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Performance Evaluation of Routing Protocols in Ad-Hoc Wireless Networks

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Abstract – This paper presents the efficiency of different routing protocol in few wireless ad-hoc network scenarious. The key motivation behind the analysis of routing protocols is the reduction of the routing load. High routing load usually has a significant performance impact in low bandwidth wireless links and we consider this aspect crucial on evaluating a link quality, hence the quality of offered services (QoS). We use NS (ns-2.26) in our simulations to evaluate the following routing protocols: DSDV, DSR and AODV.

Keywords: Network Simulator (NS), routing protocols, performance, throughput, packet loss

I. INTRODUCTION

The paper is structured in **six chapters**. First chapter give a general perspective of the paper. Chapter II describes some characteristics of ad-hoc networks, in context of routing protocols, and presents the structure of the NS (Network Simulator), the simulator we use in our evaluation. Chapter III briefly describe DSDV (**D**estination-**S**equenced **D**istance **V**ector), DSR (**D**ynamic **S**ource **R**outing Protocol) and AODV (**A**d-hoc **O**n-**D**emand **D**istance **V**ector Protocol). On Chapter IV we evaluate the routing protocols DSDV, DSR and AODV performance using NS. There are considered three different scenarios. For each scenario we analyze the following parameters: throughput (pcks/s), routing overhead (pcks), packet loss ratio (pcks), average end-to-end delay (ms) and efficiency (percentage). In our first scenario we study the influence of increasing the number of mobile nodes in an ad-hoc network. In the second scenario we study the influence of mobile node's speed on the parameters. The third scenario evaluates the efficiency of routing protocols looking on the transport layer; for DSDV and AODV we switch between TCP and UDP transport protocols. Each scenario is accompanied by four elements: scenario description, results, graphical representation and results interpretation. Chapter V includes our conclusions looking routing protocols for ad-hoc networks based on simulations results. The last chapter includes conclusions.

II. AD-HOC NETWORKS AND NETWORK SIMULATOR

A. *Overview of Ad-Hoc Networks Concept*

An ad-hoc network is an autonomous system of mobile nodes that does not need any fixed infrastructures. Ad-hoc networks are self-organizing, multi-hop wireless networks, rapidly deployable.

Mobile nodes use wireless transceivers to communicate with each other. Communications between two nodes are possible only if they are within their radio communication range. To overcome this constraint, intermediate nodes, so called relays, are chosen to forward the packets from sender to receiver. Ad-hoc networks are characterized by multi-hop wireless connectivity, frequently changing network topology and the need for efficient dynamic routing protocols. Therefore, the choice of intermediate node, that is, the choice of routing protocol is very significant subject in ad-hoc networks. All hosts in an ad-hoc network are embedded with packet forwarding capabilities. The characterizing features of ad-hoc networks are the highly dynamic topology and the very limited resources of bandwidth and computational power. These unique features pose several new challenges in the design of wireless, ad-hoc networking protocols. The performance of the routing protocols in mobile ad-hoc networks is greatly influenced by the frequency of network topology changes. Each node in the network acts as a router, forwarding data packets for other nodes. A central challenge in the design of ad-hoc networks is the development of dynamic routing protocols that can efficiently find routes between two communicating nodes.

B. *Mobile Networking in NS*

"NS is a discrete event simulator targeted at networking research. NS provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks." [1]

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Network Simulator, NS is a very good simulation tool for communications networks developed at Lawrence Berkeley National Laboratory, Berkeley. It can be installed on Unix, Linux and Windows. It implements network protocols such as TCP and UPD, traffic source behavior such as ftp, telnet, web, CBR and VBR, router queue management mechanism such as Drop Tail, RED and CBQ, routing algorithms, multicasting and MAC layer protocols for wired and wireless networks. NS supports graphical representations (e.g., *NAM* and *xgraph*) that help to visualize how protocols work and interact with different network topologies. The main steps of creating a NS scenario are: *creating the event scheduler, setting up trace support, creating network, creating connection, createing transport agents, creating traffic* (application), and *launching the simulator*.

