AdHoc routing performance study using OPNET Modeler

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Abstract

A wireless Ad Hoc network is formed by a collection of nodes disposed in a dynamic way, without the need for a central node to coordinate them. This is one of the reasons why a great number of routing protocols for Ad Hoc networks are being developed. After the study of a set of them, this paper has subjected four different protocols to different scenario situations, in order to evaluate their performance and, from the detailed analysis of simulation results using OPNET Modeler, create a choice guide of a routing protocol for a given network scenario.

Introduction

Over the last years, mobility has become an important feature which needs to be supported by any kind of communication environment. As a result, traditional data networks do not represent the most appropriate interpretation of actual needs. Furthermore, technological achievements have made possible the development of new small and smart devices providing wireless abilities, and with little battery consumption.

MANETs (Mobile Ad Hoc NETworks) [11] [22] are wireless networks without the need of any kind of neither infrastructure nor centralized administration. Because of the direct communications that MANET nodes establish between them, stations composing a MANET operate not only as a final host but also as a router.

Many alternative solutions have been proposed and analyzed to solve the need for a routing algorithm in Ad Hoc networks [1] [2] [5] [8] [10] [14] [21]. However, there is not enough knowledge to make the choice in terms of performance.

This paper provides a comparative study, through simulation, of four routing protocols (DSR, TORA, AODV and OLSR) for mobile Ad Hoc networks (MANETs) using the well-known network simulator OPNET modeler, whose models include these algorithms. The main objective of this paper is to create a choice guide of a routing protocol for a given network scenario, based on the relative performance of the protocols under different scenarios. However, the overall contribution of the paper is still rather limited and the paper also doesn't provide complete evidence in support of its conclusions.

Prior to analyze the four proposals with the use of the simulator [4], an introductory study of them and its characteristics are presented.

Adhoc Routing Protocols

This section briefly describes the main features of the four protocols deeply studied using OPNET: OLSR, DSR, AODV and TORA.

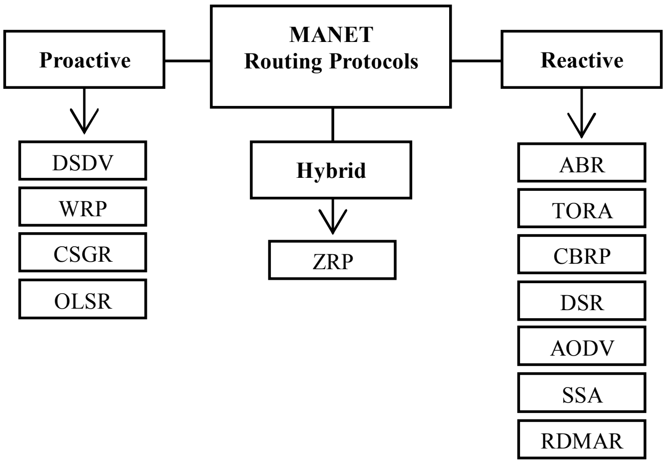

Fig. 1. MANET routing protocols

DSR [13] is an on-demand or reactive routing protocol which works on a source routing basis. Source routing prompts the source transmission node to determine an ordered list of intermediate nodes which would compose the complete route to the destination node. Each transmitted packet is then routed carrying the complete route in its header. Since the route is found in the packet, this routing mechanism exempts intermediate nodes from maintaining routing information to forward packets.

The protocol consists of two route-related processes: the route discovery process and the route maintenance one. Each node maintains a route cache. Whenever a source node wants to transmit a packet, it first checks its route cache for a route to the destination node. In case it is found, the node uses that one found. In case the node does not find any valid route to the destination, it starts the route discovery process.

In the route discovery process, the source node broadcasts a Route Request (RREQ) packet, which is flooded through intermediate nodes. Nodes without route to the destination append their addresses to the RREQ packet and rebroadcast it until it reaches the destination node or an intermediate node with a valid route to the destination. Then, it discards the RREQ packet received. The destination node (or the intermediate node with a valid route), upon received the RREQ packet, sends a Route Reply (RREP) packet to the source. It contains the complete route from the source node to the destination one.

Eavesdropping mechanism is an optional feature. It allows a node to learn routes included in the packets that retransmits or overhears. The improvement in terms of performance over the network achieved with this feature will be analyzed later.

