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DESIGN AND PERFORMANCE EVALUATION OF MORA: A MOVEMENT-BASED ROUTING ALGORITHM FOR AD HOC NETWORKS

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Design and Performance Evaluation of MORA: a Movement-Based Routing Algorithm for Ad Hoc Networks

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Abstract - In an ad hoc environment with no wired communication infrastructure, mobile hosts necessarily operate as routers, in order to provide network connectivity. Since mobile ad hoc networks change their topology frequently and without prior notice, routing in such networks becomes a challenging task.

To explicitly consider node movements, we present MORA, a movement-based routing algorithm for mobile ad hoc networks. The algorithm is completely distributed, since nodes need to communicate only with direct neighbors within their transmission range, and utilizes a specific metric, which exploits not only the position, but also the direction of movement of mobile hosts.

Extensive simulations evaluating the proposed protocol and results of comparison with existing methods demonstrate that MORA can provide an efficient and robust routing strategy.

I. INTRODUCTION

Mobile ad hoc networks (MANET) consist of wireless hosts that communicate with each other in the absence of a fixed infrastructure [1]. They can be used in a wide plethora of applications, ranging from tactical operations, to quickly establish military communications during the deployment of forces in unknown and hostile terrain; to sensor networks, for communication between intelligent sensors mounted on mobile platforms. In the last application, mobile ad hoc networks are likely to achieve wide deployment in the near future because they greatly extend the ability to monitor and control the physical environment from remote locations.

In an ad hoc wireless network, mobility and bandwidth allocation are two key elements representing research challenges. Not all hosts are within the transmission range of each other and communication is achieved by multi-hop routing, where intermediate nodes cooperate by forwarding packets between two hosts. Due to the hosts mobility, the topology of the network can change with time and no assumption can be made about the initial configuration. As a consequence, nodes have to build and update their routing tables automatically and effectively.

Traditionally, multi-hop routing for mobile ad hoc networks can be classified into proactive and reactive algorithms.

In proactive routing algorithms, each node in the mobile ad hoc network maintains a routing table that contains the paths to all possible destinations. If the network topology locally changes, all routing tables throughout the network have to be updated. These kind of routing algorithms (such as the Destination-Sequenced Distance-Vector Routing Protocol (DSDV) [2] or the Wireless Routing Protocol (WRP) [3]) are efficient only if the ratio "mobility over communication" is low [4]. If the nodes in the network are reasonably mobile, the overhead of control messages to update the routing tables becomes prohibitive. In addition, storing large routing tables in low-cost mobile nodes might be too expensive.

Reactive routing algorithms, on the other hand, find routes only on demand. Routes are designed when they are needed, in order to minimize the communication overhead. When a node needs to send a message to another node, the sender needs to flood the network in order to find the receiver and determine a path to reach it. The flooding process can still use a significant amount of the scarce available transmission resources. Such algorithms are adaptive to "sleep period" operation, since inactive nodes simply do not participate at the time the route is established. Two widely used reactive routing protocols are the Dynamic Source Routing (DSR) [5] and Ad-hoc on-demand Distance Vector Protocol (AODV) [6]. DSR builds routes on demand using flooded queries that carry the sequence of nodes they passed through, which is copied at destination in the reply packet. A variation of distance vector protocols is AODV, which maintains a routing table in all intermediate nodes on the route. For additional information, a detailed review of routing algorithms in mobile ad hoc networks can be found in [7, 8].

An interesting approach is represented by position-based routing algorithms, which require information about the physical position of the participating nodes. The forwarding decision by a node is primarily based on the position of the packet destination and the position of the node's immediate one-hop neighbors, typically learned through one-hop broadcasts. The distance between neighboring nodes can be estimated on the basis of incoming signal strength or time delay in direct communications. Alternatively, the location of nodes may be available directly by communicating with a satellite, using GPS, if nodes are equipped with a small low power GPS receiver. In any case the position can be affected by some level of approximation. A detailed survey of protocols that do use geographic location in the routing decision is presented in [9, 10] but the two main algorithms are the Distance Routing Effect Algorithm for Mobility (DREAM) [11] and the Location Aided Routing (LAR) [12]. In both DREAM and LAR a sender forwards the packet to all neighbors in a limited zone (restricted flooding) which contains the expected region containing the destination.

This paper addresses the problem of routing in an ad hoc network. An alternative movement-based routing algorithm (MORA) is presented, which exploits not only the position, but also the direction of motion of mobile hosts[1].

The structure of the work is the following: Section II introduces the method, which is then analyzed in Section III. In Section IV the characteristics of existing routing algorithms are presented, while extensive simulations of the protocol are reported in Section V. Finally, Section VI concludes the paper.

