Journal of Computer Science 3 (7): 533-539, 2007
ISSN 1549-3636

Proximity Aware Routing in Ad Hoc Networks

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Abstract: Most of the existing routing protocols for ad hoc networks are designed to scale in networks of a few hundred nodes. They rely on state concerning all links of the network or links on the route between a source and a destination. This may result in poor scaling properties in larger mobile networks or when node mobility is high. Using location information to guide the routing process is one of the most often proposed means to achieve scalability in large mobile networks. However, location-based routing is difficult when there are holes in the network topology. We propose a novel position-based routing protocol called Proximity Aware Routing for Ad-hoc networks (PARA) to address these issues. PARA selects the next hop of a packet based on 2-hops neighborhood information. We introduce the concept of "proximity discovery". The knowledge of a node's 2-hops neighborhood enables the protocol to anticipate concave nodes and helps reduce the risks that the routing protocol will reach a concave node in the network. Our simulation results show that PARA's performance is better in sparse networks with little congestion. Moreover, PARA significantly outperforms GPSR for delivery ratio, transmission delay and path length. Our results also indicate that PARA delivers more packets than AODV under the same conditions.

Keywords: Mobile ad hoc networks, location-based routing, AODV

INTRODUCTION

Ad hoc networks consist of autonomous nodes that collaborate in order to forward packets. There is no stationary infrastructure. Thus, each node acts as an end system and a router at the same time. In mobile ad hoc networks, nodes may move arbitrarily. Since such networks can change their topology drastically and unpredictably, routing is a central challenge in the design of ad hoc networks.

Two types of routing algorithms for ad hoc networks have been studied in the literature: topology-based routing and geographical routing. In topology-based routing, a route discovery explicitly finds routes among nodes. Such routing relies on state concerning all links in the network or links on a route between a source and a destination. Consequently, topology-based routing hardly scales with large mobile ad hoc networks.

More recently, there has been a growing interest on geographical routing which provides an alternative to topology-based routing. One of the most frequently used routing schemes consists in selecting the next hop of a packet in such a way that the packet is forwarded to the neighbor minimizing the remaining distance to the destination. This approach called "greedy forwarding" faces one major drawback: when no neighbor is closer to the destination than the forwarding node, a local maximum is reached. The current node is said to be concave. Many approaches have been proposed to recover from this local optimum. GPSR uses perimeter forwarding to route the packet around the problem region. However, perimeter mode may result in a non-optimal path if the source and the destination are not well connected along a straight line. Furthermore, perimeter mode may lead to routing loops and thus to packet drops.

The Proximity Aware Routing for Ad-hoc networks (PARA) protocol proposed in this paper aims at anticipating concave nodes so as to optimize the benefits of position-based routing while taking into account topology irregularity and node mobility. PARA chooses the next hop of a packet based on the 2-hops neighborhood of the forwarding node. The utilization of a 2-hops neighborhood enables our protocol to anticipate and to reduce the probabilities for a packet to reach a "hole" in the network where its geographical progress towards destination will not be possible.

The remainder of this paper is organized as follows. In Section 2 we present an overview of prior work on routing algorithms for mobile ad hoc networks. Section3 contains a detailed description of proximity aware routing. The PARA routing algorithm is fully described. Then, in Section 4, PARA's performance is compared to AODV and GPSR by means of simulation. Finally, Section 5 points out directions of future work and concludes the paper.

At the network layer, routing protocols are the main mechanism. A routing protocol finds routes through the network and transports user traffic from source to destination. In MANETs, a route is defined by a set of mobile nodes that contribute to the transmission of the data from source to destination. A lot of topology-based routing protocols were designed for rather small networks with up to some hundred

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nodes[26]. Depending on the way routes are established we distinguish two types of topology-based protocols: proactive and reactive protocols. Proactive protocols attempt to maintain consistent and updated routing information for every pair of nodes by propagating, proactively, route updates at fixed time intervals. Reactive on demand routing protocols, on the other hand, establish a route to a destination only when there is a demand for it.

