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A dynamic cross-layer routing protocol for Mobile Ad hoc Networks

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ABSTRACT

A new cross-layer routing protocol, named *Dynamic Packet Guidance* (DPG), is introduced for *Mobile Ad hoc Networks* (MANETs). Simulation results show that DPG is quite useful for usage in dense networks of mobile nodes, with medium-to-high speeds, and low-to-medium load. In these scenarios, DPG provides a superior performance compared to several well-known ad hoc routing protocols. The low end-to-end delay and smaller overhead that DPG achieves in such scenarios positively impacts the scalability of MANETs and reduces the energy requirements of nodes in such networks. DPG also shows immunity to failing nodes, as it operates consistently almost independently of failing nodes up to a certain ratio.
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1. Introduction

Mobile Ad hoc Networks (MANETs) are wireless networks that operate without infrastructure, nor prior knowledge of the network's topology [1]. Nodes in such networks are free to move randomly and organize themselves arbitrarily. MANETs have received considerable research attention over the past years due to their individual characteristics and ease of deployment. Nowadays, MANETs find applications in mesh-based mobile networks, military operations, wearable computing, and home networking.

A number of challenges face the designers of *routing protocols* for MANETs. Such protocols should guarantee the efficient delivery of data across ad hoc networks while maintaining a minimum communication overhead, high throughput and low end-to-end delay. The designer is faced with bandwidth constraints of the wireless links, fading, interference, packet loss, exhaustible energy supply, limited computing capabilities, and a dynamic (rapidly changing) topology.

In response to the above challenges, several ad hoc routing protocols have been proposed in literature [2–18,24–27], which we classify and summarize in the next section. Each and every one of these protocols presents a tradeoff between the different design objectives for MANETs, and adds to our understanding of the nature and characteristics of such a dynamic network.

In this paper, we contribute to this understanding by proposing a new reactive wireless ad hoc routing protocol that exhibits unique features in practical MANET scenarios; specifically when nodes are dense, the network topology is changing fast, communication is between a small number of pairs, while small delay and reduced overhead in delivering data packets are essential.

We assess the performance of the proposed protocol, which we name the *Dynamic Packet Guidance* (DPG) protocol, to better understand its characteristics and points of strength. We also compare it using simulations to three popular MANET routing protocols: *Dynamic Source Routing* (DSR) [3,4], *Ad hoc On Demand Distance Vector* (AODV) [5,6], and also the most recent standardization effort, the *Dynamic MANET On-demand* (DYMO) [7].

The rest of this paper is organized as follows. Section 2 introduces the different classes of ad hoc routing protocols, and presents the concepts of Route Discovery and Route Maintenance in the context of DSR, AODV and DYMO. Section 3 gives a detailed description of the behavior and characteristics of the proposed DPG protocol. Section 4 presents the simulation setup and the performance results for the DPG protocol together with the analysis and explanation of these results. Finally, Section 5 concludes our work and talks about possible future research.

2. Ad hoc routing protocols

2.1. Background

An ad hoc routing protocol dictates how an ad hoc network should be logically structured so that data packets can travel over multiple hops between source and destination nodes. This is done

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by running a distributed set of rules that are identical at all nodes. The routing protocol plays a key role in the design of MANETs since it controls the tradeoffs between the reliability, fairness, scalability, throughput and latency achieved by the network.

Ad hoc routing protocols can be classified into one of three categories: *flooding* protocols, *clustering* protocols and *geographical* protocols. We briefly discuss these categories below:

Flooding protocols are amongst the first and most enduring set of protocols to be proposed for MANETs. In their simplest form, these protocols deliver data by requiring the source node to *broadcast* its packet to all of its neighbors, each of which relays the packet to their neighbors (again by broadcasting), until the packet arrives at the destination, or the maximum number of hops is reached.

Implementing flooding protocols necessitates very little computational complexity and requires very little memory at the various nodes. In addition, flooding protocols can adapt very quickly to any link unreliability or node movement, which makes them quite attractive. However, flooding protocols suffer from large energy expenditures as extra copies of the same packet are unnecessarily sent to the same node by different neighbors. In addition, many nodes not located on the path between the source and destination transmit and receive unnecessary copies of that packet, thus wasting their resources.

To improve on the scalability of flooding protocols, flooding can be limited to only a few *control* packets, which allow the nodes to know and maintain the topology of the network (i.e., build their local routing tables). Afterwards, DATA packets can be sent as unicast packets from hop to hop to the destination without the need for broadcasting.