II. THE PROPOSED METRIC

The desirable properties of any routing protocol include simplicity, loop-free operation, convergence after topological changes, small storage, reduced computational and transmission overhead. In a position-based routing algorithm, each node makes a

[1] A preliminary version of this work was presented in DMS 04.

decision to which neighbor to forward the message based only on the location of itself, its neighboring nodes, and the intended destination. In our approach, this decision is taken considering also which direction neighbors are moving in. Moreover, the system is made more robust by avoiding centralized information management, and easier to set up and operate.

Most routing schemes use hop count as the cost metric, where hop count is the number of transmissions on the route from a source to a destination. However, different metrics for choosing the best forwarding neighboring node in position-based routing protocols were recently considered. The metric used in MORA (Movement-Based Routing Algorithm) is a linear combination of the number of hops, arbitrarily weighted, and a target functional, which can be independently calculated by each node.

A. The functional F

Since mobile ad hoc networks frequently change their topology and without prior notice, the life time of connections between hosts varies appreciably.

Our goal is to exploit information about moving directions of neighboring nodes in order to route the data over an optimal path. There are a lot of different strategies reported in literature based on which a node can select a neighbor for the forwarding of a given packet (Most Forward within Radius (MFR), Nearest with Forward Progress (NFP)...) [9]. However, none of them take into consideration that hosts in ad hoc network are moving in directions that can introduce unpredictable changes in the network topology affecting already established routes and network connectivity in general.

In the definition of the routing algorithm, we'll assume that each node will move along a "regular" route, i.e. its movement pattern will remain constant during a packet transmission. Moreover, changes in the network configuration hamper the stability of the links and routes (as pointed out in the Section I). In this study, we neglect the impact of errors in the techniques used for position estimation of the network nodes leaving it as an open issue for future investigation.

The core idea of the approach is to develop a functional which depends on the distance of forwarding node from the line connecting the source and the destination, *sd*, and on the direction the node's movement. This functional is required to be implemented in a distributed way allowing any node to calculate it.

The target functional should reach its absolute maxima in the case the node is moving on *sd* and it should decrease as the distance from *sd* increases. Moreover, the more a node moves towards *sd*, the higher should be its value, i.e. for a fixed distance from *sd* the functional should have a maximum if the node is moving perpendicularly to *sd*. Indeed, for nodes which don't lie on *sd*, we prefer not to favor the movement directions towards the source or the destination, but to associate the highest value to nodes which are moving straight to *sd.*

Let d_0 be a reference distance metric, chosen on the basis of the application context (e.g. 1 meter, or 10 cm). Let $x = d/d_0$ be the adimensional distance of the current node from *sd* and $y = l/d_0$ the adimensional distance from the destination of the intersection point between *sd* and its perpendicular starting from the node's current position (see Fig. 1). The functional F is a function of $x \in [0, \infty]$ and $\alpha \in [-\pi, \pi]$, where α

represents an angle between the line of the movement direction and the perpendicular line to *sd* (see Fig. 1).

Figure 1

We define the functional *F* as follows, in order to ensure the targeted properties:

$$F_{\delta,\gamma}(x,\alpha) = \sin\frac{|\alpha|}{3}e^{-|x|} + \cos\frac{\alpha}{3}e^{-\frac{(x-\delta)^2}{\gamma}} \tag{1}$$

where δ and γ are two parameters set on the basis of the application. In particular, they let the curvature of F vary: δ defines the value of *x* corresponding to the relative maximum along the *x* axis and γ leads to a smoother or steeper behavior down to zero. With such a definition of *F*, more weight is given to nodes moving on *sd*, and also to nodes moving towards *sd* (see Fig. 2) as required above. In fact

- for $x = 0$ there are 2 absolute maximums, for $\alpha = \pm\pi/2$ respectively;
- for $0 < x < \varepsilon$ (ε arbitrarily small) the trend is the same as above;
- for $x \to \infty$ the function decreases;
- for $x = \delta$ there is a relative maximum corresponding to $\alpha = 0$;
- for $x \in [\delta - a_{\delta,\gamma}, \delta + b_{\delta,\gamma}]$ ($a_{\delta,\gamma}$ and $b_{\delta,\gamma}$ constants defined with the choice of δ and γ) there is a maximum corresponding to $\alpha = 0$.

Figure 2

The idea is to favor relatively stable paths and not necessarily those with smaller number of hops. Moreover, by carefully setting δ and γ, it is possible to adjust the weight associated with node's movement direction and therefore the curvature of functional *F*.

The functional *F* will be sampled and put into a look up table. In this way, each node does not need to calculate *F* at any iteration, but it can easily obtain the value corresponding to a given combination of *x* and α with a simple and fast table lookup.

B. The metric m

Another degree of freedom of the metric employed in MORA is the weight assigned to each node, which can be used to represent traffic conditions, application constraints, etc. The goal of the weighting function is to obtain a fair distribution of the available resources through the overall network.