For on-demand protocols, the source node has to wait for the route to be discovered before communication can happen. This latency in route discovery might be intolerable for real-time communications. As such, proactive routing protocols may provide better Quality of Service (QoS) for some service requirements than on-demand protocols[7]. As routing information is constantly updated in proactive protocols, routes to every destination are always available and up-to-date, and hence end-to-end delay can be minimized[1,2,3].

Reactive protocols, such as DSR[9] and AODV [10] generally work well in medium size networks with moderate mobility, while proactive protocols are considered more suitable for small scale static networks. In the last few years, according to these observations, more attention was given to reactive protocol design, as they result in more scalable networks.

In[4], Conti et al. discuss a lightweight mechanism that enables reliable and efficient forwarding, and that mitigates the effects of adverse situations caused by cooperation misbehavior or network fault conditions. Chakrabarti and Kulkarni[5] present a novel way of preserving QoS guarantees in DSR by pre-computing alternate routes to a destination and using these alternate routes when the current route fails. Their method ensures that traffic load is balanced among the alternate routes but also that an appropriate amount of bandwidth will be available for a flow even when nodes move. In[6], Argyriou and Madisetti introduce a novel end-to-end approach for achieving the dual goal of enhanced reliability under path failures, and multi-path load balancing in AWNs. These goals are achieved by fully exploiting the presence of multiple paths.

In[8] Chen and Heinzelman present QoS-aware routing protocol that incorporates an admission control scheme and a feedback scheme to meet the QoS requirements of real-time applications.

Location-based routing only requires nodes to know their own positions and notify it to their neighbors and thus does not require the establishment of any route prior to data transmission. Specifically, a node selects the next hop to forward a packet to, based on the physical position of its one-hop neighbors, and the physical position of the destination node. A large number of position-based routing algorithms were proposed in the literature[11,12].

The greedy scheme was proposed in[16] and consists in selecting the node closest to the destination. In the 2-hops greedy method [17], node A selects the best candidate node C among its 1-hop and 2-hops neighbors according to the corresponding criterion (distance or progress). With Greedy forwarding, the transmitting node selects one of its neighbor to be the next hop of the packets based on a specific criterion.

However, greedy forwarding fails when no neighboring node has forward progress although a route to the destination may exist through other intermediate nodes farther to the destination. Recovery mechanisms were proposed which allow transmitting a packet to a node with backward progress if the packet got stucked [18,19].

Blazevic *et al*.,[20] proposed a location-based routing scheme for networks containing topology holes and where nodes are mobile or frequently disconnected. In [21], the authors also propose an algorithm to build route around holes in sensor networks. Greedy Perimeter Stateless Routing (GPSR) [27] is based on planar graph traversal.

A pre-requisite for position-based routing is to know the position of the destination of a packet. For this purpose, distributed algorithms, called location service, such as GRSS (Geograhical Region Summary Service)[22] have been proposed. The source node can lookup for the destination position from such a service and include it in the packet header.

A GPS free positioning algorithm – Local Coordinate System (LCS) was proposed by Capkun et al. in[23]. Many other positioning algorithms can be found in the litterature [24,25].

PROXIMITY AWARE ROUTING ALGORITHM

The PARA routing algorithm assumes that each node knows its geographic coordinates (longitude, latitude, altitude) by the means of GPS or, if GPS is not available, GPS-free positioning methods. Further, we assume that there exists a location management service, such as GLS or GRSS which enables a source node to determine the destination location. We also consider that network use the same type of radio devices to communicate with each other, all having the same radio range. In addition, communication links are assumed to be symmetric.

PARA is a compromise between topology-based and geographical-based routing algorithms. It uses a novel position-based forwarding scheme which anticipates concave nodes as long as the network topology allows it. PARA uses the following steps to achieve its goal.

First, it does not use any beaconing mechanisms such as HELLO messages in AODV or location beacons like other position-based algorithms. PARA adopts an on-demand approach.

