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PERFORMANCE EVALUATION OF MANET ROUTING PROTOCOLS: SIMULATIONS AND EXPERIMENTS

Makoto Ikeda, Leonard Barolli

Department of Information and Communication Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811–0295, Japan
e-mail: makoto.ikd@acm.org, barolli@fit.ac.jp

Masahiro Hiyama, Elis Kulla

Graduate School of Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811–0295, Japan
e-mail: masahiro.hiyama@gmail.com, eliskulla@yahoo.com

Makoto Takizawa

Department of Computers and Information Science
Seikei University
3-3-1 Kichijoji-Kitamachi, Musashino-Shi, Tokyo 180–8633, Japan
e-mail: makoto.takizawa@computer.org

Abstract. A Mobile Ad hoc Network (MANET) is a collection of wireless mobile terminals that are able to dynamically form a temporary network without any aid from fixed infrastructure or centralized administration. In this paper, we present the implementation and analysis of our implemented MANET testbed and simulation system considering Ad-hoc On demand Distance Vector (AODV) and Optimized Link State Routing (OLSR) protocols for wireless multi-hop networking. We investigate the effect of mobility and topology changing in MANET. We evaluate and compare the performance by simulation (using ns-2 simulator) and experiments in a real environment. In this work, we consider two models: stationary and mobile.

We assess the performance of our testbed and simulation in terms of throughput, number of received packets and hop distance. From the results, we found that the AODV protocol has a good performance when the relay node is moving. Also, the AODV protocol provides a flexible and effective routing for indoor environments.

Keywords: MANET, Testbed, ns-2, AODV, OLSR

Mathematics Subject Classification 2000: 68M20, 68M12, 68U20, 62K99

1 INTRODUCTION

A Mobile Ad hoc Network (MANET) is a collection of wireless mobile terminals that are able to dynamically form a temporary network without any aid from fixed infrastructure or centralized administration. In recent years, MANETs are continuing to attract the attention for their potential use in several fields. Mobility and the absence of any fixed infrastructure make MANET very attractive for mobility and rescue operations and time-critical applications. So far, most of the work for MANETs has been done in simulation, as in general, a simulator can give a quick and inexpensive understanding of protocols and algorithms. However, experimentation in the real world is very important to verify the simulation results and to revise the models implemented in the simulator. A typical example of this approach has revealed many aspects of IEEE 802.11, like the gray-zones effect [1], which usually are not taken into account in standard simulators, such as the well-known *ns-2* simulator [2]. So far, we can count a lot of computer simulation results on the performance of MANET, e.g. in terms of end-to-end throughput, delay and packet loss. However, in order to assess the computer simulation results, real-world experiments are needed and a lot of testbeds have been built to date [3]. The baseline criteria usually used in real-world experiments is guaranteeing the repeatability of tests, i.e. if the system does not change along the experiments. How to define a change in the system is not a trivial problem in MANET, especially if the nodes are mobile.

In this paper, we focus on comparing the performance of two types of routing algorithms Ad-hoc On demand Distance Vector (AODV), which is a reactive routing protocol and Optimized Link State Routing (OLSR), which is a proactive link-state routing protocol. Both protocols have been gaining great attention within the scientific community. Furthermore, the *aodv-uu* [4] and the *olsrd* [5] software we have used in our experiments are the most updated software we have encountered.

In our previous work, we found the following results. We proved that while some of the OLSR's problems can be solved, for instance the routing loop, this protocol still has the self-interference problem. There is an intricate inter-dependence between MAC layer and routing layer, which can lead the experimenter to misunderstand the results of the experiments. For example, the horizon is not caused only by IEEE 802.11 Distributed Coordination Function (DCF), but also by the routing protocol. We carried out the experiments considering stationary nodes of ad-hoc network. We considered the node mobility and carried out experiments for OLSR and B.A.T.M.A.N. protocols [6]. We found that throughput of TCP was improved by reducing Link Quality Window Size (LQWS), but there was packet loss because of experimental environment and traffic interference. For TCP data flow, we got better results when the LQWS value was 10. Moreover, we found that the node join and leave operations affect more the TCP throughput and RTT than UDP [7].

In this work, we compare the performance of two types of routing algorithms, namely AODV and OLSR. We implemented two MANET models and carried out real world experiments and simulations for different topologies. We compare the performance of the testbed for two scenarios: stationary (STA) and moving (MOVE). Furthermore, we compare the experimental results with the simulations.

The structure of the paper is as follows. In Section 2, we present the related work. In Section 3, we give a short description of OLSR and AODV. In Section 4, we present the testbed and computer simulation design and implementation. In Section 5, we show experimental and simulation results. Finally, conclusions are given in Section 6.