For the purpose of the paper, the function *W*, defined for $y \in [0, y_{source}]$ is given by:

$$W(x,y) = \begin{cases} 1 & 0 \le w(x,y) < 0.1 \\ -\log_{10} w(x,y) & 0.1 \le w(x,y) \le 10 \end{cases} \qquad (2)$$

where $w(x,y) \in [0,10]$ is the weight of node *i* with coordinates *x, y*.

Now the following metric can be defined, for $y \in [0, y_{source}]$:

$$m_{\delta,\gamma}(x,y,\alpha) = \frac{1}{2}(W(x,y) + F_{\delta,\lambda}(x,\alpha)) \qquad (3)$$

where both $W(x,y)$ and $F_{\delta,\gamma}(x,\alpha) \in [-1,1]$ and therefore $m_{\delta,\gamma}(x,y,\alpha) \in [-1,1]$. Due to the fact that *x* and *y* are the coordinates of node *I*, and α depends on the node *i*, in following sections we refer to $m_{\delta,\gamma}(x,y,\alpha)$ and m_i without distinction.

The reader should note that, by choosing such metric, the higher the value of m_i the higher the probability node *i* is include into the active route from source to destination.

The presented way of node weighing provides a possibility to include other than location and movement parameters into MORA routing. The weight $w(x,y)$ associated with the node can be calculated based on such parameters like a level of node's congestion, an outgoing date rate, available power resources, etc. For example, in case node *i* is congested and therefore $w(x,y) \to 10$, then $W(x,y) \to -1$.

III. THE MORA ROUTING PROTOCOL

In position-based routing algorithms, usually short probe messages are sent into the network in order to determine the position of the destination node, which is used for route establishment. In more details, the sender floods a route establishment request into the network or its part. The destination replies to the sender with a route reply packet including such information like its location. After a route reply has reached the sender, the data payload can be transmitted over the path using position-based routing algorithms.

The proposed MORA approach exploits the exchange of probe messages not only to locate the destination, but also in order to get information about the best available path between the source and destination nodes.

MORA routing uses flooding for destination discovery like most of existing routing protocols. The sender includes its location information into the route request flooded into the network. Upon the reception of a route request from the sender, the destination node generates a route reply message which is routed using metric *m* defined in Eq.(3).

On every hop, the current node receiving it polls for information its neighboring nodes, considering only those with the higher values of *y* in order to avoid loops (*y* is related to the distance from the destination as in Section II. *A*).

The coordinates of the source node, coordinates of the destination node, position of the node last forwarded the packet, as well as its moving direction, are included into every MORA protocol message. As a result, each node is able to obtain metric *m* for itself as well for its immediate neighbors.

The values for *d* and α used in functional F calculation presented in Eq.(3) are obtained as follows:

$$d = \frac{y_i - m_{sd} x_i - q_{sd}}{\pm\sqrt{(1+m_{sd})^2}} \tag{4}$$

$$\alpha = \cos^{-1}\left(\frac{d}{dist}\right) \tag{5}$$

where m_{sd} and q_{sd} are calculated using coordinates of the source and destination nodes (x_s, y_s) and (x_d, y_d), respectively:

$$m_{sd} = \frac{y_d - y_s}{x_d - x_s} \tag{6}$$

$$q_{sd} = y_s - \frac{y_d - y_s}{x_d - x_s} x_s \tag{7}$$

where *dist* is the distance of the node from *sd* along the direction of movement.

The probe message is then forwarded to the neighbor with the higher value of *m* (see Section II.*B*), attaching path information.

The routing metric *m* assumes an availability of up-to-date information about positions and moving directions of the source node, destination node as well as nodes located along the *sd* line and their immediate neighbors. The availability of this information is crucial in case of a highly dynamic ad hoc networking environment.

The frequency of the updates is dependant on the particular implementation of the routing protocol. In this paper we consider two possible implementations of MORA routing:

- *Standalone*. This implementation, referred to as "MORA", separates the framework of the proposed routing protocol into a standalone routing layer. As a result, location and movement information is carried by only routing protocol messages (such as Route Request and Route Reply). The main drawback of the standalone implementation is that position information is not updated in correspondence on node packet exchange.
- *Link layer integrated*. In order to overcome the update limitations of the standalone approach, integration of MORA protocol with the MAC protocol at the link layer is considered as a modification referred to as

"MORA+". In addition to the features of the standalone implementation, MORA+ includes the location and movement information into the ordinary MAC protocol headers - which carry signaling or data payload. This technique enables a dynamic update of such information along the entire data path for every transmitted packet, thus avoiding waste of available communication resources.

IV. CHARACTERISTICS OF EXISTING ROUTING SCHEMES

This section outlines potential advantages and disadvantages of the MORA approach with respect to other existing routing algorithms, taking as a starting point the taxonomy of position-based routing protocols proposed in [10]. Table 1 reports the selected features of some routing algorithms. It is clear that none of the existing localized routing algorithms takes into account the movement of the hosts.