Second, it uses the concept of proximity discovery. When a source node S initiates a communication with another node, it launches a proximity discovery by broadcasting proximity requests. This proximity discovery enables S to identify its immediate neighbors, but also its 2-hops neighbors. Proximity discoveries are also performed by the intermediate nodes to forward the packet. Indeed, PARA chooses the next hop N of a packet destined to destination D, according to N's distance to D, but also by taking into consideration N's neighbors' distance to D. Thus, instead of forwarding the packet to the neighbor that minimizes the remaining distance to reach D, PARA sends it to the neighbor that:

- Maximizes the packet's geographic progress towards destination *D* or in other words, that reduces the remaining distance to the destination node compared to the forwarding node;
- Possesses the highest number of neighbors that are geographically closer to *D* than itself.

This approach thus enables PARA to anticipate holes in the network topology and consequently to reduce the probability that a packet reaches a concave node. Consider the mobile ad hoc network illustrated in Figure 1a. The source node S needs to transmit a packet to destination node D. In classical approaches, the packet would be sent to neighbor V1, although we can clearly see that it is concave. Using the proximity discovery mechanism, PARA can eliminate such ineffective packet forwarding. Thus, as we can see on Figure 1a, PARA forwards the packet to neighbor V2 which does not achieve the greatest geographic progress towards D, but that enables the packet to reach D without any recovery procedure.

GPSR uses perimeter mode to route the packet around the problem region where greedy forwarding fails. An important issue with GPSR perimeter mode is that it may generate a suboptimal path in large or sparse networks. It is also not loop free. To address this issue, PARA relies on a new recovery procedure which takes into account or anticipates concave nodes in the network. Nonetheless, if the recovery procedure is not successful, AODV is used to route the packet to destination. This guarantees the absence of routing loops and the use of shortest paths to reach the destination.

A node is said to be active when it generates or forwards data packets. We refer to the active destinations of an active node as the set of its data packet destinations. Suppose a forwarding node N having a packet destined to destination node D. Each neighbor V of N, which is closer to D than N is called N good neighbor and noted GNN, D (V). The accessibility index, IsDest(GNN, D (V)), reflects the accessibility of destination D through good neighbors set GNN, D (V).

In addition to the distance to the destination and the accessibility index, another parameter is used by PARA: the proximity index. The proximity index of next hop N for a specific destination D, IProx(N, D), is defined as the number of N's immediate neighbors that are geographically closer to D than N, that is N's good neighbors number. This parameter reflects the chances for a packet to geographically progress towards its destination D via node N. The larger the number of N's good neighbors, the lower the probability to reach a concave node through N. Indeed, the number of nodes that can reduce the distance to the destination is then higher. If, on the contrary, node N has a null proximity index, then none of its immediate neighbors can ensure the geographic progress of a packet towards D. In this case, N is said to be concave. In other words, N should not be chosen to forward the packet. A node is said to be anticipated concave if each of its good neighbors is concave. Figure 1b presents an example of anticipated concave node.

Node M has a packet destined to D. Nodes V1 and V2 are closer to D than M. Then they are M's good neighbors for destination D. However, none of these nodes have neighbors closer to D than themselves. Consequently, V1 and V2 are concave and node M is anticipated concave. When such an antipated concave node is detected, PARA's recovery procedure may be used.

In the following sections, we present PARA routing by describing in detail every aspect of the protocol.

Communication initialization: A node N initiates a communication with node D if it generates a data packet destined to D or if it receives a packet that needs to be forwarded to destination D from another node. Node N then becomes active. However, as it does not have any knowledge of the surrounding nodes, N is not able to forward the packet. Indeed, in both cases just mentioned, N's good neighbor table for destination D is empty. This table will be populated during the initial proximity discovery for D while all data packets generated or received for destination D will be buffered. When the proximity discovery phase ends, buffered packets will be forwarded to the next hop.