Route cache expiry timer	300 s.
Node buffer expiry timer	30 s.
Send buffer size	Unlimited
Packet Salvaging	Enabled
Eavesdropping	Enabled

Table 1. OPNET simulation model parameters used for DSR

TORA [17] is an adaptive on-demand routing protocol designed to provide multiple loop-free routes to a destination, thus minimizing reaction to topological changes. The protocol belongs to the link reversal algorithm family set.

TORA is layered on the top of the Internet MANET Encapsulation Protocol (IMEP). TORA only provides a routing mechanism, relying on IMEP protocol for all the remaining underlying functions. Such functions are the following: link sensing, delivery of broadcast and control messages, resolution of IP addresses, addition of security mechanisms between routing devices and so on. IMEP was designed to dispose of a common protocol carrying out basic common features. In terms of performance, the idea generates much more overhead.

The process of creating routes basically assigns directions to links in an undirected network or portion, just building a Directed Acyclic Graph (DAG) routed at the destination, associating a height with each node in the network. All messages flow from nodes with higher height to nodes with a lower one.

When a node needs a route to a destination node, it broadcasts a QUERY (QRY) packet containing the destination address. This packet propagates through the network until it reaches the destination node or a node with a valid route to the destination. Then, this node broadcasts an UPDATE (UPD) packet containing its own height to the destination node. Every node receiving that UPD broadcast sets its height to a value higher than the one specified in the UPD packet. It results in a series of directed links from the source node to the destination node.

Operation mode	On-Demand
Node buffer expiry timer	10 s.
IMEP beacon time	1 s.
Beacon Timer	3
Maximum IMEP packet size	1.500 bytes

Table 2. OPNET simulation model parameters used for TORA

AODV [20] is an on-demand distance-vector routing protocol, based on hop-by-hop routing. It can be understood as a modified DSR protocol incorporating some features presented in the DSDV [18] protocol, such as the use of hop-by-hop routing, sequence numbers and periodic beacon messages. It also can be understood as a modified DSDV protocol, thus minimizing the broadcasting process, as the routes are created on demand.

Like DSR, in the route discovery process, the source node broadcasts a RREQ packet, but now includes the last known sequence number for the desired destination. The RREQ packet is flooded through intermediate nodes, which create a reverse route to the source node. The flooding process continues until it reaches the destination node or an intermediate one with a route to the destination, that generates a RREP packet containing the number of network hops in the path from the source to the destination. Route maintenance process is carried through the transmission of periodic HELLO messages.

Route table entry lifetime	3 s.
Route obtaining maximum attempts	3
Maximum route discovery send rate	10 packets/s.
HELLO interval	Between 1 and 1.1 s.
HELLO timer	2 x HELLO interval
Node buffer expiry timer	8 s.
Send buffer size	Unlimited

Table 3. OPNET simulation model parameters used for AODV

OLSR [6] is a modular proactive hop by hop routing protocol. It is a modular protocol which consists of an always required core, and a set of auxiliary functions. It is a proactive approach, so it continuously tries to find routes to all possible destinations in the network. Proactive and link state behaviour could increase congestion in the network due to the routing traffic generated. However, due to its proactive basis, it has the advantage of having routes immediately available whenever they are required.

In order to reduce the amount of routing traffic generated by the protocol and thus optimize the algorithm to meet the requirements of a mobile WLAN, OLSR introduces Multipoint Relays (MPR). A MPR is a set of selected nodes which forward messages during the flooding process. Only nodes selected as MPR members can forward routing and control traffic. Using this technique traffic generated at the flooding process is highly reduced, making this technique a sort of selective flooding.

A node selects its MPR node members out of its neighbours located at one hop distance from it. A node which selects another node as a MPR node member is also called MPR Selector of that node. Following these guidelines, neighbours of a given node not included in its MPR set receive and process control messages, but do not forward them. MPR set covers all nodes located two hops from the node. Obviously, the smaller a MPR set, the lower control traffic generated in the network.

In order to establish a communication process between nodes running a protocol instance, OLSR uses a unique packet, in which more than one message can be encapsulated. OLSR packets can carry three different message types, each one for a specific purpose: HELLO messages, which perform the task of link sensing, neighbour detection and MPR signalling; TC (Topology Control) messages, which advertise link states and MID (Multiple Interface Declaration) messages, which perform the multiple interface declaration on a node.