Table 1

The knowledge of node's postion could be not sufficient in a network with with frequent topological changes, as analyzed in the next Section V. In such a situation it is important to guarantee high stability of the links and therefore the robustness of routing protocol. An awareness of a node's movement direction implemented in MORA routing is an attempt to find a solution to this critical problem. In ad hoc networks, for communication between fixed terminals such considerations will not improve the communication, but if the terminals are mounted on mobile platforms exploiting the knowledge of direction of movement has relevant advantages (see Section V).

If only position information is used, it is possible to lose some good candidates to forward the packet. For example, considering LAR and DREAM, if one host, moving in the direction of *sd*, and it is out of the "request zone" it will never be considered for data forwarding (extensive comparison with LAR is provided in the next Section V.). Similarly, MFR makes no difference if the node moves to or out from the destination or even coverage area. Similar comments can be made for Compass Routing (DIR) [13].

Depth First Search (DFS) [14] could appear similar to MORA, since the decision among direct neighbors is taken by minimizing a distance function. However, the links considered by DFS are unstable in highly dynamic topology.

The solutions based on the shortest-path routing technique are also very sensitive even to small changes in network topology and activity status of the nodes. On the contrary, MORA is adaptive to the "sleep period" operation, since power consumption is extremely reduced for inactive nodes (not participating in route establishment), and only a few nodes are involved in packet routing.

V. PERFORMANCE EVALUATION

Performance evaluation of the proposed routing protocol was performed by simulations using GloMoSim 2.0 [15] network simulator. GloMoSim is a scalable simulation environment for wireless mobile networks based on the Parsec parallel discrete-event simulation library. GloMoSim is chosen out of the set of available network simulators to the fact of the availability of physical layer models fairly approximating real-world behavior as well as for an extensive support of mobility in ad hoc networks.

IEEE 802.11 physical layer standard is chosen for the set of conducted experiments. An additional software module enabling MORA functionality was inserted into a standard Glomosim package. In order to achieve integration between routing plane and link layer protocol required by MORA+ the corresponding modifications were performed for the MAC protocol. The propagation of route request is implemented using flooding model. However after coordinates of a destination are discovered the route reply message as well as data payload packets are routed using MORA techniques.

In case a node can not find the route to destination (which is probably caused by wrong/changed coordinates of the destination) it sends route error message to source.

A. Simulation scenario

The simulations were performed for five routing protocols: AODV, DSR, LAR, MORA, and MORA+. The results are obtained for variable number of nodes, their moving speed as well as transmission range.

The nodes are uniformly placed onto a 1000 x 1000 square meters two-dimensional terrain forming mobile ad hoc network. The number of network nodes is chosen to be 30 in order to have the topology connected.

Simulations use transmission range values equal to 200, 300, 400, and 500 meters. As a result, data communication between any pair of nodes can occupy from 1 to 7 hops. The sender and destination nodes are randomly chosen.

Standard FTP client operating over TCP protocol was chosen as a traffic source application. For evaluation of routing overhead, the FTP client was configured to produce bulks of 10 packets in large (0.5 second) intervals of time. After each bulk transmission, the routing table as well as the table with neighbor nodes were cleared for all the nodes. This resulted in route discovery initiated for every generated bulk of packets. In other scenarios, FTP application performs uninterrupted data transfer up to the end of simulation which lasts for 1000 seconds.

The random waypoint with pause time equal to zero is used for mobility model. In this scenario each node performs several moves during the simulation time without remaining static between moves. The nodes move with an average speed of 5, 15, and 25 meters-per-second.

Our simulation results are averaged over 20 runs with different seeds for random generator. The results where the communication between randomly chosen sender and receiver nodes was not possible due to disconnected topology (which happened rarely) were excluded.

B. Routing Overhead

Here we compare MORA routing overhead against other evaluated routing techniques. The overhead is defined as the number of routing packets (requests, replies, route failures) sent over the entire network within a single burst transmission. Forwarding of routing control packet is considered as a separate transmission.

Figures 3, 4 and 5 presented for average speeds of 5, 15, and 25 meters respectively show MORA implementation behaves similar to flooding routing algorithms which comes from the fact that destination discovery is performed by flooding request packets into entire network. A slight difference from flooding curve is due to the difference in the propagation of the route reply message which is routed using node movement information in case of MORA. LAR scheme produce much lower overhead than flooding schemes which is the result of its limited request propagation region.

Figures 3, 4, 5

However we recall the fact that the MORA protocol does not limit the technique used for destination discovery to flooding. In fact MORA operation starts from the point when the position of the source node and the destination nodes are available which happens upon the route request message reaches the destination. It allows an implementation or any existing route request propagation scheme leading to the corresponding advantages.

C. Performance vs Range

The throughput performance versus transmission range for different levels of the mobility is shown in Figures 6, 7 and 8. FTP source always achieve lowest throughput in case DSR routing is used. DSR fixes the routes for route reply propagation as well as for subsequent data communication on the end-to-end basis. As a result, any changes in the connectivity between any neighboring nodes result in the route failure, which can be resolved by only generation of a new route discovery.