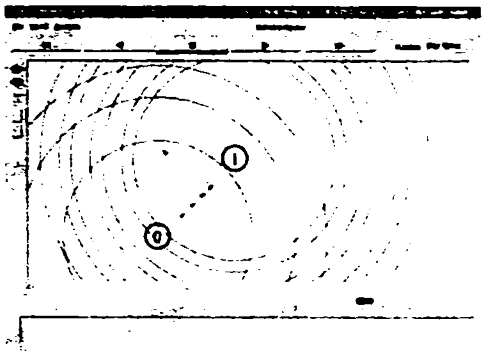


Figure 1. A NAM (Network AniMator) screen-shot of NAM animating a simple ad-hoc network topology

III. ROUTING PROTOCOLS IN AD-HOC NETWORKS

In order to communicate with a destination, a source needs to discover a suitable route for sending packets to that destination. This work is done by a *routing protocol*.

The problem of routing in a network has two componens: *route discovery* and *route maintenance*. Paths (routes) usually are optimised with respect to the following metrics: *number of hops* (to reach the destination) and *cost of a path* (delay, bandwidth, lenght of the queue, reliability). Three basic routing techniques can be identified: *routing by network address, label swappin* and *source routing*. Routing by address technique is tipical for connectinoless protocols like IP.

Ad-hoc wireless network characteristics (*dynamic topologies, asymetric link characteristics, multihop communictions, decentralized operation, bandwidth constrained, variable capacity links* and *energy constrained operation*) request specific routing protocols. The exising routing protocols in ad-hoc wireless networks can be classified as *proactive routing protocols* and *reactive routing protocols*.[2]

In case of proactive routing protocols, the routing information is always know beforehand trough *continous route updates*. These techinique require one to know the topology of the entire network and this information needs to be propagated through the network. Hence, these protocols integrate route discovery with route maintenance by sending routing update packets continuously so that routes are know a priori when needed. In highly dynamic environements these schemes are less efficient. As the nodal mobility increases, a smaller fraction of this total amount of traffic will be use because the lifetime of a link decreases. The advantage of the proactive routing protocols is that, once a route is requested, it is immediately available from the routing table.

Reactive routing protocols invoke a route discovery procedure *on demand* only. When a route is needed, a global search procedure is employed. These global search procedure of the reactive protocols generates significant control traffic. On the other hand, the delay to determine a route can be quite significant because the route information may not be avaliable a the time a route request is received. Because of this excessive control treffic and long delay, reactive routing protocols may not be applicable to real-time communications.

There are four different ad-hoc routing protocols currently implemented for mobile networking in NS: one proactive routing protocol (DSDV) and three reactive routing protocols (DSR, AOVD and TORA).

A. *DSDV (Destination-Sequenced Distance Vector)*

In this routing protocol, messages are exchanged between neighboring mobile nodes. Each DSDV node maintains a *routing table* listing for the *next hop* for each reachable destination. The routing table of each node has an entry for each destination in the network. The attributes for each destination are: *next hop ID, hop count metric* and *a sequence number* originated by the destination node. DSDV is a *hop-counting distance vector* protocol requiring each node to periodically broadcast routing updates.

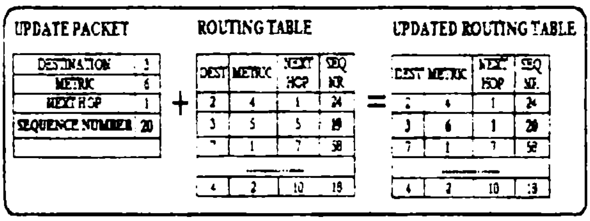


Figure 2. Routing table maintenance for DSDV

DSDV labels each route with a sequence number and considers a route ROUTE_1 more favourable than ROUTE_2 if ROUTE_1 has a *greater sequence* number than ROUTE_2, or if the two routes ROUTE_1 and ROUTE_2 have equal sequence numbers but ROUTE_1 has a *lower metric*. The mean of *destination sequence* (DS) is that new updated route has a greater *sequence number* (each node in the network advertises a monotonically increasing even sequence number for itself) and *distance vector* (DV) indicates the *network metric* (the number of hops to the destination).