2 RELATED WORK

Many researchers performed valuable research in the area of wireless multi-hop network by real world experiments or computer simulations [8, 9]. Most of them are focused on throughput improvement, but they do not consider mobility [10]. In [11], the authors implemented multi-hop mesh network called MIT Roofnet. Roofnet consists of about 50 nodes. They consider the impact of node density and connectivity in the network performance. The authors show that the multi-hop link is better than single hop link in terms of throughput and connectivity. In [12], the authors analyzed the performance of an outdoor ad-hoc network, but their study is limited to reactive protocols such as AODV [13] and Dynamic Source Routing (DSR) [14]. The authors of [15] perform outdoor experiments of non standard pro-active protocols. Other ad-hoc experiments are limited to identify MAC problems by providing insights on the one-hop MAC dynamics as shown in [16].

A similar work to ours is that in [17]. However, the authors did not care about the routing protocol. In [18], the disadvantage of using hysteresis routing metric is presented through simulation and indoor measurements. Our experiments are concerned with the interaction of transport protocols and routing protocol.

In [19], the authors present an experimental comparison of OLSR using the standard hysteresis routing metric and the Expected Transmission Count (ETX) metric in a 7 by 7 grid of closely spaced Wi-Fi nodes to obtain more realistic results. The throughput results are similar to our previous work and are affected by hop distance [20, 21].

3 ROUTING PROTOCOLS

3.1 OLSR

The link state routing protocol that is most popular today in the open source world is OLSR from *olsr.org*. OLSR with Link Quality (LQ) extension and fisheye-algorithm works quite well. The OLSR protocol is a pro-active routing protocol, which builds up a route for data transmission by maintaining a routing table inside every node of the network. The routing table is computed upon the knowledge of topology information, which is exchanged by means of Topology Control (TC) packets. OLSR makes use of `HELLO` messages to find its one hop neighbors and its two hop neighbors through their responses. The sender can then select its Multi Point Relays (MPR) based on the one hop node which offers the best routes to the two hop nodes. By this way, the amount of control traffic can be reduced. Each node has also an MPR selector set which enumerates nodes that have selected it as an MPR node. OLSR uses TC messages along with MPR forwarding to disseminate neighbor information throughout the network. Host Network Address (HNA) messages are used by OLSR to disseminate network route advertisements in the same way TC messages advertise host routes.

In our OLSR code, a simple RFC-compliant heuristic is used to compute the MPR nodes [22]. Every node computes the path towards a destination by means of a simple shortest-path algorithm, with hop-count as target metric. In this way, a shortest path can result to be also not good, from the point of view of the packet error rate. Accordingly, recently *olsrd* has been equipped with the LQ extension, which is a shortest-path algorithm with the average of the packet error rate as metric. This metric is commonly called the ETX, which is defined as ETX(i) $= 1/(NI(i) \times LQI(i))$. Given a sampling window W, NI(i) is the packet arrival rate seen by a node on the i-th link during W. Similarly, LQI(i) is the estimation of the packet arrival rate seen by the neighbor node which uses the i-th link. When the link has a low packet error rate, the ETX metric is higher. The LQ extension greatly enhances the packet delivery ratio with respect to the hysteresis-based technique [23].

3.2 AODV

AODV is a combination of both DSR and DSDV protocols. It has the basic route discovery and route maintenance of DSR and uses the hop by hop routing, sequence numbers and beacons of DSDV. The node that wants to know a route to a given destination generates a Route Request (RREQ). The RREQ is forwarded by intermediate node that also creates a reverse route for itself from the destination. When the request reaches a node with route to destination it generates a Route Reply (RREP) containing the number of hops required to reach destination. All nodes that participate in forwarding this reply to the source node create a forward route to destination. This state created from each node from source to destination is a hop by hop state and not the entire route as is done in source routing.

In our AODV code, a simple RFC-compliant heuristic is used [13]. AODV-UU [4] is an AODV routing protocol implementation developed at Uppsala University. It runs in a user space on the Linux operating system or in the ns-2 simulation environment. AODV discovers routes on demand. Therefore, AODV-UU needs to intercept any packets to a destination for which there is no route, so that the packets can be buffered, while a route RREQ is disseminated. If packets are not intercepted, and allowed to continue their traversal of the networking stack, they will eventually generate any of the above described error messages, which can be fatal for connection oriented protocols like TCP.

4 TESTBED DESIGN AND IMPLEMENTATION

4.1 Target Environment

We have implemented a MANET testbed which provides a realistic platform for analyzing various aspect of these networks, including the different topology models. For our testbed, we make the following considerations.

