On optimising route discovery for multi-interface and power-aware nodes in heterogeneous MANETs

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Keywords

optimising, route, discovery, for, multi, interface, power, aware, nodes, heterogeneous, MANETs

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On Optimising Route Discovery for Multi-Interface and Power-Aware nodes in Heterogeneous MANETs

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Abstract—This paper presents a new routing discovery strategy for heterogeneous MANETs. Node heterogeneity is modeled in terms of: types and number of different interfaces, power, and transmission ranges. Our proposed route discovery algorithm is implemented on the top of On-demand Tree-based Routing Protocol (OTRP) and hence it is called OTRP Heterogeneity-Aware (OTRP_HA). OTRP_HA utilizes node heterogeneity and optimizes route discovery to reduce overheads and ensures connectivities between different types of nodes with different interfaces. Each node makes its own decision to participate in the route discovery process according to its location, local density, and available resources. Simulation results show that OTRP_HA outperforms OTRP and AODV and it reduces overheads as a number of nodes and traffic increase, while it also further prolongs the lifetime of battery-powered single-interface nodes when compared to AODV.

Keywords-Heterogeneous MANET; routing protocols; overheads; multi interfaces; scalability;

I. INTRODUCTION

Mobile Ad hoc NETworks (MANETs) are networks of wireless mobile nodes that have no fixed structure. Each node may act either as a router or an end-user node. Many routing protocols have been proposed to manage the communication in this kind of networks [2]. Each routing protocol reacts differently to network conditions. In MANETs, node heterogeneity is one of the main network conditions that significantly affects the performance of the routing protocols [5]. The issue of node heterogeneity is not considered in current MANET routing protocols. Although most current MANET routing protocols assume homogeneous networking conditions where all nodes have the same capabilities and resources, in real life MANET may consist of heterogeneous nodes that have different capabilities and resources like military (battlefield) networks and rescue operations systems. Homogeneous networks are easy to model and analyse, but they exhibit poor scalability compared with heterogeneous networks [7]. The simulation results in [5] show that while all protocols perform well in homogeneous networking conditions, their performance degrades significantly when used in heterogeneous networks. Therefore, current MANET routing protocols do not adapt well to heterogeneous conditions. Previous work on Heterogeneous MANET (HMANET) routing protocols have not modelled the heterogeneity clearly [1][8][9]. In [1][8][9], different transmission powers have only been used to simulate node heterogeneity over MANETs. Moreover, some publications consider to have only two different types of nodes [8][9], while in reality the network may have more than two types of nodes with different resources. Moreover the issues of scalability and connectivity with HMANET routing protocols have not been considered.

The objective of this paper is to utilize the heterogeneity of resources to reduce overheads that is introduced by having multi-interfaces and simultaneously ensure the connectivity between different types of nodes. This is done by modelling node heterogeneity and then investigating the performance of routing protocols in terms of scalability and connectivity in this model. Node heterogeneity is modelled by having nodes with different resources in terms of: types and number of different interfaces, power, and transmission ranges. Scalability and connectivity issues are implemented in this model on top of On-demand Tree-based Routing Protocol (OTRP)[4]. OTRP combines the idea of hop-by-hop routing such as AODV[6] with an efficient route discovery algorithm called Tree-based Optimized Flooding (TOF) to improve scalability of homogeneous ad hoc networks when there is no previous knowledge about the destination. To achieve this in OTRP, route discovery overheads are minimized by selectively flooding the network through a limited set of nodes, referred to as branching-nodes. OTRP is extended here to be aware of: heterogeneous multi-interfaces, different power resources, and connectivity between nodes in HMANET.

The rest of this paper is organised as follows. Section II presents a summary of previous literature related to MANET routing protocols and heterogeneous nodes. In section III, the proposed routing protocol is described. The simulation parameters and scenarios that are used to investigate the performance of the proposed routing strategy are given in section IV. Then the results of the simulation study are summarised in section V. Section VI concludes the paper.

