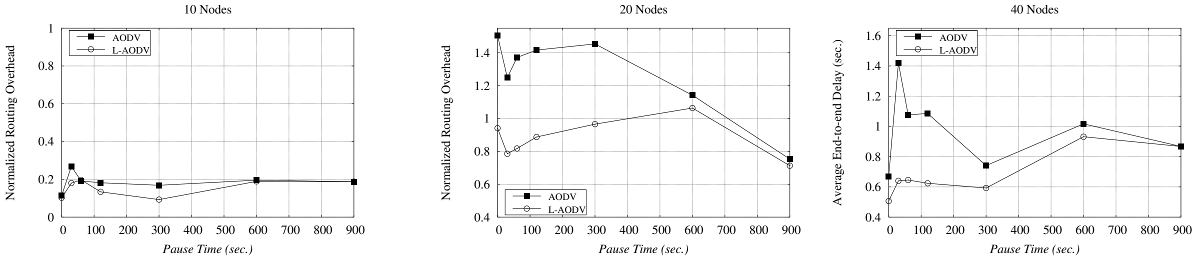
(c) Average E2E delay (40 nodes)



(d) Packet Delivery Ratio (10 nodes)

(e) Packet Delivery Ratio (20 nodes)

(f) Packet Delivery Ratio (40 nodes)



(g) Normalized Routing Overhead (10 nodes)

(h) Normalized Routing Overhead (20 nodes)

(i) Normalized Routing Overhead (40 nodes)

Figure 1: Simulation results varying node density

to unmodified AODV. These enhancements are mainly due to the more effective route discovery phase that insures that fewer route breakages will occur during packets' transmissions.

As expected the same trends, with better performances due to higher connectivity, have been experienced also increasing the node density. Finally it should be noticed that when the topology is static for most of the time (that is when topology change rate is significantly higher than the average route maintainance rate) the standard and the modified version of the protocol have similar performances.

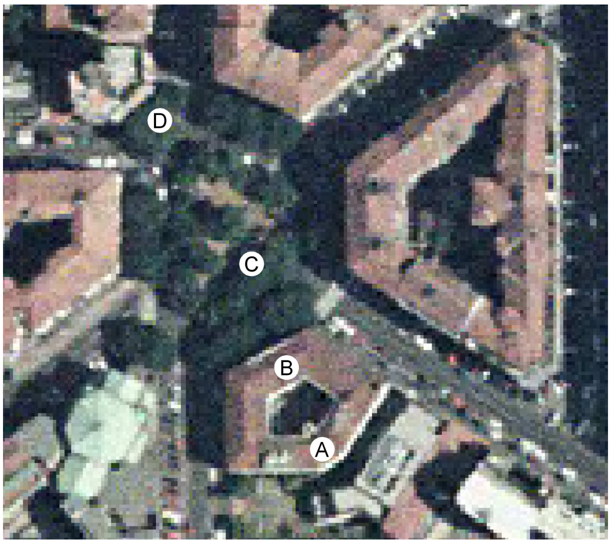
4 DEMONSTRATION DESCRIPTION

4.1 Demonstration phases

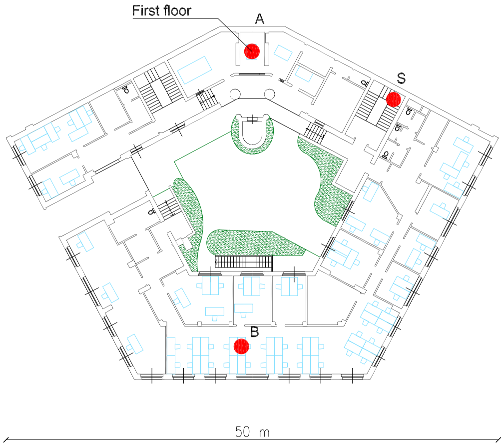
Demonstration consisted in testing two real-time applications in the mixed indoor/outdoor environment shown in Figure 2(a) and Figure 2(b) where several reference points are highlighted. First trial is a VoIP call established and monitored during the various steps described hereunder; second trial is an audio streaming between the nodes **A** and **D** in the configuration shown in Figure 2(a). The choice of using a VoIP call and a real-time audio streaming as test applications is mainly related to have a direct experience, from an end user point of view, of the transmission quality, in particular considering delay and jitter.

The first step is aimed at verifying the MANET capability of self-discover the network topology. PDAs are switched on and routing module is loaded: by exchanging HELLO packets, each node determines connectivity with direct neighborhood. We have tuned both the parameters' values in the AODV code to better suite the network characteristics, and the configuration parameters of the routing module aiming at determining the optimal number of HELLO packets needed in order to consider the link sufficiently stable. After several attempts with nodes deployed as shown in Figure 2(a), we found that the value of three is a good trade-off between the number of packets received and the rapidity of the convergence in the routing table also in a high multipath environment as those in the demonstration.

This step did never create problems: routing module always adapted rapidly to changes in topology and no nodes were isolated in the simulation area because the node density was sufficient. Node density is strongly related to the radio coverage as a function of the transmission range com-



(a) Aerial overview of the demonstration area



(b) CEFRIEL plan details: propagation environment in the building is very harsh

Figure 2: Simulation environment

pared to the simulation area, the number of nodes, the antenna radiation diagram and gain and the propagation environment (multipath) characteristics.