Such improved flooding protocols are very popular in literature and can be subcategorized into *proactive*, *reactive* and *hybrid* routing protocols:

- A proactive protocol (such as the Destination Sequenced Distance Vector (DSDV) protocol [2] and the Optimized Link State Routing (OLSR) protocol [26,27]) continuously learns the topology of the network by periodically flooding topological information among the network nodes. Thus, when there is a need to forward a DATA packet to a destination, the routing information to that destination is up-to-date and available immediately. There are two problems in such proactive protocols: (a) if the network topology changes too frequently, the amount of control packets exchanged to maintain the network topology becomes very high and (b) if the number of active communicating nodes is low, information about most of the network topology will be needlessly collected.
- On the other side of the coin, reactive routing protocols do not maintain a consistent and up-to-date routing information to every node in the network. Instead, they find a route only when needed (i.e., *on demand*) by flooding the network with Route Request (RREQ) packets and waiting for Route Reply (RREP) responses. This makes sure that the routing overhead scales automatically to only what is needed to react to changes in the routes currently in use. However, such reactive protocols have to slightly delay the transmission of the first DATA packet in a data stream until proper routing information is found. The most familiar reactive ad hoc routing protocols are: DSR, AODV and DYMO.
- Finally, in hybrid routing protocols a mixture of the reactive and proactive features are used to exploit specific advantages. An example is the Zone Routing Protocol (ZRP) [18], in which a node maintains proactively all routing information in its local neighborhood, called the *routing zone*. However, for all destinations beyond the routing zone, routes are acquired on demand.

The second category of ad hoc routing protocols is called clustering protocols, in which nodes in the network are grouped into clusters, with a cluster head elected for each single cluster [24,25]. When a node wants to transmit a DATA packet, it first sends the packet to its own cluster head, who sends it to the other cluster head, who finally forwards the packet to the destination node. Because of the way these routing protocols operate, cluster heads in such paradigms are expected to have superior processing power and higher energy reserves. Another drawback of this class of routing protocols is that they have problems catering for movements and/or failure of nodes, as new clusters need to be formed and new cluster heads need to be elected. Examples of cluster-based routing algorithms include: Low-Energy Adaptive Clustering Hierarchy (LEACH) [12] and Hybrid Energy-efficient Distributed clustering protocol (HEED) [13].

Finally, in geographical routing protocols, nodes are presumed to have perfect knowledge of their geographical location in the network. The knowledge of the exact location of each node simplifies the process of building network-wide routes, as nodes can relay the packets to their neighbors geographically closest to the destination. However, having each node know its location comes at a price, such as the cost of a Global Positioning System (GPS) hardware at each node, or the energy needed to continuously run this GPS hardware. Examples of such routing techniques include: Greedy geographic routing [14], Greedy Perimeter Stateless Routing (GPSR) [15], End-to-End routing process (EtE) [16], and Beaconless Forwarder Planarization (BFP) [17].

In the following sections, we narrow our focus to reactive flooding-based routing protocols by discussing the most popular protocols in this category: DSR, AODV and DYMO.

2.2. Dynamic Source Routing (DSR)

DSR uses explicit *source routing*, in which each DATA packet carries in its header the complete, ordered list of nodes through which the packet should pass [3,4]. This use of explicit source routing allows the sender to select and control the routes used for its own packets, supports the use of multiple routes to any destination (for example, for load balancing or increased robustness), and allows a simple guarantee that the routes used are loop-free. However, because of source routing, DSR suffers from the fact that the header size of DATA packets increases with increasing route length.

To obtain the routes to arbitrary destinations in the ad hoc network, the DSR protocol invokes the two main mechanisms of *Route Discovery* and *Route Maintenance*. Route Discovery is activated on demand, that is to say, it is used only when *S* attempts to send a packet to *D* and does not already know a route to *D*.

To initiate Route Discovery, node *S* transmits a RREQ as a single local broadcast packet, which is received by node *S* neighbors. Each RREQ identifies the source and destination of the Route Discovery, and also contains a unique request identifier, determined by the initiator of the RREQ. Each RREQ also contains a record listing the address of each intermediate node through which this particular copy of the RREQ has been forwarded.

If the node is not the target of the Route Discovery, it appends its own address to the route record in the RREQ and propagates it by locally broadcasting the packet, with the same request identifier. An exception to this rule occurs if the node receiving the RREQ has recently seen another RREQ message from the same source bearing the same request identifier, in which case the node discards the RREQ.

When node *D* receives the RREQ, it returns a RREP to the initiator of the Route Discovery, giving a copy of the accumulated route record from the RREQ. In returning the RREP to the source, node *D* will typically examine its own Route Cache for a route back to the initiator and, if one is found, will use it as the source route for delivery of the RREP. Otherwise, it can simply (and optionally) reverse the route accumulated in the RREQ. When node *S*

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