Figures 6, 7

AODV protocol demonstrates better throughput performance if compared with DSR. A per-hop based routing appears to be more stable than the one fixed on the end-to-end routes. The routes determined by MORA protocol are more stable in presence of mobility. However, the fact that coordinates of destination are determined only during the route request phase limits the performance of MORA when the destination moves relatively far from its initial position determined during the route discovery.

This problem is solved in MORA+ version of the protocol which is an example of close integration between routing plane and the MAC protocol layer. The location of the destination as well as intermediate nodes is dynamically updated with every data or control packet transmission. As a result, MORA+ is almost insensitive to mobility in the presence of continuous data exchange along the route.

The difference in performance of evaluated protocols is better shown for low values of transmission range, while for high transmission ranges communication between nodes occupy less number of hops limiting performance to similar throughput values.

Figures 9, 10, 11 and 12 present the performance of evaluated routing protocol versus node's mobility. It appears DSR to be the most sensitive to mobility. The performance of MORA+ is consistently stable for low as well as for high nodes' moving speeds.

Figures 9, 10, 11, 12

VI. CONCLUSIONS

In this paper, a motion-based routing algorithm for ad hoc networks MORA is proposed. The algorithm is completely distributed, since nodes need to communicate with only direct neighbors located within their transmission range.

The metric utilized in MORA routing provides a way to utilize not only positioning information but also the direction the nodes move which is the concept not accounted by any of the existing routing algorithms. Currently available location-based routing techniques operate using static models of ad hoc networks while MORA approach considers tending changes of the network in addition to available topological information.

The extensive evaluation results outline the stability and high level of the performace of MORA especially in case of high mobility of network terminals and frequent topology changes.

Future work will consider the problem of accuracy of techniques used for positioning and its impact on protocol performances. However at present moment our work is focused on the extension of the metric used in MORA algorithm. A new metric will include the speed of the node's movement in addition to the movement direction.

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METHOD	POSITION INFORMATION	PATH STRATEGY	METRIC	SCALAB.
SHORTEST PATH	NO	SINGLE-PATH	HOP COUNT	NO
MFR, GREEDY	ONLY POSITION	SINGLE-PATH	HOP COUNT	YES
DIR	ONLY POSITION	SINGLE-PATH	HOP COUNT	YES
LAR, DREAM	ONLY POSITION	FLOODING	HOP COUNT	NO
DFS	ONLY POSITION	SINGLE-PATH	HOP COUNT	YES
POWER AWARE	ONLY POSITION	SINGLE-PATH	POWER	YES
GFG	ONLY POSITION	SINGLE-PATH	HOP COUNT	YES
MORA	POS + MOVEMENT	SINGLE-PATH	COMBINED	YES

