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Abstract

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Keywords

heterogeneous routing, MANET, unidirectional links

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A Routing Strategy for Heterogeneous Mobile Ad Hoc Networks

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***Abstract*— This paper presents a new routing strategy for heterogeneous Mobile Ad Hoc Networks. We refer to this strategy as On-demand Utility-Based Routing Protocol (OUBRP). This protocol introduces a Utility-Based route discovery strategy, which aims to minimise the number of control packets disseminated into the network during route discovery by efficiently using available resources at each node. Furthermore, we propose a new strategy to eliminate uni-directional links during the route discovery phase. We refer to this strategy as Uni-directional Link Elimination (ULE). We performed a simulation study to compare the performance of OUBRP with a number of different routing protocols proposed for MANETs. Our results show that OUBRP compared to other routing strategies produces significantly fewer control packets and achieves higher levels of successful packet delivery with increasing number of nodes. Furthermore, we propose a number of alternative Uni-directional Link Elimination strategies**

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I. Introduction

Mobile Ad Hoc Networks (MANETs) are mobile data networks, which are made up of a number of nodes, which are all capable of performing routing in a distributed fashion. This new approach in networking promises a totally self-reliant way of providing end-to-end communication over single or multiple hops in a dynamic environment. This attractive feature of these networks make them a likely candidate technology in providing a seamless method of communication in scenarios where a communication infrastructure does not exist or cannot be implemented. Two such scenarios include the search and rescue operations carried out by emergency services and military communications.

Much of the research performed for MANETs assumes that these networks are made up of homogeneous devices. That is, all devices in the network have identical capabilities. In reality, in the envisioned applications, the network may consist of devices with different capabilities. For example, during an emergency recovery mission, a number of different communication devices may be used, which can have different capabilities (such as different levels of transmission range), and different constraints (such as different user requirements). In such scenarios, the network is made up of devices with heterogeneous capabilities and constraints. Therefore, applying homogeneous networking strategies may not be a very efficient solution for a heterogeneous environment.

One challenging issue in MANETs is routing, which has received significant attention. Routing in MANETs can be classified into three categories: Proactive, Reactive and Hybrid. In proactive routing, each node periodically or conditionally determines a route to all parts or a sub-part of the network [5] [2]. In On-demand routing, each node only determines and maintains a route when it is required by a source node [3]. Hybrid routing protocols employ both proactive and reactive properties, in an attempt to provide a highly scalable routing solution for MANETs [4][6][1]. However, these strategies assume that the network is entirely made up of Homogeneous devices. Therefore, they do not make adjustments according to the resources available at each node and their capabilities.

Heterogeneous MANETs have not received much attention. Previous work in Heterogeneous MANETs include [8], where the authors propose a new approach to optimised flooding in a Heterogeneous environment. In this paper, we propose On-demand Utility-Based Routing Protocol (OUBRP), which is designed to improve the efficiency of on-demand routing protocols under a Heterogeneous networking environment.

The rest of this paper is organised as Follows. In section II, we describe an On-demand Utility-Based Routing Protocol. Section III describes our simulation model and Section IV presents a discussion of our results. Section V presents a number of alternative strategies, which aim to improve the performance of OUBRP. Finally, Section VI presents the conclusions.

II. Proposed Strategy

In this section, we introduce On-demand Utility-Based Routing Protocol. In current routing protocols proposed for MANETs it is assumed that the network is made entirely of homogeneous nodes [3][4][5][2]. In Heterogeneous networks there may exist varying types of devices with different capabilities. OUBRP, takes into account the possible heterogeniality of MANETs and proposes a new strategy to efficiency use the available resources in these networks, while minimising the number of control packets transmitted into the network.

A. Route Discovery in OUBRP

OUBRP aims to reduces the number of rebroadcasting nodes in the network during the route discovery phase. This is achieved through a utility-based route discovery algorithm, which selects the most resource rich nodes in the network. Route discovery is performed over a number of different iterations. In the first iteration the algorithm allows only the most resource rich (i.e. the nodes with the highest required utility level) nodes to re-broadcast during the route discovery phase. If the first iteration fails to determine a route to the required destination, then the source node reduces the utility level requirement (in calculated levels, after a route discovery

failure) to allow less resource rich nodes to also participate in routing. The route discovery algorithm (we refer to this algorithm as UBRD) for OUBRP is outlined below.