Once all the information has been acquired through the message exchange, OLSR calculates the route table for each node.

MID timer	5 s.
HELLO timer	2 s.
TC timer	5 s.
Neighbour Hold Time	6 s.
Topology Hold Time	15 s.

Table 4. OPNET simulation model parameters used for OLSR

Simulation Environment

All scenarios have been modeled and evaluated using OPNET [16] [4] [23] simulator, in its version 11 PL1. It provides models for the four analyzed routing protocols: OLSR, DSR, AODV and TORA. In order to represent the main features of a real Ad Hoc network, all these simulations have been synthesized in two different scenarios.

Modeling node mobility

In order to evaluate the performance of a generic scenario in Ad Hoc networking, when analyzing mobile networks, modelling the movement of the set of nodes forming a MANET is essential. Two different mechanisms are being used for this purpose: traces and synthetic mobility models. Traces are registered movements from nodes in a given real network. The recorded values are then inserted in the simulator, in order to analyze the behaviour of the given network. The objective of this paper is to determine the most suitable protocol depending on the network situation, and not for one given real scenario, so traces will not help us to obtain the desired results. In this case, a mobility model has been used. Mobility models attempt to represent the movements of the nodes of a network. They are based on an algorithm which creates a random movement pattern for each node.

Six different models [3] have been studied: Random Walk, Random Waypoint, Random Direction, Boundless Simulation Area, Gauss-Markov model and City Section model. The Random Waypoint model has been selected to be used in all simulations presented in this document. Using Random Waypoint [3] model, nodes go moving until they arrive at a random destination calculated by the algorithm. Once there, they get still for a period of time, called the pause interval. Once passed that pause interval, a new movement is calculated by the algorithm, with a random direction and speed. For the estimation of the new movement, the algorithm does not process any information of the last movement.

Scenario 1 – Static Analysis

This scenario represents a motionless network. The main goal of analyzing the behavior of a network whose nodes maintain their position over the time is to determine the improvements of the main features of each protocol.

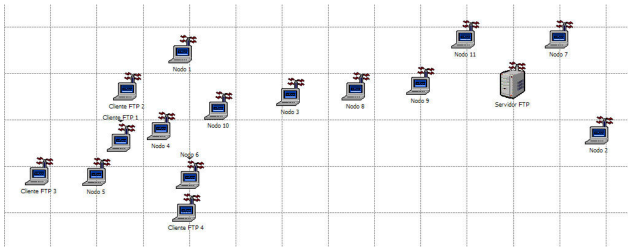

Fig. 2. Scenario 1 – Static Analysis

There are four client nodes which download a 100 KB file from a FTP server 20, 30, 40 and 50 seconds after the simulation starts, respectively. Just 400 seconds after that download, each client starts again with the same download process, which is repeated every 50 seconds.

Statistic	Value
Scenario size	1.000 m. x 1.000 m.
802.11b data rate	11 Mbps
Transmission range	300 m.
Simulation time	10 min.
Nodes	16

Table 5. Main characteristics of the scenario 1

Each client needs to run two route discovery processes. The first process is called when there is no route to the destination. The second call is due to the time interval elapsed between the first and the second download for each client. This interval is 400 seconds, which is greater than the 300 seconds expiry timer of the route cache. For this reason, the route obtained after the first route discovery process is no longer kept in the cache after 300 seconds. Because of that, the node does not have a valid route for the destination whenever it is needed.

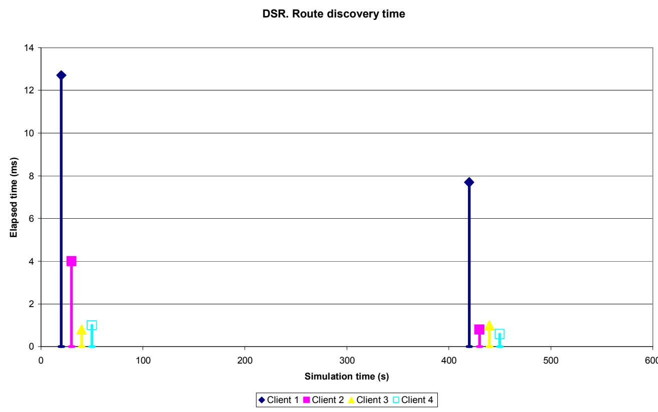

Fig. 3. Route discovery elapsed time

As observed in figure 3, the time elapsed in the discovery process is greater for the first client than for any other one. This is due to the use of the eavesdropping feature. For example, it allows node 4 to reply the RREQ packet sent from client 2 to discover a route to the server, because node 4 had previously learned a route to the server. It also means an important reduction in the control traffic generated by the protocol. The number of RREQ and RREP propagated through the network is much less when enabling the eavesdropping feature.