Proximity discovery walk through: The proximity discovery is the process enabling a node N to discover its immediate neighborhood, as well as its 2-hops neighborhood. As was mentioned, PARA relies on an on-demand approach. Initially, a node has no knowledge of its surrounding nodes. Thus, each node initiating a communication has to trigger a proximity discovery in order to determine the next hop of its data packets. Thereafter, periodical proximity discoveries will keep its good neighbor table up-to-date. At the end of a proximity discovery, node N:

- Has an up-to-date good neighbor table;
- Can determine its own proximity index from the content of its good neighbor table;
- Is able to choose the next hop of a data packet;

We distinguish two types of proximity discoveries depending on the goal of the discovery. Thus, a proximity discovery can be:

- Initial: the discovery is triggered as soon as a communication with a specific destination is initiated.
- Periodical: when a node switches from an inactive to an active state, it starts a trigger which will ensure the periodical launch of proximity discoveries. These periodical proximity discoveries keep the good neighbor

table up-to-date for each of its active destinations.

Next hop choice: PARA aims to reduce the risk to reach a concave node. Assume node N has a packet to send to node D. Instead of forwarding the packet to its neighbor that is closest to the destination D, as in most position-based approaches, PARA forwards the packet to the node V that:

- Is a good neighbor, which reduces the remaining distance to the destination *D*:
  DIST(V, D) < DIST (N, D)
- Has, among all *N's* good neighbors, the higher number of good neighbors for destination *D*:
  $I\Pr ox(V) = \max(I\Pr ox(I))_{I \in MV_N}$

PARA anticipates the presence of concave nodes by forwarding the packet to the node which has the highest number of good neighbors, thus attempting to raise the chances of geographical progress towards the destination. The accessibility index is used in order not to lengthen the route to the destination when the destination is directly reachable through a good neighbor. Hence, for each active destination, good neighbors are ordered in the table according to their priority as determined by their accessibility index, proximity index and distance to the destination.

Packet forwarding: As mentioned early, when node N generates or receives a packet destined for a node for which it does not have any information in its good neighbor table, it launches an initial proximity discovery for this destination and buffers the packet. All packets destined for D received or generated before the end of the initial discovery are also buffered.

PERFORMANCE EVALUTATION OF PARA ROUTING

To measure the performance of PARA, we simulated the algorithm on a variety of MANET topologies. The performance of our protocol was also compared against the performance of AODV and GPSR, well-known reactive and location-based protocols.

Simulation environment: The simulations were performed using the ns-2 network simulator. All node were using the existing IEEE 802.11 Medium Access Control (MAC) protocol with the Distributed Coordination Function (DCF). The radio range was 250 m and the channel capacity 2 Mbps.

The ns-2 wireless simulation model simulates nodes moving in an unobstructed plane. All nodes move according to the random way point model with a maximum speed of 20 m/s.

Our simulations do not include a distributed location database for annotating packets with the destination's position. We argue that the PARA approach to routing warrants investigation into efficient location database, such GLS or GRSS.

PARA periodical proximity discovery interval may influence the results obtained. Thus, a decrease in precision in best neighbor table caused by a longer interval of periodical proximity discoveries will result in reduced delivery success rate. However, to limit the number of simulations, we only simulated PARA with prequest_interval = 1.5s. AODV parameters are compliant to RFC 3561. Table 1 and Table 2 give a summary of the parameters used for PARA and GPSR.

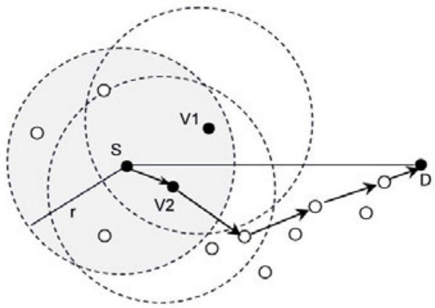
Simulated scenarios: Many factors will influence the performance of the evaluated protocols. To study their impact on the protocols' behavior, we vary experimental conditions in different network scenarios.

Network diameter: The number of control packets generated by AODV and GPSR depends on the number of nodes in the network. We simulated ad hoc networks containing 50 and 100 nodes.