- We consider an indoor environment at our departmental floor.
- We investigate the effect of mobility and topology changing in the performance of MANET.
- We constructed two experimental models: Model 1 (all nodes are in stationary state); Model 2 (only one relay node is moving).
- In order to make the experiments easier, we implemented a testbed interface and web tool.
- Experimental time is 100 seconds.

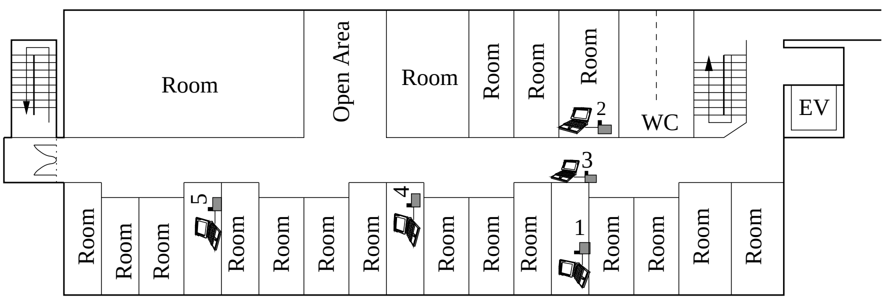


Fig. 1. STA model (using iptables). Node #1 is accessible via node #3. When the destination node is #2, the hop distance is 2, i.e. $1 \rightarrow 3 \rightarrow 2$.

Our testbed is composed of four laptops and one gateway (GW)[1] machine as shown in Figures 1 and 2. In Figure 1, all nodes are in a stationary state. We call

[1] GW node ID is #1.

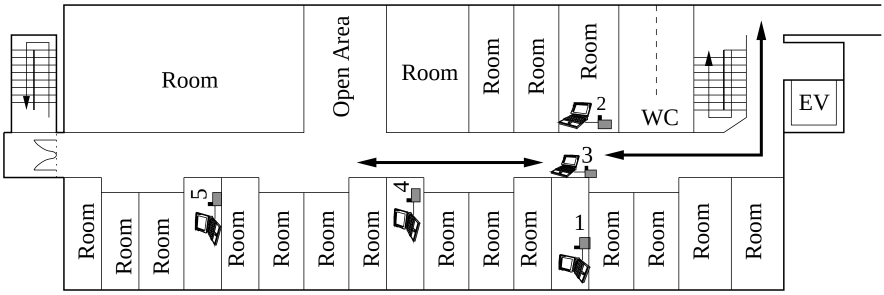
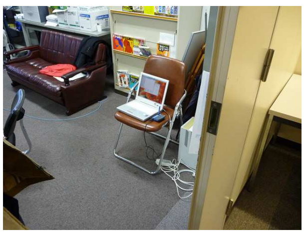


Fig. 2. MOVE model (using iptables). The packet filtering rule is the same as STA.

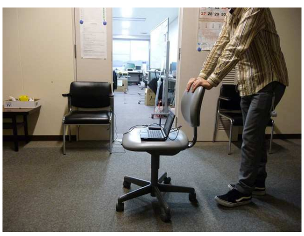
this model STA. The nodes' position and movement are shown in Figures 3 a)–f). In Figure 2, only one relay node (node id #3) is moving. The mobile node moves toward the destination at a regular speed. When the mobile node arrives at the corner, it stops for about three seconds (see Figure 3 d)). The round trip time is 100 seconds. We call this model MOVE.

a)



b)

c)



d)

e)

f)

Fig. 3. Snapshot of each node: a) Node ID #1, b) Node ID #2, c) Node ID #3 (STA), d) Node ID #3 (MOVE), e) Node ID #4, f) Node ID #5

4.2 Testbed Description

4.2.1 Operating System

The operating system mounted on these machines is Fedora Core 4 or eeeUbuntu 9.04 Linux with kernel 2.6.x, suitably modified in order to support the wireless cards. The wireless network cards are from Linksys. They are usb-based cards with an external antenna of 2 dBi gain, transmitted power of 16+/−1 dBm and receive sensitivity of −80 dBm. We verified that the external antenna improves the quality of the first hop link, which is the link connecting the ad-hoc network. The driver can be downloaded from the web site in references [24, 25][2].

4.2.2 Testbed Services

The source node serves as HTTP, FTP, DNS and Internet router for the nodes in the MANET. These features are provided by the `iptables` mechanism, readily available under Linux machines. The iptables is a user-space command line program used to configure the Linux 2.4.x and 2.6.x IPv4 packet filtering rule-set. By this way, the GW can be accessed ubiquitously from anywhere. Moreover, the GW hosts also all routines used to coordinate the measurement campaign, as well as graphical tools to check network connectivity. In our testbed, we have two systematic background or interference traffic we could not eliminate: the control traffic and the other wireless Access Points (APs) interspersed within the campus. The control traffic is due to the `ssh` program, which is used to remotely start and control the measurement software on the source node. The other traffic is a kind of interference, which is typical in an academic scenario.