After this preliminary phase with nodes in fixed positions, we repeated the topology discovery phase in a dynamic way with nodes moving at pedestrian speed starting from marker **A** and reaching the foreseen positions. In particular, the call is firstly established between two nodes in direct radio visibility (see marker **A** in Figure 2(b)). Then, one of the two nodes moved away and passed by the stairwell (marker **S** in Figure 2(b)) where we experienced radio isolation. In this case, without perceptible loose in intellegibility, we registered that the call has been rerouted towards a common neighbor (placed in position **B** in Figure 2(b)) building a two-hop path.

In the third phase of the demonstration we wanted to verify the loss in quality due to routing the bit stream over an alternative path because of a sudden death of an intermediate node. While the call was still up between nodes in position **A** and **C**, through the node in position **B** (see Figure 2(a)), we placed another node around position **B** and then we switched-off the former intermediate router. We registered the fact that the bit stream automatically redirected to the other router without no perceptible loss in intellegibility during the call.

Table 2: Delay measurements

Segment	Average (s)	Std.Dev. (s)
A-B	0.0454	0.0088
B-C	0.0460	0.0108
C-D	0.0454	0.0089

Finally we incremented by one the number of intermediate routers in order to stress the multi-hopping capability. The called node moved towards position **D** in Figure 2(a) while a second node was placed in position **C**. In this case, we experienced a noticeable loss in performances due to packet loss and delays. The main reasons for this behaviour in our opinion should be attributed to the high multipath due to parked car and traffic and, of course, to the not optimized AODV code.

For that it concerns the audio streaming test, we considered the nodes in the positions shown in Figure 2(a). The quality (i.e. intellegibility) perceived was comparable to that of the VoIP call. The results of the delay and jitter measurments we made in this configuration are summarized in Table 2.

We then estimate that the maximum number of hops for VoIP calls with this hardware and software is only 3 if we assume that the processing capabilities are constant and we refer to an end-to-end delay upper bound of 150 ms for interactive voice applications [11].

4.2 Equipment & demonstration environment

For the demonstration we used the following hardware and software (see Figure 3(a) and 3(b)):

- 5 HP iPAQ h5500 Personal Digital Assistants (PDAs): 400 MHz Intel XScale technology processor, 128MB RAM, integrated WLAN 802.11b card and 920mAh lithium-ion battery.
- PC card expansion pack with supplementary 920mAh lithium-ion battery
- Avaya Silver 802.11b PCMCIA WLAN cards: data rate of 2Mbit/s has been set to achieve a more robust channel coding.
- ARTEM omnidirectional antennas [12]: these antennas have been necessary because we found that the PDA integrated antenna was not very performing; besides the WLAN card integrated antenna has an asymmetric radiation diagram optimized for a horizontal deployment, that is not suitable for our purposes.

Each PDA runs the Linux Familiar Operating System. The routing protocol is implemented in user space and loaded as a

```
~ # ping 192.168.0.51
PING 192.168.0.51 (192.168.0.51): 56 data bytes
64 bytes from 192.168.0.51: icmp_seq=0 ttl=63 time=48.3 ms
64 bytes from 192.168.0.51: icmp_seq=1 ttl=63 time=17.4 ms
64 bytes from 192.168.0.51: icmp_seq=2 ttl=63 time=15.8 ms

--- 192.168.0.51 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max = 15.8/27.1/48.3 ms
~ # route
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
192.168.0.57    *               255.255.255.255 UH    1      0        0 eth0
192.168.0.51    192.168.0.57    255.255.255.255 UGH   2      0        0 eth0
192.168.0.0     *               255.255.255.0   U     0      0        0 eth0
~ # ps -fade
  PID  Uid     VmSize Stat Command
    1 root        500 S   init [2]
    2 root            SW  [keventd]
    3 root            SWN [ksoftirqd_CPU0]
    4 root            SW  [kswapd]
    5 root            SW  [bdflush]
    6 root            SW  [kupdated]
    7 root            SW  [mtdblockd]
    8 root            SWN [jffs2_gcd_mtd1]
   85 root            SW  [khubd]
  116 root            SW  [kapmd]
  163 root            SW  [kusb-ethd]
  321 root        540 S   /sbin/syslogd -n -C
  323 root        528 S   /sbin/klogd -n
  332 root        556 S   /usr/sbin/dropbear
  341 root        416 S   [portmap]
  376 root        688 S   /sbin/cardmgr
  395 root        576 S   /bin/sh /etc/rc2.d/S98opie start
  399 root       2440 S   /opt/QtPalmtop/bin/opie-login
  400 root        620 S   logger
  465 root        544 S   -sh /opt/QtPalmtop/share/opie-login/opie-session
  491 root       7308 S   /opt/QtPalmtop/bin/qpe
  492 root       4008 S N quicklauncher
  509 root        788 S   -sh
 1162 root        568 S   aodvd -i eth0 -d
```

(a) A MANET node

(b) Routing table and processes running on the node

Figure 3: Hardware and software details

specific module. VoIP calls have been established using Linphone, a web-phone SIP compliant, using G711-μlaw codec.

5 CONCLUSIONS AND FUTURE WORK

In this paper we focused on the implementation of a MANET demonstrator. A traditional routing protocol like AODV has been tuned and partially modified to better fit system requirements.

We validated the effectiveness of our proposed approach by simulations and we illustrated the phases of the demonstration highlighting practical implementation problems and technical solutions.

In the future we are going to carry out activities along two directions: for that it concerns routing protocol optimization we want to enhance the route stability approach by including power-aware-based metrics in order to increase the network lifetime. On the other hand we want to test performances of the MANET testbed using, and mixing, different layer 1-2 technologies (e.g. Bluetooth, sensors, IEEE 802.11a/g) performing extended measurements campaigns under different scenarios.

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