Table 1

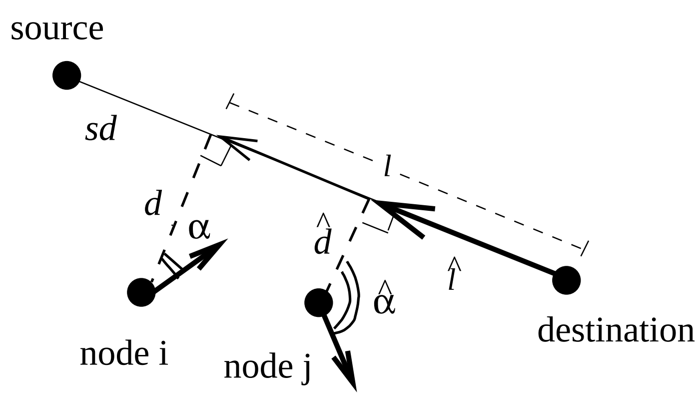


Figure 1

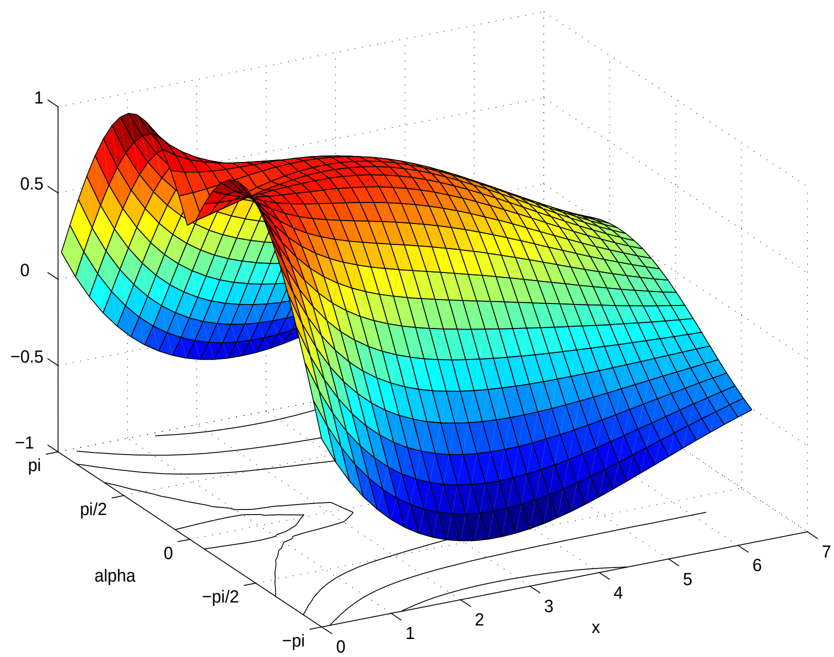
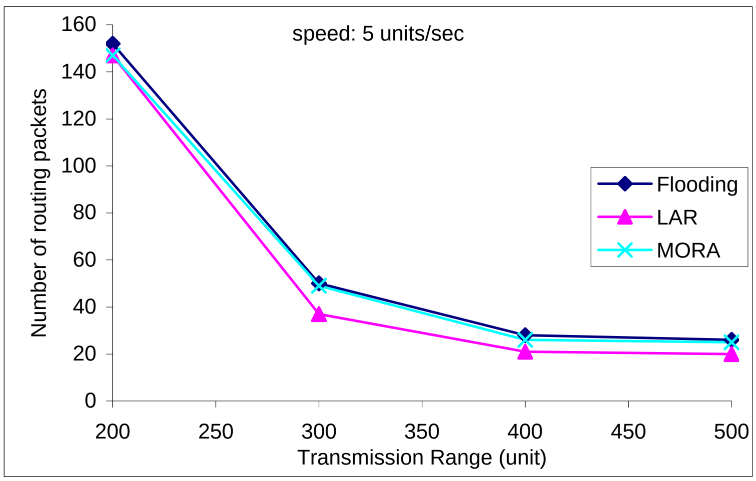
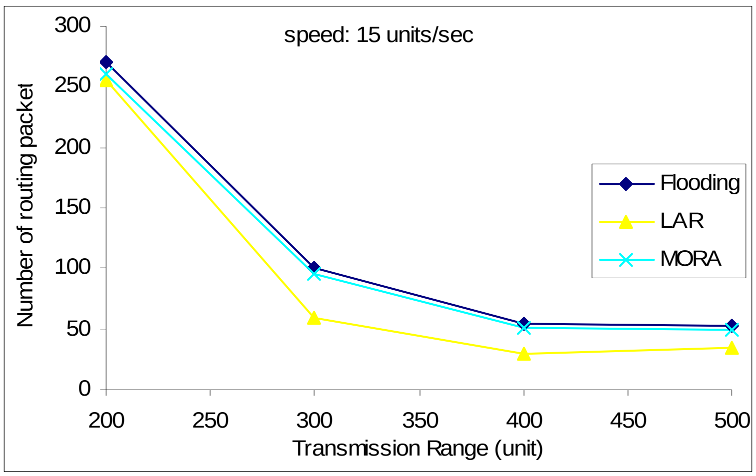


Figure 2



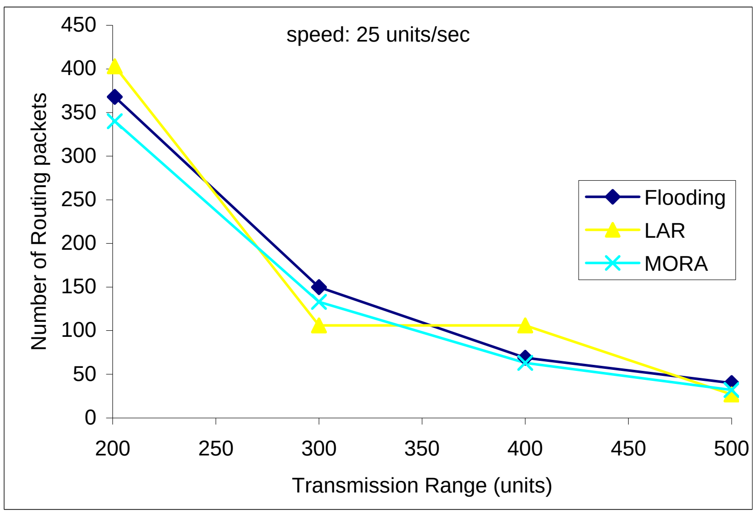
speech: 5 units/sec
Number of routing packets
Transmission Range (unit)
Flooding
LAR
MORA
0
20
40
60
80
100
120
140
160
200
250
300
350
400
450
500

Figure 3



speed: 15 units/sec
Number of routing packet
Transmission Range (unit)
Flooding
LAR
MORA
300
250
200
150
100
50
0
200
250
300
350
400
450
500

Figure 4


speed: 25 units/sec
Number of Routing packets
Transmission Range (units)
Flooding
LAR
MORA
0
50
100
150
200
250
300
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400
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200
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300
350
400
450
500