4.2.3 Testbed Interface

Until now, all the parameters settings and editing were done by using command lines of bash shell (terminal), which resulted in many misprints and the experiments were repeated many times. In order to make the experiments easier, we implemented a testbed interface. The interface is shown in Figure 4. For the Graphical User Interface (GUI) we used wxWidgets tool and each operation is implemented by Perl language. wxWidgets is a cross-platform GUI and tools library for GTK, MS Windows and Mac OS X.

We implemented many parameters in the interface such as transmission duration, number of trials, source address, destination address, packet rate, packet size, LQWS, and topology setting function. We can save the data for these parameters in a text file and can manage the experimental conditions in a better way. Moreover, we implemented collection function of experimental data in order to make the experimenter's work easier.

[2] As far as we know the latest kernel includes rt2500usb driver. However, this driver does not work for ad-hoc mode.

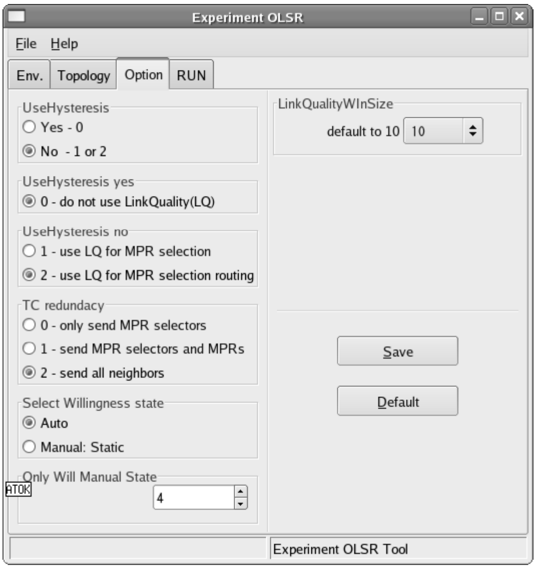


Fig. 4. GUI tool

4.3 Simulation Description

We used two mobile ad-hoc routing protocols: AODV and OLSR. We select parameters values according to the features of external antenna. In particular, for this antenna we found that for a carrier frequency of $f = 2.412\,\text{GHz}$, the data rate is $499.712\,\text{Kbps}$.

Ns-2 implements several propagation models (free space, two-ray ground, and shadowing models) to predict the signal power received by the receiver. We used shadowing model to simulate the 802.11b channel. Shadowing model simulates shadow effect between the transmitter and receiver. It is mainly used to simulate wireless channel in indoor environment.

The shadowing model consists of two parts. The first one is known as path loss model, which also predicts the mean received power at distance d, denoted by $\overline{P_r(d)}$. It uses a close-in distance d_0 as a reference. $\overline{P_r(d)}$ is computed relative to $P_r(d_0)$ as follows.

$$\frac{P_r(d_0)}{\overline{P_r(d)}} = \left(\frac{d}{d_0}\right)^{\beta} \tag{1}$$

β is called the path loss exponent, and is usually empirically determined by field measurement. The path loss is usually measured in dB. So, from Equation (1) we have:

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right). \tag{2}$$

The second part of the shadowing model reflects the variation of the received power at certain distance. It is a log-normal random variable, that is, it is a Gaussian distribution and is measured in dB. The overall shadowing model is represented by:

$$\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) + X_{dB} \tag{3}$$

where X_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB}. Equation (3) is also known as a log-normal shadowing model. The shadowing model extends the ideal circle model to a richer statistic model: nodes can only probabilistically communicate when they are near the edge of the communication range.

5 EXPERIMENTAL AND SIMULATION RESULTS

5.1 Settings

The experimental parameters are shown in Table 1. We evaluate and compare the performance through simulations (using ns-2) and experiments. We study the impact of best-effort traffic for STA and MOVE models. We collected data for three metrics: throughput, number of received packets and hop distance. These data are collected using the Distributed Internet Traffic Generator (D-ITG) [26], which is an open-source Internet traffic generator.

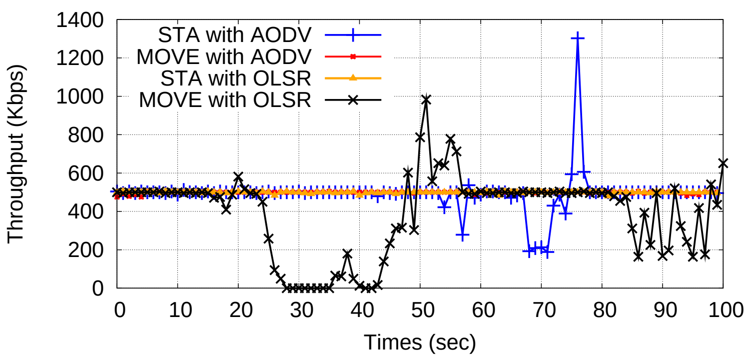
In previous experiments [6, 20, 27], we realized that an external antenna improves radio signal reception. The Constant Bit Rate (CBR) of the data flows is 122 pps which is equal to 499.712 Kbps, i.e. the packet size of the payload is 512 bytes. All experiments have been performed in indoor environment, within our departmental floor (the size roughly 100 meters). All nodes are in radio range of each other.