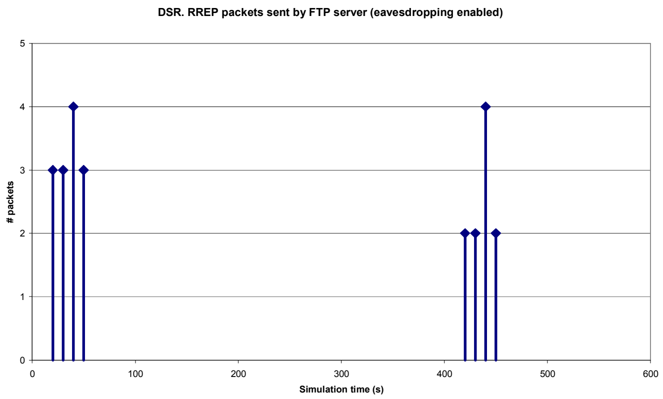

Fig. 4. RREP generated with eavesdropping disabled

Figure 4 shows the number of RREP generated at the server after disabling eavesdropping, while in figure 5 this feature is enabled.

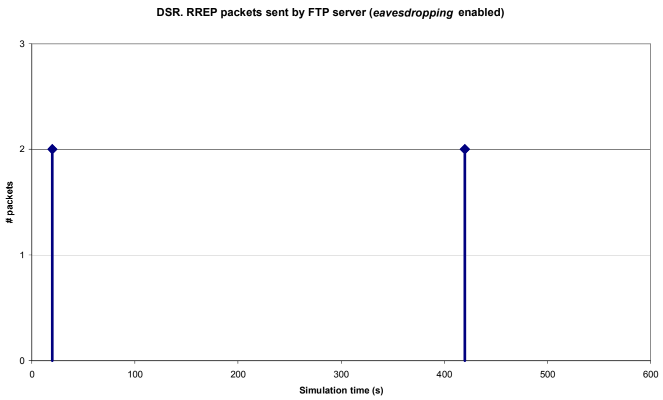

Fig. 5. RREP generated with eavesdropping enabled

The decrease in routing traffic generated and propagated through the network entails a reduction in the network load, as seen in figure 6 when eavesdropping DSR is enabled.

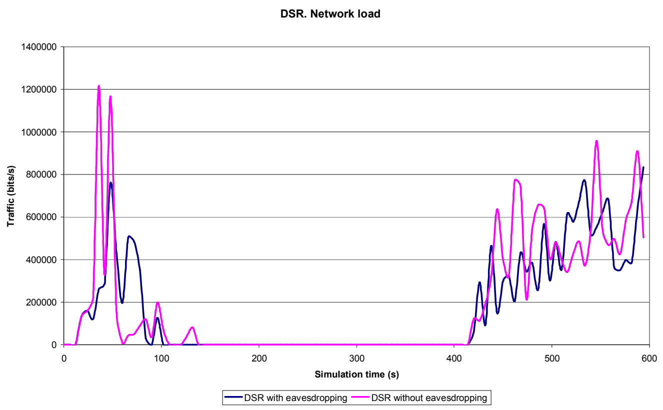

Fig. 6. Network overload

TORA routing traffic must be split into two traffic sources. At first, IMEP traffic, which is a constant generated traffic pattern, and then, TORA explicit traffic, only generated when there is a need for a route to any destination in the network. IMEP traffic responds to a generation of one HELLO message per beacon interval. The beacon interval has been modified to 1 second for the simulations with respect to the value used in OPNET model by default, which is 20 seconds. This modification has been made to adjust the model behavior to the protocol definition as much as possible. Due to the use of IMEP as an underlying protocol, simulation results determine that the use of TORA generates a great quantity of routing information. That would be unnecessary in motionless scenarios, because despite there would be no changes in the position of the nodes, too much traffic would be generated.