DSDV uses both *periodic* and *triggered* routing updates. Triggered routing updates are used in addition to the periodic updates in order to propagate the routing information as quickly as possible whenever there is any topological change. The update packets include the destinations accessible from each node and the number of hops required to reach each destination along with the sequence number associated with each route. Upon receiving a route update packet, each node compares it to the existing information regarding the route. Routes with old sequence numbers are simply discarded. In case of routes with equal sequence numbers, the recently advertised route replaces the old one if it has a better hop count metric. The metric is then incremented by one, since the incoming packet will require one more hop to reach the destination. Newly recorded routes are immediately advertised to the neighbours. When a link to a next hop is broken, any route through that next hop is immediately assigned an *infinity metric* with a *new sequence number*. When a node receives an infinity metric and has an equal or greater sequence number with a finite metric, a route update broadcast is triggered. Thus, real routes propagated from the newly located destination will quickly replace the routes with infinity metrics.

The main advantage of DSDV over traditional distance vector routing protocols is that it *guarantees loop-free routes*. [3] DSDV has also a few number of drowbacks: *excesive communication overhead*, *waste of bandwidth* and *delays on routing table update*.

B. *DSR (**D**ynamic **S**ource **R**outing **P**rotocol)*

The Dynamic Source Routing protocol is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad-hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. [4] The protocol is composed of three main mechanisms: *routing*, *route discovery* and *route maintenance*.

The key feature of DSR is the use of *source routing* (SR), a routing technique in which the sender knows the complete sequence of nodes through the destination. These routes are stored in a *route cache* and each packet to be routed carries in its header the complete, ordered list of nodes through which the packet must pass. The packets themselves already contain all necessary routing information.

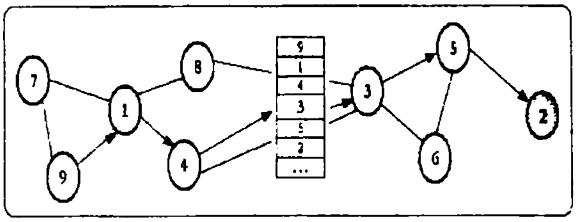


Figure 3. DSR routing mechanism

Route discovery is the mechanism by which a node wishing to send a packet to a destination obtains a path to the destination. To achieve this, the source node broadcasts a route request packet adding in a source route listing only itself (each route request has a unique ID and an initialy empty list). This route request packet propagates hop-by-hop from the destination node until either the source node is found or until another node is found, which can supply a route to the destination. Each node on the route request, from the source to the destination, adds its own address to the source route listing in the packet and forwards the packet to its neighbours. In addition, each node memorizes the recently received route requests and all source routes learned by a node are kept in route cache. The route discovery is performing only if no suitable source route is found in cache memory. When the route request (R_REQ) attends the destination node, this replies with a route replay (R_REP). This packet is routed back form the destination to the original source. If any link on a source route is broken, the source node is notified using a route error (R_ERR) packet. The source will initiate a new route discovery process, in case of the route is still needed.

Route maintenance is the mechanism by which a node detects a break in its source route and obtains a corrected route. Most of time, routing protocols integrate route discovery with route maintenance mechanism. In DSR, no periodic control messages are used for route maintenance. The route maintenance is possible only if an alternative route to destination exist.

In DSR, only in case of a desire communication, the source initiates route discovery. The major advantage of DSR is that there is little or no routing overhead when a single or few sources communicate. The sources of routing overhead (bandwidth overhead) are route discovery and route maintenance. Them occur when a route discovery mechanism is initiated (i.e. new routes need, error on a route, network topology change). This source of bandwidth overhead can be avoided by caching source in each node; even do that, the remaining source of bandwidth, that cannot be reduced, is the required source route header included in every packet. Since ad-hoc networks have limited available bandwidth, in large networks and highly dynamic environments, it may result large delays and large communication overheads (need to carry the addresses of every node in the path).

A key advantage of source routing is that intermediate hops do not need to maintain routing information in order to route the packets they receive.

C. *AODV (Ad-Hoc On-Demand Distance Vector)*

Ad Hoc On-Demand Distance Vector (AODV) routing mechanism is a combination of DSR (*on-demand mechanism of route discovery and route maintenance*) and DSDV (*hop-by-hop routing, sequence numbers, and periodic update packets*).