In our previous work, one experiment lasted about 10 seconds and was repeated 50 times. But, the experimental time was very short. For this reason, in this paper we set the experimental time about 100 seconds. Moreover, we set the packet rate of the CBR flows at 122 pps. We measured the throughput for UDP, which is computed at the receiver. We estimated the packet loss to compute the link quality metric LQ. For OLSR, $wT_{\text{HELLO}} < T_{\text{Exp}}$, where T_{Exp} is the total duration of the experiment, i.e., in our case, $T_{\text{Exp}} = 1\,000$ s, and T_{HELLO} is the rate of the HELLO messages. However, the testbed was turned on even in the absence of measurement traffic. Therefore, the effective T_{Exp} was much greater.

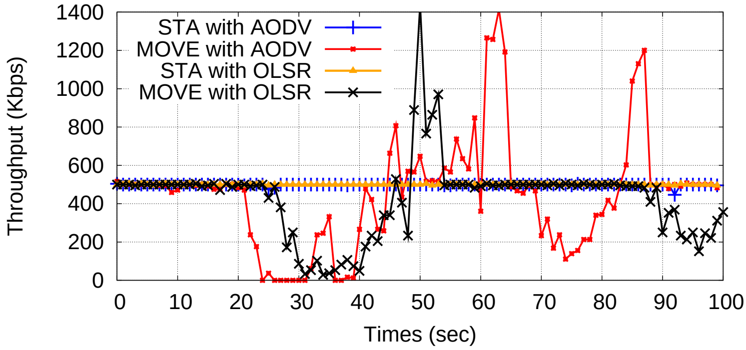
As MAC protocol, we used IEEE 802.11. The transmission power was set in order to guarantee a coverage radius equal to the maximum allowed geographical distance in the network. Since we were interested mainly in the performance of the routing protocol, we kept all MAC parameters unchanged, such as the carrier sense, the retransmission counter, the contention window and the Request to Send (RTS)/Clear to Send (CTS) threshold. Moreover, the channel central frequency was set to 2.412 GHz (channel 1). In regard to the interference, it is worth noting that, during our tests, almost all the IEEE 802.11 spectrum had been used by other APs disseminated within the campus. In general, the interference from other APs is a non-controllable parameter.

Parameters	**Values**
Propagation path loss model	Shadowing
Path loss coefficient β	2.7
Shadowing deviation σ_{dB}	4.0
Transmit power	0.031622777
Transmit antenna gain	1
Receive antenna gain	1
System loss	1
Carrier frequency (GHz)	2.412 GHz
Antenna	Omni
MAC	IEEE 802.11
MAC: dataRate_	11 Mbps
MAC: basicRate_	1 Mbps
Traffic type	CBR
Packet size	512 bytes
Packet rate	122 pps
Duration	100 000 msec
Number of nodes	5
Number of trials	10
Routing protocol	AODV and OLSR
OLSR: LQWS	10

Table 1. Radio model and system parameters



a)



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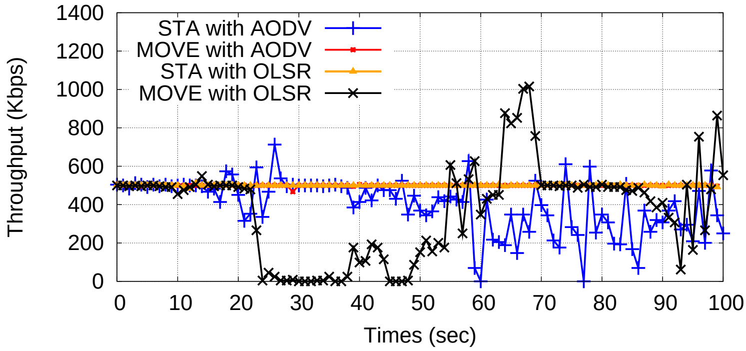