Algorithm *UBRD*

```
(* The Utility-Based Route Discovery algorithm *)
U_f ← Utility function for RREQ forwarding
RREQ_max ← Maximum number of route request retries
U_p ← Utility function for transmission power
U_l ← Utility function for load
U_b ← Utility function for battery power
P ← {1.0, 0.75, 0.5, 0.25} (* % requirement of utility *)
RREQ_max ← 4
for i ← 0, i ≠ RREQ_max, i++
      U_f ← (U_p.U_l.Ub).P_i
      Transmit_RREQ(U_f)
      wait for reply
      if Route = found
            break loop
            initiate data transmission
if Route = notfound
      Transmit_RREQ(No required utility)
      wait for reply
      if Route = found
            initiate data transmission
```

In the *UBRD* algorithm, the source node begins by calculating a utility function and assigns a minimum level of utility (i.e. P) to which each node must have in order to be able to rebroadcast the Route Request (RREQ) message. In the *UBRD* algorithm, we have chosen four different levels of utility requirement after which if a route to the required destination is not found, the source node will transmit and RREQ without a utility (i.e. all intermediate nodes are allowed to rebroadcast). Note that the idea behind our OUBRP comes as a result of the following observations:

1) By allowing the most resource rich nodes to participate or be part of an active route, we can reduce the stress on less resource poor nodes.
2) Minimising the total number of re-broadcasting nodes reduces the number of control packets disseminated Thereby redundancy, channel contention (reduce delay) and increasing available bandwidth.
3) Reduce the effect of route failure due do nodes being frequently drained of battery power.
4) Minimise the number of hops between the source and the destination by selecting nodes which have the highest transmission power. This in turn may reduce the end-to-end delay experienced by each data packet.

B. Uni-directional Link Elimination (ULE)

In a Heterogeneous routing environment where there are devices with different transmission capabilities (e.g. Transmission power), it is highly likely that many nodes may form uni-directional links. This can create problems during route discovery in on-demand protocols. For example, assume a node A with a high transmission power forwards a RREQ to another node B with lower transmission power, which has a route to the destination D. However, node A is not within node B's transmission range. In this case, the link reversal algorithms used in on-demand routing strategies such as AODV will fail. Furthermore, nodes may store inaccurate routing information in their routing table by assuming they have a reverse link to the sender (i.e. node B may assume that it has a link to node A and store this in its routing table). To solve this problem, we propose Uni-directional Link Elimination (ULE).

In this section we describe a GPS-based strategy which addresses this problem, which we refer to as ULE-L (i.e. ULE using Location information). In Section V, we present a number of alternative strategies for ULE.

In ULE-L, each node forwarding a RREQ stores its location information within the RREQ packet. The receiving node will then check to see if the forwarding nodes location falls within its transmission range. If yes, it updates its route table (i.e. assuming bi-directionality) and rebroadcasts the RREQ packet, or sends back a RREP if a route to the destination is known. Otherwise, it deletes the RREQ packet. In section IV, we implement this strategy on the top of AODV and illustrate the performance gains and the impact of this strategy on the success of the route discovery phase in AODV.

III. Simulation Model

We performed our simulations using the GloMoSim[7] simulation package. Our simulations were carried out for a network which contains 100 and 500 nodes which are migrating in a 1000m x 1000m area. IEEE 802.11 DSSS (Direct Sequence Spread Spectrum) was used with various transmission power ranging from 5dbm to 25 dbm (i.e. 5, 10, 15, 20 and 25) at a 2Mb/s data rate, and each node was assigned a different transmission power randomly at the startup. In the MAC layer, IEEE 802.11 was used in DCF mode. Random way-point mobility model was used with the node mobility ranging from 0 to 20m/s and pause time varied from 0 to 200s. The simulation was run for 200s for 10 different values of pause time, and each simulation was averaged over multiple simulation runs using different seed values. Constant Bit Rate (CBR) traffic was used to establish communication between nodes. Each CBR packet was 512 bytes and transmitted at 0.25s intervals. The simulations were ran for 20 different Flows (Client/Server) and each session was set to last for the duration of the simulation.

In our simulation, we used transmission power as the only metric in our utility function, to simulate a simple heterogeneous scenario. We implemented OUBRP on the top of AODV. We also implemented ULE-L on the top of AODV, which we refer to as AODV-ULE-L. Note that OUBRP implementation also includes the ULE-L strategy. Therefore, we were able to compare the performance of AODV with AODV-ULE and OUBRP.

The performance of each routing protocol is compared using the following performance metrics.