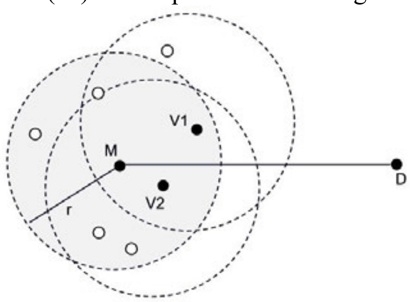
Node connectivity: In most studies based on MANET simulations, nodes are connected in a dense way. In [27], GPSR performs well mostly because it operates in greedy mode. Thus, in a dense network, almost every node has a path to each other node in the network, generally a few hops away. In addition, the control overhead may cause congestion. A sparse network possesses different characteristics. In such networks, a path between two nodes does not always exist, the network may be partitioned and routing decisions are affected by node mobility. To evaluate PARA's ability to anticipate concave nodes in the network, we simulate different network densities.

To obtain different average node connectivity, we expand the network region as shown in Table 3. According to the average node connectivity, we classify the simulated topologies as sparse (each node has an average of approximately 5 neighbors), quite dense (each node has an average of approximately 13 neighbors) and dense (each node has an average of approximately 20 neighbors).

Node mobility: Nodes move according to the random waypoint model. A node chooses one random destination in the simulation area. Then, it moves to that destination at a random speed (uniformly chosen between 0 - 20 m/s). Upon reaching its destination, the node pauses for a pause time before repeating the same process. In this model, the pause time reflects the degree of mobility in a simulation. We simulated pause times of 0, 40, 80, 120, 160, 200 and 300 seconds.

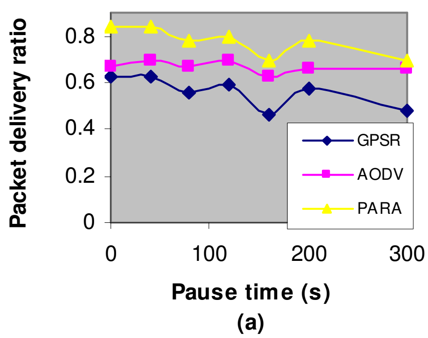


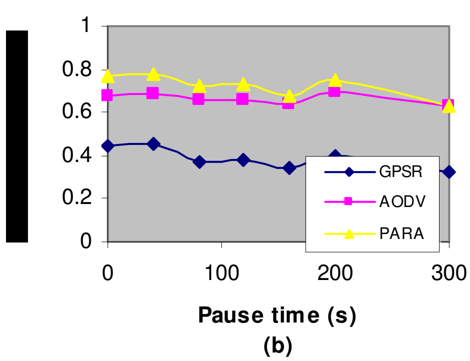
(1a) PARA packet forwarding



(1b) Anticipated concave node

Fig 1: Proximity Aware Routing for Ad-hoc networks





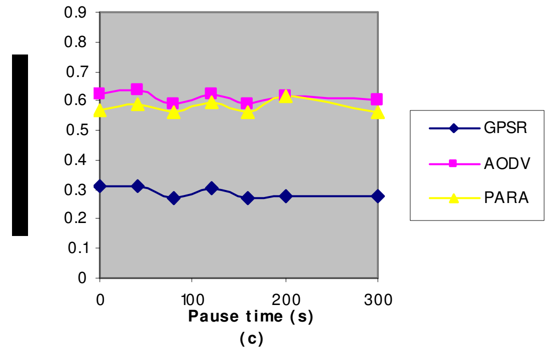


Fig. 2: Packet delivered ratio with 50 sparse nodes for (a) 10, (b) 20 and (c) 30 CBR connections

Table 1: PARA parameters

Parameter	Value (seconds)
Prequest_interval	1.5
Discv_delay	0.07
Reply_delay	0.05
Validity period for each entry (3 · *prequest_int*)	4.5

Table 2: GPSR parameters

Parameter	Value (seconds)
Beacon_interval	1.5
Beacons implicates	Yes
Mode perimeter	Yes

Data traffic: On-demand routing protocols initiate routing activities only in the presence of data packets in need of a route. Thus the number of traffic flows has an influence on protocol overhead. We simulate 10, 20 and 30 CBR traffic flows. Each CBR flow sends packets at 2 Kbps. The packet size is limited to 64-byte packets to reduce the impact of the IEEE 802.11 MAC on the measured routing protocol behavior. CBR connections are started at times uniformly distributed between 100 and 330 seconds.