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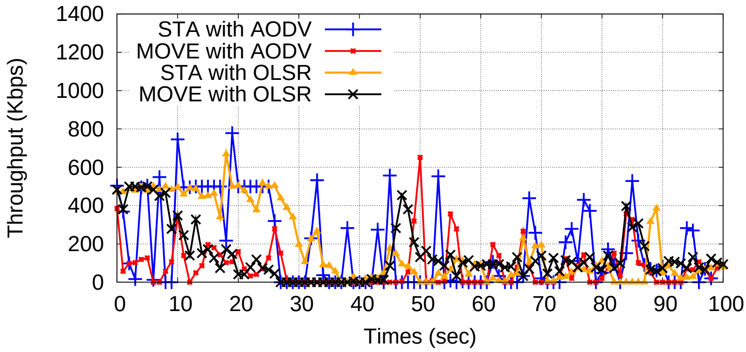
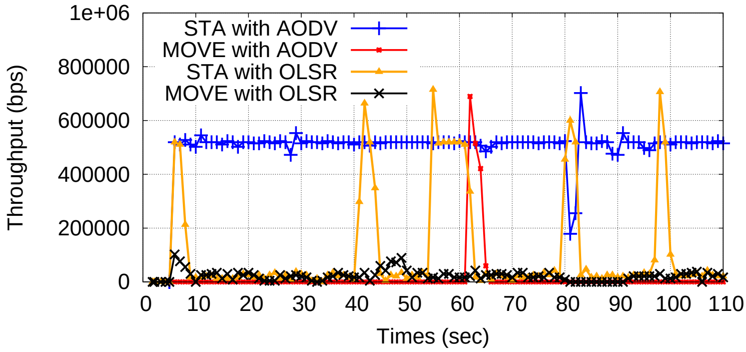


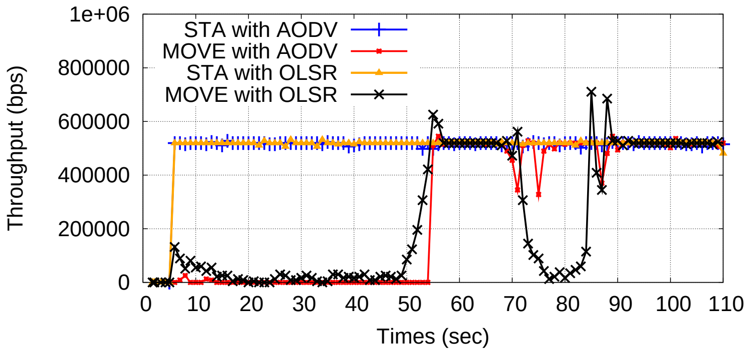
d)

Fig. 5. Throughput results of experiment: a) Source node #1 → destination node #2, b) Source node #1 → destination node #3, c) Source node #1 → destination node #4, d) Source node #1 → destination node #5



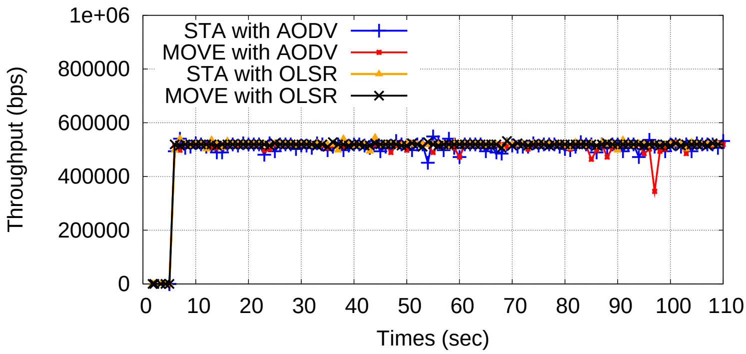
1e+06
800000
600000
400000
200000
0
Throughput (bps)
0 10 20 30 40 50 60 70 80 90 100 110
Times (sec)
STA with AODV
MOVE with AODV
STA with OLSR
MOVE with OLSR

a)



1e+06
800000
600000
400000
200000
0
Throughput (bps)
0 10 20 30 40 50 60 70 80 90 100 110
Times (sec)
STA with AODV
MOVE with AODV
STA with OLSR
MOVE with OLSR

b)



1e+06
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Throughput (bps)
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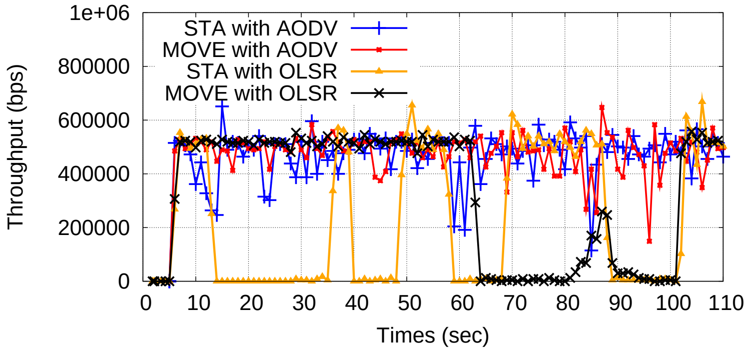
Times (sec)
STA with AODV
MOVE with AODV
STA with OLSR
MOVE with OLSR

c)



d)