- Packet Delivery Ratio (PDR)
- Control Overhead
- End-to-End Delay

PDR is the Ratio of the number of packet sent by the source node to the number of packets received by the destination node. Control presents the number of routing packets transmitted through the network for the duration of the simulation. This metric will illustrate the levels of the introduced routing over head in the network. Finally, the End-to-End Delay metric illustrates the average end-to-end delay for transmitting one data packet from the source to the destination.

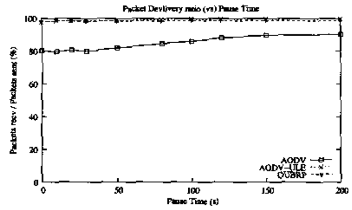

Fig. 1. PDR for 100N and 20 Flows

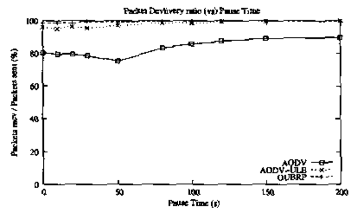

Fig. 2. PDR for 500N and 20 Flows

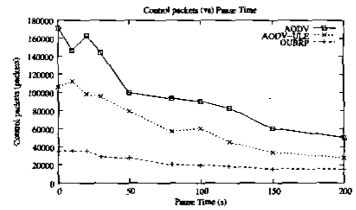

Fig. 4. Control(O/H) for 500N and 20 Flows

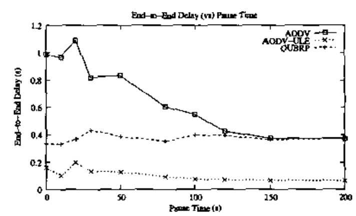

Fig. 5. End-to-end Delay for 100N and 20 Flows

IV. Results

This section presents the results we obtained for AODV, AODV-ULE-L and OUBRP (which also included ULE-L), and provides a performance comparison between each routing strategy.

Figures 1 and 2 illustrate the PDR results obtained for the 100 and 500 node network respectively. These figures illustrate the performance of the routing strategies in a medium to largely dense mobile ad hoc network. In both the 100 node and the 500 node scenario OUBRP and AODV-ULE-L achieve over 95% PDR. However, AODV only achieves up to 88% PDR for the 200s pause time, and for constant mobility (i.e. 0 pause time), it achieves approximately only 80% for both 100 and 500 node network scenarios. The lower delivery ratio achieved by AODV is due to the inaccurate route information stored in each nodes routing table as a result of the presence of uni-directional links. Our results for AODV-ULE-L shows that our uni-directional link elimination strategy successfully over comes this problems by achieving over 95% PDR.

Figures 3 and 4 illustrate the control overhead introduced for the 100 and 500 node network respectively. In both scenarios it can be seen that OUBRP produces significantly less control packets than AODV and AODV-ULE-L. Note that as the node density is increased OUBRP starts to show even better results than the other two strategies.

This is because as the number of nodes are increased, so is the number of high powered nodes. This in turn increases the probability of a route being found on the first or second iteration of the OUBRP's route discovery algorithm. Therefore, fewer control packets are disseminated into the network.

Figures 5 and 6 illustrate the end-to-end delay introduced for the 100 and 500 node network respectively. In the 100 node scenario, AODV-ULE produces the smallest end-to-end delay across all mobility levels (i.e. pause times). OUBRP, experiences higher delay than AODV-ULE-L, this is because in the 100 node scenario, the number of high powered nodes are fewer than 500 node scenario. Therefore, the probability of a successful route discovery in the first few iteration of the OUBRP's route discovery phase is less than in the 500 nodes, which means that each data packet would experience more delays before a route is found, when compared to the 500 node scenario. This is illustrated in the graph in Figure 5 where OUBRP produces significantly lower delay when compared to Figure 6. AODV without uni-directional link elimination produces the highest end-to-end delay when compared to the other two strategies.

This is more evident during the high mobility levels (i.e. smaller pause times), where the combination of inaccurate route information stored in the route tables and high levels of mobility initiates more frequent route re-discoveries. Thus, adding more end-to-end delay to each data packet.