AODV adopts a very different mechanism to maintain routing information. It uses traditional routing tables, one entry per destination. This is a departure from DSR, which can maintain multiple route cache entries per destination. Without source routing, AODV relies on routing table entries to propagate a route replay (R_REP) back to the source and, subsequently, to route data packets to the destination. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops. [2] When a route is needed, a node broadcasts a route request (R_REQ) message. The response message is then echoed back once the request message reaches the destination or an intermediate node that contains a fresh route to the destination. A mobile node also maintains a list of those neighbors actively for each route. Similar to DSDV, each route table entry is tagged with a destination sequence number to avoid loop formation. Moreover, nodes are not required to maintain routes that are not active. Thus, wireless resource can be effectively utilized. However, since flooding is used for route search, communication overhead for route search is not scalable for large networks. As route maintenance considers only the link breakage and ignores the link creation, the route may become nonoptimal when network topology changes. Subsequent global route search is needed when the route is broken.

IV. ROUTING PROTOCOLS FFICIENCY IN AD-HOC WIRELESS NETWORKS IMPLEMENTED BY NS

On this chapter we evaluate the routing protocols DSDV, DSR and AODV performance. Considered scenarios were analysed looking on the following parameters: *throughput* (pcks/s), *routing overhead* (pcks), *packet loss ratio* (pcks), *average end-to-end delay* (ms), *efficiency* (percentage).

For a better evaluation, we define efficiency as:

Efficiency = [Number of Received Packets / Total Transmitted Packets]*100 [%] (1)

A. *Scenario_1*

Scenario description:

In our first scenario we have a wireless network with 10 mobile nodes (MNs) on a 500 x 500 square meters topology. Wireless MNs are fixed; they keep the initial position during simulation. Omni-directional antenna having unity gain are used by mobile nodes. Antenna height is 1.5 m and emission power range is 200 m for each station.

Friis transmission equation ($1/r^2$) is the radio propagation model considered. r is the distance from mobile node, at near distances and an approximation to two-ray ground ($1/r^4$) at far distances. The approximation assumes specular refection off a flat ground plane.

A FTP application between two MNs over a TCP transport protocol was set up. Simulation time is 50s. Assuming these initial conditions we switched the three routing protocols (DSDV, DSR and AODV). Also we increase to 20 the number of MNs and observe the effect of a larger network.

Synthesizing results are shown in Table 1.

Table 1. Synthesizing results for analyzed configurations (Scenario 1)

PROTOCOL / PARAMETERS	DSDV		AODV		DSR	
	10 MNs	20 MNs	10 MNs	20 MNs	10 MNs	20 MNs
1. Throughput [pcks/s]	157.6	157	159.88	159.86	159.7	159.6
2. Routing overhead [pcks]	83	221	10	20	2	2
3. Packet loss ratio [pcks]	20	20	20	20	20	20
4. Average end-to-end delay [ms]	132	138	122	125	118	142
5. Efficiency [%]	99.56	99.74	99.77	99.74	99.74	99.74

Results interpretation:

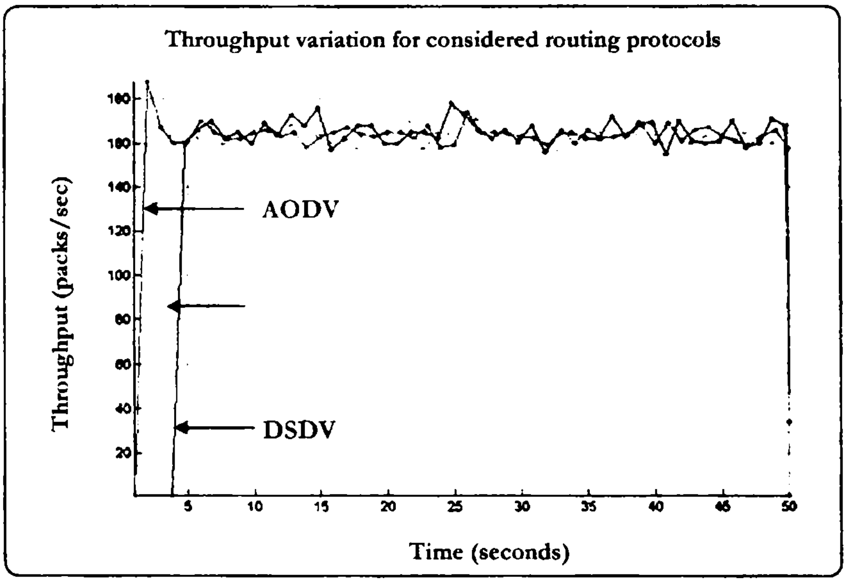
There are two distinct situations: *for the same protocol, witch is the effect increasing number of mobile nodes* and *witch is the three routing protocols efficiency in each case.*