Figure 5

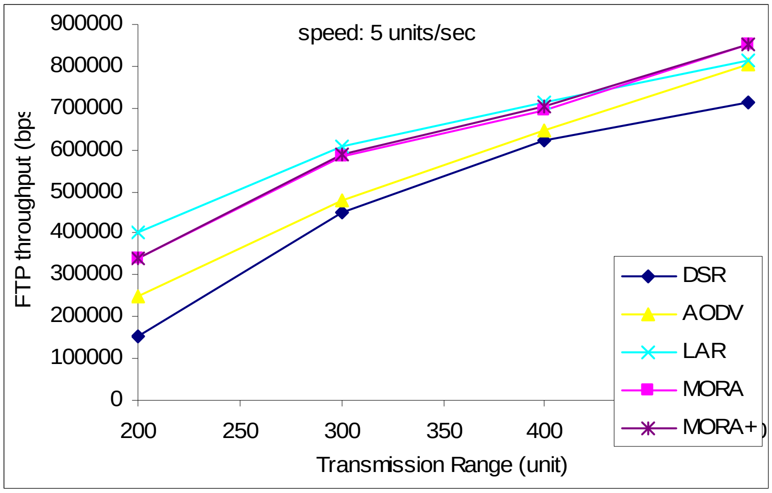
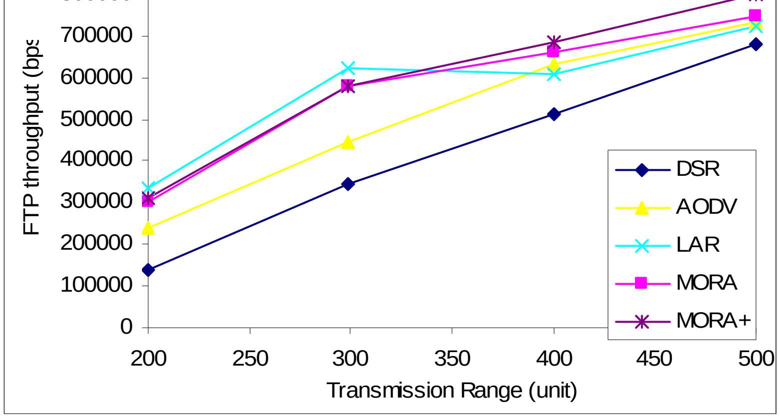
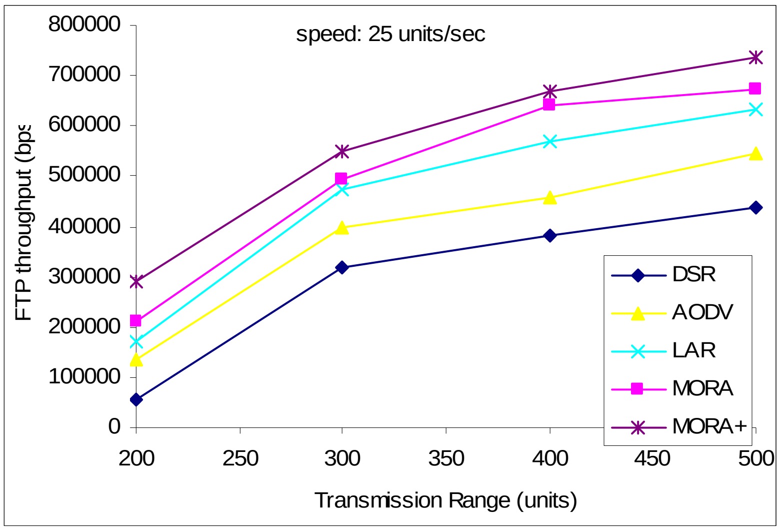

speed: 5 units/sec
FTP throughput (bps
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
200
250
300
350
400
Transmission Range (unit)
DSR
AODV
LAR
MORA
MORA+

Figure 6



speed: 15 units/sec
FTP throughput (bps
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
200
250
300
350
400
450
500
Transmission Range (unit)
DSR
AODV
LAR
MORA
MORA+

Figure 7



speed: 25 units/sec
FTP throughput (bps
800000
700000
600000
500000
400000
300000
200000
100000
0
200
250
300
350
400
450
500
Transmission Range (units)
DSR
AODV
LAR
MORA
MORA+