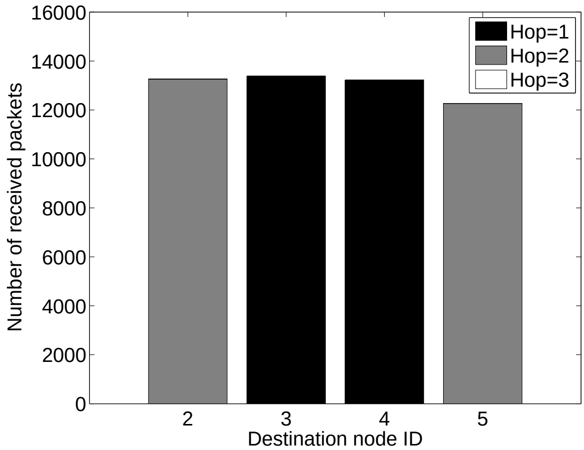
Fig. 6. Throughput results of simulation: a) Source node #1 → destination node #2, b) Source node #1 → destination node #3, c) Source node #1 → destination node #4, d) Source node #1 → destination node #5

5.2 Measurements

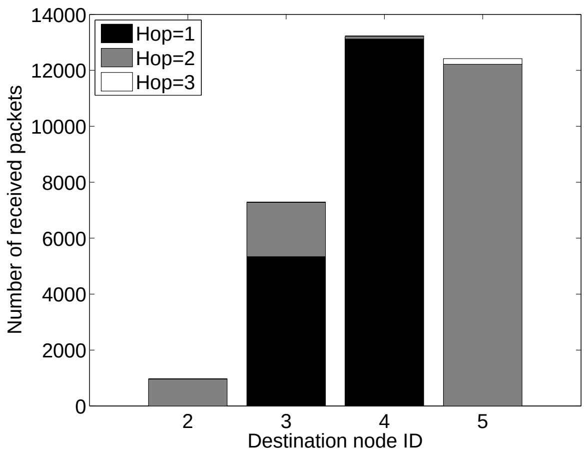
In Figures 5 and 6, the horizontal axis shows the time (sec) and the vertical axis shows the throughput (bps), which is computed at the receiver. We can see a stable CBR flow of STA model for both routing protocols; but, we found that the throughput was decreased for 1 → 5 and 1 → 2 flows. This is because of the hop distance and mobility effect. This fact shows that the OLSR chooses correctly 2-hop or 3-hop routes, i.e. 1 → 3 → 5 or 1 → 3 → 4 → 5. In MOVE case, OLSR often selects intermediate node #3, to reach the destination. So, we can see a lot of oscillations (see Figures 6 a), b), and d)). On the other hand, in Figure 6 c), we can see a stable CBR flow for each simulation model.

In all experimental results, when we used MOVE with OLSR routing protocol, we have a lot of oscillations. As shown in Figures 5 and 6, it seems that throughput is decreased much more than in the other cases. These oscillations are created by the routing mechanism, which is affected by the relay node movement. Especially with MPR selection proccess, it is not optimized for indoor scenarios. Therefore, the OLSR protocol needs to be equipped with more realistic topology control mechanism in order to be used in different scenarios. During this experiment, we got a lot of errors and could not communicate with node #5.

In Figure 7, the horizontal axis shows the destination node ID, while the vertical axis shows the number of received packets measured by simulation. From these simulation results, we see that the number of received packets and hop distance of AODV is higher than OLSR results. When the topology is very dynamic, the AODV provides a flexible and effective routing for indoor scenarios.



a)



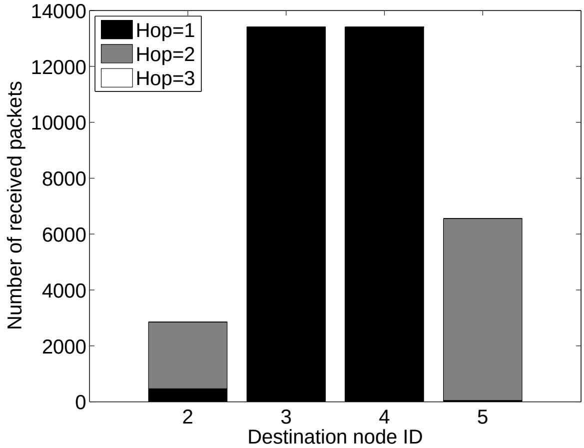
b)

6 CONCLUSIONS

In this paper, we carried out experiments and simulation for MANETs considering AODV and OLSR routing protocols. In our experiments, we considered two models: STA and MOVE. In STA, all nodes are in stationary state. In MOVE, one relay node is moving (every data flow has to relay via this moving node). We assessed the performance of our system in terms of throughput, number of received packets and hop distance.