Simulations run for 900 seconds. Each data point represents an average of many runs with identical traffic model, but different randomly generated mobility scenarios.

SIMULATION RESULTS

We evaluate PARA, GPSR and AODV using five metrics: packet delivery ratio, average end-to-end delay, normalized routing load and average path length. In the following we discuss our results for 50 and 100 nodes.

Packet delivery ratio: The packet delivery fraction is the ratio of the data packets delivered to the destinations to data packets generated by sources.

Table 3: Connectivity scenarios

Nodes	Region	Node density	Connectivity
50	1500 m x 300 m	1 node / 9000 m^2	21
	1500 m x 500 m	1 node / 15000 m^2	13
	1500 m x 1300 m	1 node / 39000 m^2	5
100	2250 m x 1730 m	1 node / 39000 m^2	5

Figure 2 shows the packet delivery fraction in a 50 nodes sparse network for varying CBR connections numbers. As expected, PARA performs better in sparse networks with low traffic load (10 CBR connections). PARA delivers more data packets than GPSR and AODV in networks with low or medium traffic load (20 CBR connections) (Figure 3 (a) and (b)) especially when the mobility is high. However, AODV packet delivery ratio is closer to PARA's. AODV does not need to know a node's position in order to deliver packets. Thus it is not sensitive to the connectivity degree of the nodes contrary to GPSR, which does not perform well in sparse networks, revealing the perimeter mode weak points. Most of the packet drops with GPSR are due to loops in perimeter mode.

On the other hand, in dense networks, PARA outperforms AODV and GPSR as long as there is no congestion in the network (with 10 CBR connections). However, with 30 CBR connections, PARA performs similar to AODV.

Node mobility does not influence PARA packet delivery fraction. Hence, as in all position-based approach, routing decisions are taken at each active node. The concept of route does not exist. In this context, routing is less affected by node mobility than with AODV when a route is established between the source and the destination of the packet. In this case, each link break requires several nodes to find a new route. Then, in high mobility network, AODV suffers more from link failure than GPSR and PARA.

CONCLUSION

The routing scheme presented in this paper aims aims at anticipating concave nodes so as to optimize the benefits of position-based routing while taking into account topology irregularity and node mobility. Using location information to help routing is often proposed as a means to achieve scalability in large mobile networks. However, location-based routing is difficult when there are holes in the network topology. Thus, the power of position-based forwarding in its basic form comes with one drawback: when no node is closer to the destination then the current node, a local maximum is reached. Then the current node is said to be concave. Many approaches were proposed to recover from this local optimum. GPSR uses perimeter forwarding to route the packet around the problem region. Perimeter mode may give suboptimal paths in networks where the source and the destination nodes are not well connected. Furthermore, perimeter mode may lead to routing loops and thus to packet drops. We have proposed a novel position-based routing protocol called Proximity Aware Routing for Ad-hoc networks (PARA) to address these issues. PARA selects the next hop of a packet based on its direct neighborhood, but also on its 2-hops neighborhood. We introduced the concept of "proximity discovery". The knowledge of 2-hops neighborhood enables the anticipation of concave node and helps to reduce the risks to reach a hole in the network.

The PARA protocol was simulated using the ns-2 network simulator along with AODV and GPRS protocols. These three routing schemes were compared in a variety of mobility, network size, and traffic load conditions. Our simulation results show that PARA performs better in sparse networks with little congestion. PARA significantly outperforms GPSR in packet delivery ratio and transmission delay. Our results also indicate that PARA delivers more packets than AODV under the same conditions.

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