Table I: Types of nodes that are used with OTRP_HA

Type	Number of Radio Interfaces	Types of Interfaces	Number of Channels	Types of Powers
Type1	2	IEEE 802.11 a/b	1	Continous Power
Type2	1	IEEE 802.11 a	1	Continous Power
Type3	1	IEEE 802.11 b	1	Continous Power
Type4	1	IEEE 802.11 b	1	Battery Power

Trial_No	Source_Node _Type	Location_1st_Prev _Node	Location_2nd_Prev _Node	Original RREQ Packet

Figure 1: The formate of RREQ packet with OTRP_HA

Figure 2: Location and local density of rebroadcasting nodes

II. RELATED WORK

On-demand routing protocols have the potential to achieve high levels of scalability in homogeneous MANETs. However, we found from simulation results that current routing protocols behave inefficiently and unexpectedly in heterogeneous networks [5]. Moreover, the study of scalability and connectivity of HMANET routing protocols is limited. Few papers have considered multi-interfaces heterogeneity and issues of routing and scalability in HMANETs[12]. OLSR has been enhanced to Hierarchical OLSR (HOLSR) in [12] to work with three types of nodes with different number of interfaces and the network is assumed to be fully connected. Each type of node forms a cluster to exchange network topology information independently . We observe that HOLSR limits the propagation of the topology information but incurs more overhead since hierarchical messages are periodically propagated between the cluster heads to keep them aware of the membership information of their peers.

Most of the proposed protocols and methods that are related to our work are designed for Wireless Mesh Network (WMN) where there are only two types of nodes: Mesh-Router, which is static and capable of multi radios and multi channels and Mesh-Client, which is mobile and has only single radio and single channel [11][10][3]. In most cases, the network is assumed to be fully connected. Moreover, the issue of power consumption are not considered. In [11], AODV [6] has been developed to work with Multi-Radios (AODV-MR) in hybrid WMN. AODV-MR maintains an interface number of the next hop to destination in routing table and RREQ packets are rebroadcasted to all interfaces. Although simulation results show the superiority of AODV-MR when compared to AODV with single radio under high mobility and traffic load conditions, AODV-MR has higher overheads as number of interfaces increases. AODV-MR has been extended to utilize the heterogeneity and reduce overheads in [10]. AODV-MR is extended to use: node-type aware, link quality estimation, and optimal link selection. Although the simulation results show the benefits of extended AODV-MR, the scalability issue has not been considered. Moreover, the proposed protocol is designed to work with Mesh-Routers and Mesh-Clients only where they have common interfaces and channels to communicate.
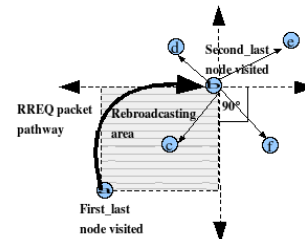
III. DESCRIPTION OF OTRP_HA

Node heterogeneity is modelled by having different types of nodes. Nodes are identified by: number of radio interfaces, type of interfaces, type of power that provides energy for nodes. Each interface has one communication channel. There is no guarantee of direct connectivity between two different types of nodes with different interfaces. Our work will be based on four types of nodes as shown in Table I. The main idea of OTRP[4] is to minimise the number of rebroadcasting nodes when previous knowledge about destination is not available. The main criteria to select the rebroadcasting nodes was based on the node location, where the nodes should be located in one of four regions of transmission range of source node or three regions of the relays to ensure that routing packets reach most of the nodes in the network [4]. OTRP does not perform well with above model as it selects rebroadcast nodes according its location only. In a scenario where Type2 nodes need to find path to type 3 nodes, it searches for 4 of its 1-hop neighbours according to their locations. Then relay nodes will do the same procedure to find the next hop relays. If all rebroadcasting nodes are from the same type as the source node, then destination that is from a different type can not be reached unless all nodes are rebroadcasting. This means that OTRP behaves like AODV with higher overheads and delay where all nodes will rebroadcast in the last trial to find route. Therefore, our work here is based on answering the following questions:

1) How to find a path efficiently with OTRP from a node with interface a to a node with interface b where $a \neq b$ and there is an existence of nodes with multi-interfaces a/b.