Figure 8

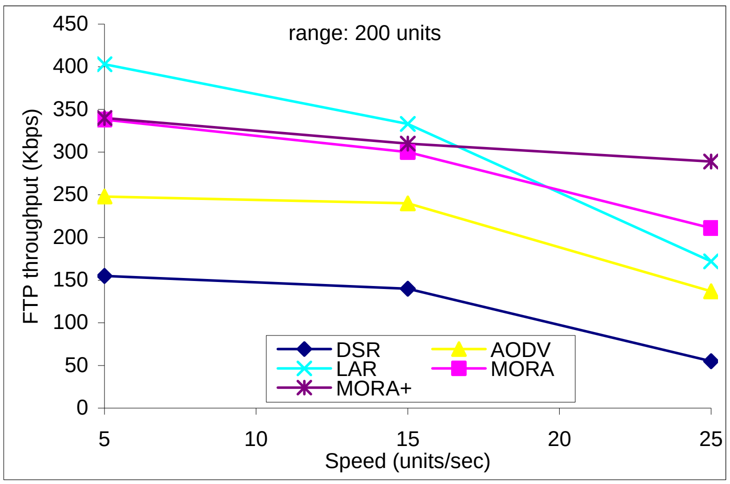

range: 200 units
FTP throughput (Kbps)
Speed (units/sec)
0
50
100
150
200
250
300
350
400
450
5
10
15
20
25
DSR
AODV
LAR
MORA
MORA+

Figure 9

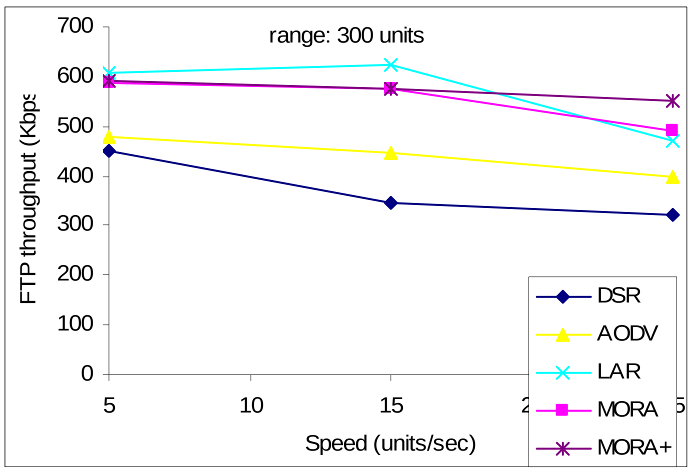
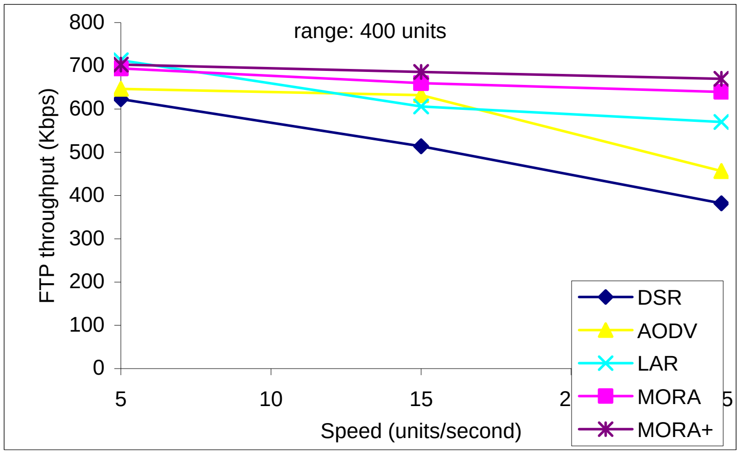
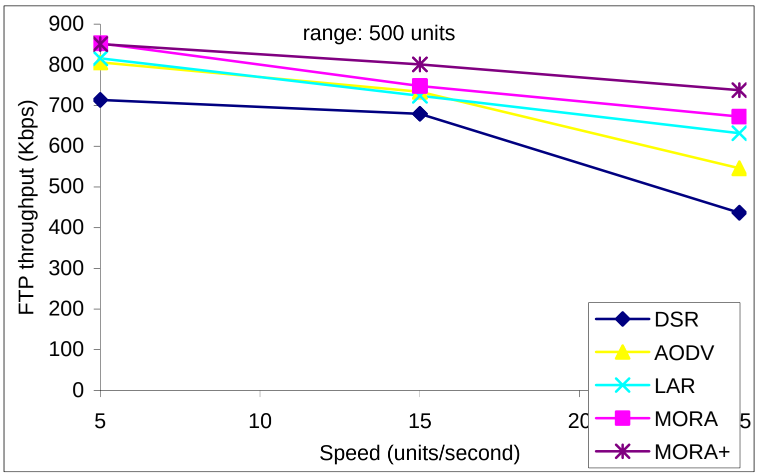

range: 300 units
700
600
500
400
300
200
100
0
FTP throughput (Kbps
5
10
15
Speed (units/sec)
DSR
AODV
LAR
MORA
MORA+

Figure 10



range: 400 units
FTP throughput (Kbps)
800
700
600
500
400
300
200
100
0
5
10
15
Speed (units/second)
DSR
AODV
LAR
MORA
MORA+

Figure 11



range: 500 units
FTP throughput (Kbps)
900
800
700
600
500
400
300
200
100
0
5
10
15
20
5
Speed (units/second)
DSR
AODV
LAR
MORA
MORA+

Figure 12