When analyzing network packet delay, results obtained using OLSR must be emphasized, as seen in figure 7. As a proactive approach, the fact of having a route before its demand, greatly reduces the amount of time a packet waits in the node buffer before being transmitted. It is necessary to remark that the generation of routing traffic by OLSR is more or less constant over time. This is also due to its proactive basis.

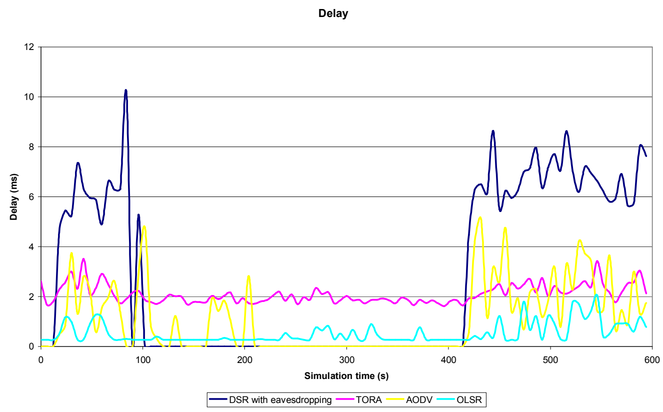

Fig. 7. Network delay

On the other hand, DSR delay results are almost unacceptable; delay takes the highest values. DSR is a reactive approach, so there is a high probability that packets will be waiting in buffers before a route is learned. Furthermore, it is based on source routing. This feature includes the complete route in the packet header. It results on increasing the length of the packet, which means an increase of the delay experimented by packets in the network.

Scenario 2 - Dynamic analysis

This scenario is expected to symbolize the mobile behavior of the nodes. Nodes follow a movement scheme modeled using the Random Waypoint model. The node traffic pattern is VBR (Variable Bit Rate), where the packet length is obtained from an exponential distribution between 1 and 64 bytes, transmitted at a rate of 1 packet per second. The scenario has been evaluated regarding two mobility-linked parameters: the speed of nodes and the frequency of each movement. If the speed of nodes is analyzed, two different kinds of movements have been modeled:

- People's movement; speed in the mobility model has been set to 2 m/s.
- Mobile device located inside a vehicle; speed has been set to 20 m/s.

Statistic	Value
Scenario size	1.000 m. x 1.000 m.
802.11b data rate	11 Mbps
Transmission range	300 m.
Simulation time	30 min.
Nodes	16

Table 6. Main characteristics of the scenario 2

In both cases, the pause interval has been set at 200 s. On the other hand, when analyzing the scenario regarding the frequency of each movement, the speed of the nodes has been set to a value obtained from a uniform distribution between 1 and 20 m/s, and the scenario has been simulated with different pause interval values: 0, 10, 50, 200 and 600 seconds.

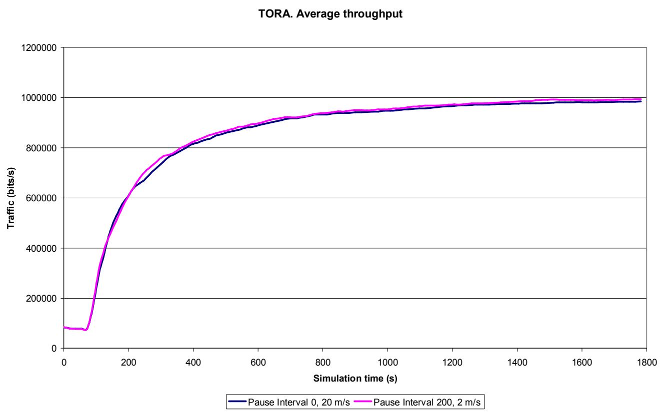

Fig. 8a. Average throughput (TORA)

At first, an analysis of the amount of the average routing traffic generated in the scenario has been made. Result shows that AODV and DSR are protocols with less routing overhead generated when mobility is increased, due to their reactive basis. Results are shown in table 7. Furthermore, carrying the whole route in the packet header allows DSR intermediate nodes in the path of a route not to continuously search for routes. OLSR results show a moderate impact over the network, while TORA adds a considerable overhead because of the fact that it adds an extra layer to the protocol stack.