As we expected, the higher the number of mobile nodes the lowest the throughput in the network. We also observe that the packet loss ratio is the same for all considered scenarios. This important because we can conclude that the lowest throughput is not influenced by the number of packet loss.

The causes are the average and-to-and delay and the routing overhead (the amount of routing information is higher). We also confirm that AOVD and DSR are more optimal than DSDV.

The routing information is higher in case of DSDV routing protocol. The routing information in DSR case is minimal. This information is transmitted only between the two communicating nodes.

Graphical representation:



B. *Scenario_2*

Scenario description:

In this scenario we keep the initial network configuration with 10 mobile nodes (MNs). We study the influence of mobile node's speed on the parameters. Synthesizing results are shown in Table 2.

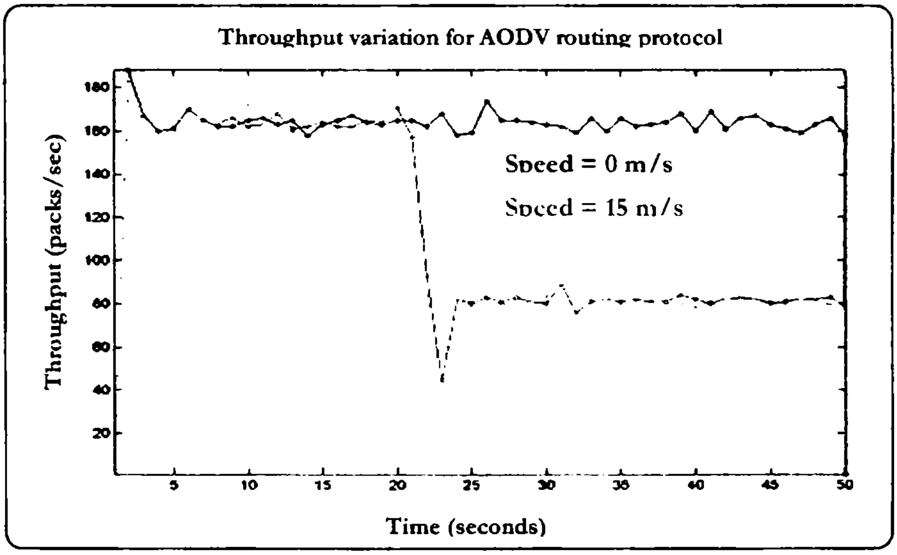
Results interpretation:

As we expected, the higher the speed of mobile nodes the lower the throughput in the network. From the point of view of routing protocols, we demonstrate again that AODV has the best performance even in a network with moving mobile nodes.

Table 2. Synthesizing results for analyzed configurations (Scenario_2)

PROTOCOL / PARAMETERS	DSDV		AODV	
	15 m/s	30 m/s	15 m/s	30 m/s
1. Throughput [pcks/s]	87.64	38.74	112.5	98.9
2. Routing overhead [pcks]	70	80	23	23
3. Packet loss ratio [pcks]	41	25	40	40
4. Average end-to-end delay [ms]	165	164	146	198
5. Efficiency [%]	99	98.7	99.22	99.19

Graphical representation:



C. *Scenario_3*

Scenario Description:

In this scenario we have 10 mobile nodes and we try to evaluate the efficiency of routing protocols looking on the transport layer. So, for DSDV and AODV we switch between TCP and UDP transport protocols. There are established four TCP or UDP connections in each scenario.

Synthesizing results are shown in Table 3.