V. Alternative Strategies and Improvements

In ULE-L, a GPS-based strategy is proposed to eliminate uni-directional links. In this section we propose a number of differ-

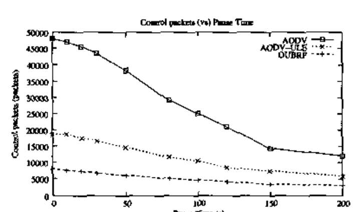

Fig. 3. Control(O/H) for 100N and 20 Flows

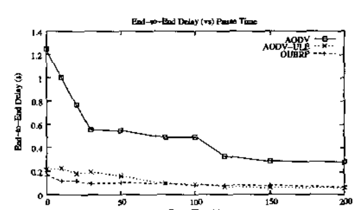

Fig. 6. End-to-end Delay for 500N and 20 Flows

ent strategies to eliminate uni-directional links

A. ULE using Neighbour List Forwarding

Another way to eliminate the uni-directional link selection problem during the route discovery phase is by appending a neighbour list to the RREQ packets. We refer to this strategy as ULE using Neighbour List Forwarding (or ULE-NL). In this strategy, the nodes, which participate in route discovery append a list of their neighbouring nodes to the RREQ packet. The nodes which then receive the RREQ packet check the neighbour list forwarded by the previous node to see if the forwarding node has a direct link to them. If yes, the receiving nodes would assume that they have a bi-directional link with the forwarding node and update their route tables. The receiving nodes then send a RREP if they have a route to the destination or rebroadcast the RREQ packet and replace the forwarding nodes neighbour list with their own neighbour list. Otherwise, the RREQ is deleted.

The advantage of ULE-NL over ULE-L is that ULE-NL does not rely upon a GPS device to detect uni-directional links. Furthermore, by providing a neighbour list the receiver can confirm bi-directionality if its address exists in the senders neighbour list. However, in ULE-L bi-directionality is assumed according to transmission range of the receiver and no confirmation is given by the sender (i.e. the sender has not confirmed a reverse link from the receiving node). The disadvantage of ULE-NL is than each RREQ packet may be significantly larger that the RREQ used by ULE-L. This is because in ULE-L nodes exchange location information rather than a neighbour list.

B. ULE using Neighbour List Elimination

This strategy attempts to reduce the size of the neighbour list in the ULE-NL strategy by eliminating redundant nodes (we refer to this strategy as ULE-NLE). To do this, each node participating in route discovery only append a list of neighbours to the RREQ packet, which were not included in the received RREQ neighbour list. To illustrate how this is done, assume node 0 (see figure 7) sends a RREQ with a neighbour list $RREQ\_NBR_0 = [1,2,3,4]$. When node 4 receives this RREQ it compares the received neighbour list with its own neighbour list and includes only these neighbours, which are not listed in node 0's neighbour list. This is:

$$RREQ\_NBR_4 = NBR_4 - RREQ\_NBR_0$$
$$RREQ\_NBR_4 = [0,1,2,3,4,5,6] - [1,2,3,4]$$
$$RREQ\_NBR_4 = [5,6]$$

The advantage of this strategy is that the number of redundant nodes in the neighbour list is reduced compared to ULE-NL. Furthermore, in ULE-NLE strategy, the number of rebroadcasting nodes can be reduced. For example, when node 1 receives the RREQ from node 4, node 1 can determine that node 4's RREQ has reached all its neighbours (from its neighbour list). Therefore, node 1 does not need to further rebroadcast the RREQ.

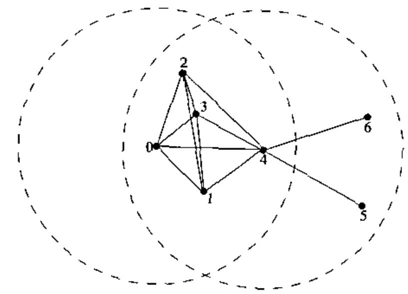

Fig. 7. Illustration for ULE-NLE strategy

VI. Conclusions

In this paper we presented a new routing strategies for Mobile Ad Hoc Networks, which are made up of heterogeneous devices. We proposed a utility-based routing strategy (called OUBRP), which attempts to minimise the number of control packets disseminated into the network. Furthermore, we demonstrated the effects of uni-directional links on routing performance and data delivery and proposed a number of uni-directional link elimination strategies for on-demand routing protocols in mobile ad hoc networks. We implemented OUBRP (which also included our location-based link elimination strategy, ULE-L) in Glomosim simulator and compared its performance to AODV and AODV-ULE-L. Our results show that OUBRP produces significantly fewer control packets than AODV and AODV-ULE-L, while maintaining very high level of packet delivery. Our results also show that our uni-directional link elimination strategy, significantly improves the performance of AODV. In the future, we plan to investigate the performance of OUBRP in large (both node density and network boundary) mobile networks with high levels of traffic.

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