When referring to the throughput analysis (see figure 8), an absolute evaluation of results is not applicable. The purpose is to evaluate the performance, in throughput terms, between the four protocols, and not the final absolute value of obtained throughput. As predictable, throughput decreases as mobility increases. It is important to note that OLSR drastically reduces its performance as mobility increases, much more than any other protocol. However, in a low-mobility environment, its results could be qualified as good ones. TORA is not reporting good results whatever the mobility situation analyzed. However, its performance doesn't decrease with mobility, so it would be an eligible approach in case the network requirements were not very strict and if the aim is to maintain a certain performance over network regardless of the behavior of its nodes.

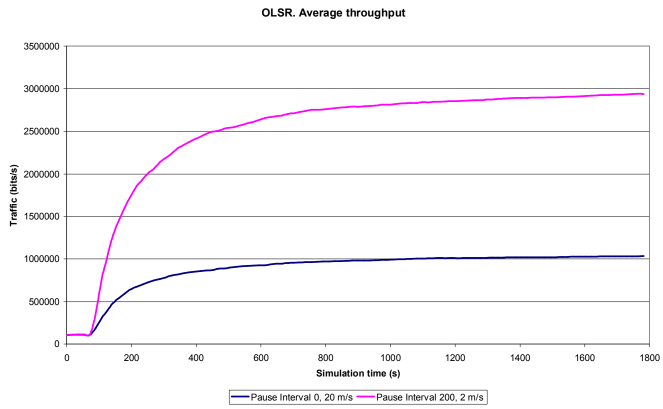

Fig. 8b. Average throughput (OLSR)

Statistic	Mobility	OLSR	AODV
Average throughput (Kbits/s)	**High**	761,35	2.031,30
	Low	2.122,52	2.165,26
Average routing traffic (bits/s)	**High**	5.639,63	3.933,17
	Low	5.639,09	3.308,25
Average delay (ms)	**High**	16,97	18,20
	Low	3,78	17,12

Table 7a. Numerical results of scenario 2 simulations

Statistic	Mobility	DSR	TORA
Average throughput (Kbits/s)	**High**	1.094,80	821,58
	Low	1.110,57	829,19
Average routing traffic (bits/s)	**High**	5.246,68	60.807,52
	Low	4.804,05	53.594,76
Average delay (ms)	**High**	25,31	5,71
	Low	20,25	5,63

Table 7b. Numerical results of scenario 2 simulations

Once again, OLSR is the approach which introduces the lowest delay, while DSR's delay is unacceptable under certain environments where traffic transmitted is delay dependent. It is also interesting that, in high-mobility environments, delay introduced by OLSR gets significantly increased. The reason of this is the inexistence of valid routes to the destination due to the great number of topology changes in the network. Although OLSR is a proactive protocol, when so many topology changes occur, it is not capable of creating so many new routes.

Conclusions

At a first glance, results demonstrate that proactive protocols introduce a lower delay in the network, as they have routes before their demand. However, because they continuously search for routes to all possible destinations, routing overhead introduced is high. On the other side, reactive protocols do not maintain unused routes and search them when they are needed. This fact increases the delay suffered by packets, because they remain waiting at buffers before being transmitted. They generally generate less control traffic than proactive ones.

OLSR: Its use is recommended neither in mobile environments nor in networks with a large number of nodes. In the first case, there is a high probability that the protocol would not obtain routes quickly enough, thus it would increase the convergence time. In the second situation, it constantly searches routes for all the possible destinations in the network, so network nodes increase control traffic. Its use is highly recommended in motionless or very low-motion environments with a small number of nodes, because of its great delay results obtained.

AODV: According to the simulations results, AODV presents the best all around performance. Its improvement of DSDV and DSR protocols turn it a highly versatile protocol.

DSR: It is a suitable approach for mobile networks and all around data load environments. The extremely high delay introduced in the network gets increased as the number of nodes and network size do. In those environments, routes are larger, increasing the packet length more and more. This is the reason to restrict its use to small and medium sized mobile networks.

TORA: Its main advantage, as well as it provides multiple routes to a destination, is its support for multicast environments. But in most common MANET cases, TORA would cause a collapse in the network. Its dependence of an underlying protocol as IMEP which generates such a lot of control traffic makes its use not very recommended, as simulation results demonstrate. However, it may be suitable for environments where a non critical performance level is required, and it needs to be constantly maintained. Its use is also recommended if the network is suspected to become larger with a large highly mobile number of nodes, as TORA would not decrease its performance and would minimize network delay.

Acknowledgement

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