2) How to utilize heterogeneity to reduce delay and overheads and achieve scalability as number of nodes increases.

Here we will extend OTRP to be aware of node heterogeneity (OTRP Heterogeneity Aware(OTRP_HA)). OTRP_HA will be aware of the following features to select rebroadcasting nodes: local density of node, node location, node type, and connectivity. In OTRP_HA, the source node does not select rebroadcasting nodes, however the decision to rebroadcast is left to the relay nodes. Relay node decides also their own type according to available resources as shown in Table I. **Algorithm 1** presents the algorithm of OTRP-HA and outlines the conditions for forwarding received RREQ packet. The decision to rebroadcast depends on:

1) Trial Number: this is the number of trials that the source node tries to find a route to the destination. As the trial number increases, more nodes can rebroadcast.

2) Available Node Resources: the nodes that have more resources (like multi-interfaces, continuous power, and high transmission range) have the priority to rebroadcast. Battery-powered single-interface nodes are avoided in first 3 RREQ trials. These nodes are called limited nodes. C2 and C1 represent powerful nodes and limited nodes respectively in **Algorithm 1**.

3) Local density: Relay nodes must have at least three 1-hop neighbours that are located in three regions of their transmission range. This is to ensure that RREQ packet will be rebroadcast in all directions within network area. The routing table is used to extract this information. The condition of local density is clear in C4 in **Algorithm 1**. This condition is shown in Figure 2 where node b will rebroadcast which has more than 3 neighbours in different directions.

4) Location: The relay nodes must not be located between two rebroadcasting nodes. In other words, node must not be in the area that have been already covered. This is dictated by comparing the location to the location of the first and the second visited nodes by RREQ packets. These locations are attached to RREQ packet. C5 shows this point in **Algorithm 1**. Figure 2 shows this condition.

5) The availability knowledge about the type of destination node in received node of RREQ packet. This information helps to selects proper type of nodes to rebroadcast. This condition is presented in **Algorithm 1** in C3 and C6.

Input: Received RREQ Packet.
Output: action to received RREQ packet (rebroadcast it or ignore it).

```
 1: for i ← 1, 7 do //Initialization
        //C is a boolean set to represent conditions to be a relay node
 2:      C_i ← FALSE
 3: end for
 4: C_1 ← NodeType = Type4
 5: C_2 ← NodeType = Type1
 6: C_3 ← NodeType = DestinationType
 7: C_4 ← Have3Neigh(Node_loc, RT)
        //Have3Neigh function checks if node has at least 3 neighbours in
        different 90 degree angle
 8: C_5 ← Node_reb(Node_loc, RREQ_Location_2nd_Prev_Node,
 9: RREQ_Location_1st_Prev_Node)
        //Node_reb function checks the node is not located in between two
        rebroadcasting nodes
10: C_6 ← DestinationType ≠ null
        //ckech if destination node type is known
11: C_7 ← NodeType = RREQ_SourceType
12: if (RREQ_Trial_No == 4) then
13:     All_Nodes_Rebroadcasting
14: else if (Not(C_1)) then
15:     if (C_2) then
16:         Rebroadcasting
17:     else if (C_6) then
18:         if ((RREQ_Trial_No == 1)&C_3&C_4&C_5) then
19:             Rebroadcasting
20:         else if ((RREQ_Trial_No == 2)&C_3&C_5) then
21:             Rebroadcasting
22:         else if ((RREQ_Trial_No == 3)&C_3 then
23:             Rebroadcasting
24:         end if
25:     else
26:         if ((RREQ_Trial_No == 1)&C_2) then
27:             Rebroadcasting
28:         else if ((RREQ_Trial_No == 2)&C_7&C_4&C_5) then
29:             Rebroadcasting
30:         else if ((RREQ_Trial_No == 3)&C_4&C_5 then
31:             Rebroadcasting
32:         end if
33:     end if
34: end if
```

Algorithm 1: The self-selection relay algorithm for OTRP_HA

Therefore the format of RREQ packet is shown in Figure 1.