From our evaluations, we found the following results.

- There were some oscillations in each model. This was because of hop distance and interferences of environment.



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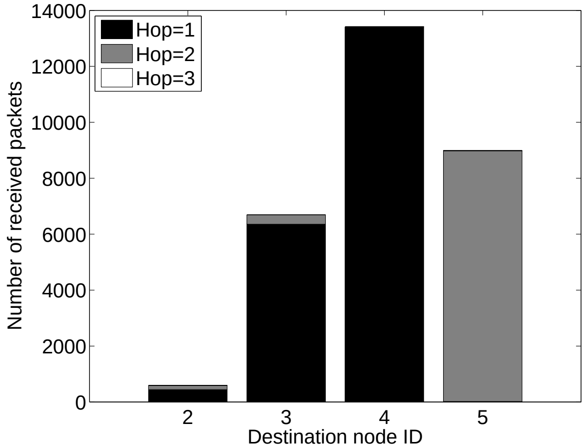

d)

Fig. 7. Hop distance for each model during simulation scenarios: a) STA with AODV, b) MOVE with AODV, c) STA with OLSR, d) MOVE with OLSR

- OLSR protocol showed a lot of oscillations.
- AODV protocol had a good performance when the relay node was moving.
- AODV protocol provides a flexible and effective routing for indoor environments.

These results were performed using AODV and OLSR routing protocol. In the future, we would like to consider new reactive protocols. Moreover, we would like to consider new link quality metrics and extend our testbed.

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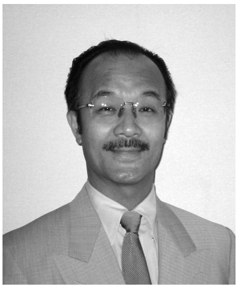
Makoto Ikeda is an Assistant Professor at Fukuoka Institute of Technology (FIT), Japan. He was a Research Fellow in the Center for Asian and Pacific Studies, Seikei University, from April 2010 to March 2011. He received Bc. E., M. E. and Ph. D. degrees in Information and Communication Engineering from Fukuoka Institute of Technology (FIT), Japan, in 2005, 2007, and 2010, respectively. He was a Japan Society for the Promotion of Science (JSPS) Research Fellow from April 2008 to March 2010. He has widely published in peer reviewed international journals and international conferences proceedings. He is a member of IEEE, ACM, IPSJ and IEICE. His research interests include wireless networks, mobile computing, high-speed networks, P2P computing, mobile ad hoc networks and wireless sensor networks.

Masahiro Hiyama is a Ph. D. student in the Graduate School of Engineering, Fukuoka Institute of Technology (FIT), in Japan. He received Bc. E. and M. E. degrees in Information and Communication Engineering from FIT in 2009 and 2011, respectively. His research interests include wireless networks, mobile computing and mobile ad-hoc networks. He is a student member of IEICE.

Elis Kulla is a Ph. D. student at the Graduate School of Engineering, Fukuoka Institute of Technology (FIT). He received Bc. E. and M. E. from Polytechnic University of Tirana (PUT), in 2007 and 2010 respectively. His research interests include ad-hoc networks, sensor networks and vehicular networks.

Leonard Barolli is a Full Professor in the Department of Information and Communication Engineering, Fukuoka Institute of Technology (FIT). He has published about 300 papers in referred Journals, books and international conference proceedings. He has served as Guest Editor for many international journals. He has been a PC Member, PC Chair and General Chair of many international conferences. He is the Steering Committee Chair of CISIS International Conference and is serving as Steering Committee Co-Chair of IEEE AINA, NBiS, BWCCA and 3PGCIC International Conferences. He has won many awards for his scientific work and has received many research funds. His research interests include network traffic control, fuzzy control, genetic algorithms, agent-based systems, ad-hoc networks and sensor networks. He is a member of IEEE, SOFT, and IPSJ.



Makoto Takizawa is a Professor in the Department of Computer and Information Science, Seikei University. He was a Professor and the Dean of the Graduate School of Science and Engineering, Tokyo Denki University. He was a Visiting Professor at GMD-IPSI, Keele University, and Xidian University. He was on the Board of Governors and a Golden Core member of IEEE CS and is a fellow of IPSJ. He received his DE in Computer Science from Tohoku University. He chaired many international conferences like IEEE ICDCS, ICPADS, and DEXA. He founded IEEE AINA. His research interests include distributed systems and computer networks.