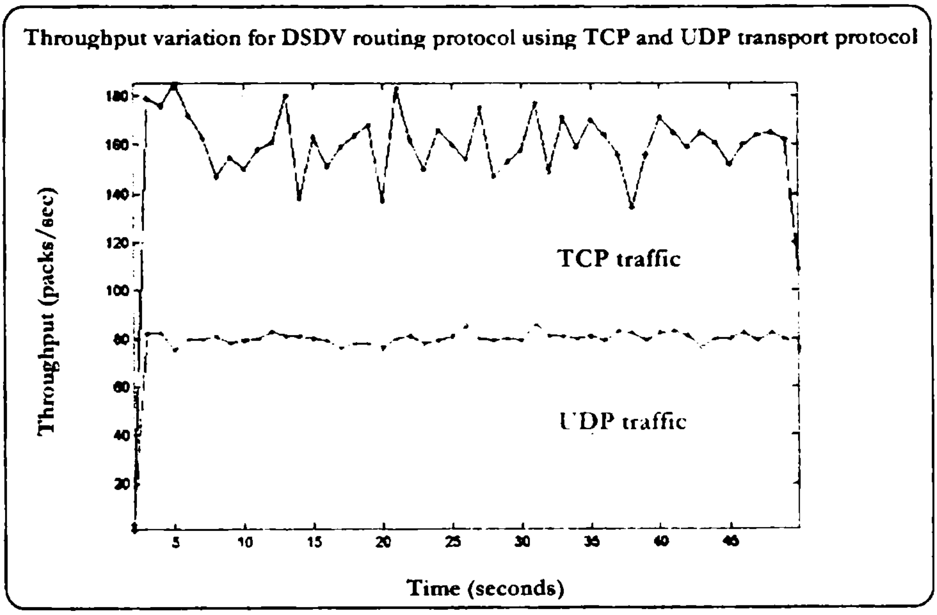
Results interpretation:

As we know, UDP protocol is a connexion less (CL) transport protocol. There is no confirmation of receiving data. It is more suitable in critical-time applications (real-time applications) than in no transmission error applications. This is obvious from our simulation: even we have a lower throughput, the packet loss ratio is lowest. Looking o routing protocols, we observe that the efficiency is the same (UDP). As the key motivation behind the analysis of routing protocols is the reduction of the routing load, this goal is attend in case of AODV.

Table 3. Synthesizing results for analyzed configurations (Scenario_3)

PROTOCOL / PARAMETERS	DSDV		AODV	
	TCP	**UDP**	**TCP**	**UDP**
1. Throughput [pcks/s]	**155.24**	**77**	**156.92**	**77**
2. Routing overhead [pcks]	**59**	**60**	**37**	**42**
3. Packet loss ratio [pcks]	**84**	**1**	**120**	**1**
4. Average end-to-end delay [ms]	**378**	**7**	**366**	**3.5**
5. Efficiency [%]	**98.91**	**99.98**	**98.47**	**99.98**

Graphical representation:



V. CONCLUSIONS

We analysed three diferent scenarios. Each scenario is accompanied by four elements: scenario description, results, graphical representation and results interpretation. The results interpretation section include simulation results and conclude the results.

The key motivation behind the analysis of routing protocols is the reduction of the routing load. High routing load usually has a significant performance impact in low bandwidth wireless links and we consider this aspect crucial on evaluating a link quality, hence the quality of offered services (QoS).

VI. REFERENCES

[1] - http://www.isi.edu, *Information Sciences Institute* (ISI)

[2] - Amitava Mukherjee, Somprakash Bandyopadhyay, Debashis Saha, *Location Management and Routing in Mobile Wireless Networks*, Artech House, 2003

[3] - Ismail Ari, Neelu Jethani, Aniruddha Rangnekar, Sushma Natarajan, *Performance Analysis and Comparison of Ah-Hoc Routing Protocols*, Department of Computer Science and Electrical Engineering, University of Maryland Baltimore County, 2000

[4] - David B. Johnson, David A. Maltz, Yih-Chun Hu, *The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)*, IETF MANET Working Group, draft-ietf-manet-dsr-09.txt, April 15, 2003