With OTRP_HA, the route discovery process goes through 4 RREQ retries (trials) to find the destination. In each trial, there are different number of conditions to relay RREQ packet. **Algorithm 1** illustrates selection relay algorithm. If there is no route found in trial 1 then source node retries again with more rebroadcasting nodes. If there are unreachable nodes or no route was found through three trials, then all nodes will rebroadcast the RREQ packets. All Type1 nodes rebroadcast in all trials regardless of their locations and local density, and information about destination node type. These nodes are the most powerful nodes that have multiple interfaces, high transmission range, and can link between different and unconnected nodes like type 2, type 3 and type 4. Nodes of Type4 are avoided in first 3 trials because they are limited in their resources.

Nodes of Type4 are rebroadcasting in last trial to find unreachable node, which may be a destination node. If a node receives a RREQ packet it then checks if it satisfies the

Node_Address	Node_Type	Battery_State

Figure 3: The formate of TypeTable with OTRP_HA

Table II: Nodes distribution among interfaces

	IEEE 802.11a	IEEE 802.11b	IEEE 802.11a/b
Number of Nodes out of 200	95	95	10
Number of Nodes out of 400	190	190	20

rebroadcasting conditions for the current RREQ retry. If yes then it forwards the packets, otherwise drops it. Forwarding nodes update the RREQ packet before rebroadcasting it by copying the value of Location_2nd_Prev_Node to Location_1st_Prev_Node and assigns its location into Location_2nd_Prev_Node. It also keeps node type information in the TypeTable. OTRP_HA maintains a TypeTable that stores information like: id, node type and the state of battery if it is a limited node. The formate of TypeTable is shown in Figure 3. TypeTable gets node id and node type from the RREQ and RREP packets. Battery state has two values: 0 and 1. Value 1 means that the node is alive and 0 indicates that the node is dead. The battery state of continuous power nodes is always 1. The state 0 of the battery of a limited node is predicated by routing process of other nodes where this limited-node does not respond to route requests. In other words, it is assumed that if the destination node is a limited-node and there is no route has been found in all RREQ trials then this node is considered as dead node and it is state battery is 0. Battery state value helps to avoid initiating any traffic or route request to dead nodes, which therefore reduces redundant overheads. TypeTable information in the source node are used to identify the destination type and, which types of nodes can be selected to discover route efficiently. The decision to rebroadcast depends on the availability of destination node type in the received node. If the destination node type is known then the relay nodes type must be the same as destination (see **Algorithm 1**). In this case, these nodes will rebroadcast if they satisfy the conditions of:

1) local density and location in the first trial,
2) location only in second trial,
3) all nodes that have the same type as destination node rebroadcast in the third trial.

In case the destination type is unknown, then:

1) in the first trial powerful nodes are the only nodes, which rebroadcast.
2) in the second trial, nodes, which have the same type as source node type, which satisfy the conditions of local density and location rebroadcast.
3) in the third trial, all nodes that satisfy the location and local density conditions rebroadcast.

The route maintenance process is the same as a OTRP. The location of one-hop neighbours of the parent nodes are valid as long as their link is active between two nodes. As node mobility affects the stored information such as node locations, the locations of neighbours are updated using the control packets (i.e. RREQ, RREP, and RERR) that include location of last node that has been visited. When a node receives any control packet, it copies the location of its neighbour that forwarded the packet, to its routing table. Then it replaces the location values in the control packet with its own location information.

IV. SIMULATION MODELS

The performance of OTRP_HA is compared to AODV and OTRP using the QualNet4.5 package. In route discovery phase of AODV [6], the source node initiates a blind flood of RREQ packets throughout the network regardless of nodes resources and types. While in OTRP, rebroadcasting nodes are selected according their positions to relay RREQ packets regardless of nodes resources and types.

The simulations ran for 200s with different values of seeds. 200 and 400 nodes were randomly distributed on 1000 x 1000 m^2. Random way point was used as mobility model with the four different values of pause times that were 0s, 50s, 100s, and 200s. Speeds of the nodes were varied from 0 to 20 m/s. The simulated protocols have been evaluated with 30 data traffic flows. Constant Bite Rate (CBR) was used to generate data traffic at 4 packets per second. Each packet was 512 bytes. There were 200 and 400 nodes, see Table II for nodes distribution among interfaces. IEEE 802.11a interface has transmission bandwidth of 6Mbps and transmission power of 20dbm while IEEE 802.11b interface has constant transmission bandwidth of 2Mbps and transmission power of 15dbm. 50 nodes out of total number of nodes with IEEE 802.11b interface only are battery-constrained nodes. The traffic load was constant for both 200 and 400 nodes. Protocols were evaluated according to: average of end-to-end delay, Packet Delivery Ratio (PDR), Normalised Control Overhead (NCOH), average of energy consumed by all nodes (in mJoule) for transmit and receive modes, and residual battery capacity (in mAhr) of battery-powered nodes. Normalized Control Overhead refers to the total number of control packets that are transmitted by routing protocol to the total number of data packets that are sent.

V. RESULTS

Figure 4 shows the results of simulation. Delay, PDR and NCO have been used to evaluate protocols with different nodes mobility(pause times) as nodes movements affect the

performance of protocols.

OTRP has the highest delay for 200 and 400 nodes (Figure 4(a)). This is because OTRP does not consider node heterogeneity and the sender just selects at most 3 nodes according to their location to rebroadcast. In some cases there are no similar nodes to sender on the specified location. Hence, the source node has to go through all four trials to find a path to the destination. On the other hand, with AODV all nodes rebroadcast,, which speeds up the process of finding paths to destination. However, when the number of node increases then the loads per node increase as all nodes are rebroadcasting,, which increases the rate of collisions contention. Therefore, this will delay delivery of data packets and increase data loss rate. OTRP_HA outperforms the other two protocols.

OTRP has the lowest PDR with 200 nodes (see Figure 4(b)). However, it is more scalable than AODV when number of nodes increases, as OTRP delivers more than 65% of data packets with 400 nodes while AODV drops more than 90% of the data packets. The behaviour of OTRP can be explained as follows. As number of nodes increases, the chance to find rebroadcasting nodes increases simultaneously, which means that there are more paths to deliver data with less overheads. However, OTRP_HA outperforms both protocols as it delivers more than 85% of data packet with 400 nodes. This is because OTRP_HA utilises node heterogeneity and at the same time reduces the NCOH.

AODV suffers from high NCOH as number of nodes increases as shown in Figure 4(c). This is because all the nodes are rebroadcasting, which increases the rate of collisions and the number of route recalculation. OTRP has lower overheads than AODV even with 400 nodes because it chooses finite number of nodes to rebroadcast regardless of the total number of nodes in the network. However, both protocols do not take into account node heterogeneity where OTRP selects rebroadcasting nodes according to locations and in AODV all nodes are rebroadcasting. Although OTRP_HA does not select finite number of nodes to rebroadcast, it has the lowest NCOH and consequently the highest PDR and lowest delay. The consistency of NCOH of OTRP_HA for both 200 and 400 nodes can be explained as follows:

1) Powerful nodes with multi-interfaces have the highest priority in rebroadcasting, which results in reducing the number of rebroadcasting nodes.
2) Using node type information, the search area for destination and number of rebroadcasting nodes can be controlled.
3) Avoiding battery-powered nodes in route discovery process decreases link failures and route recalculations.
4) Awareness of battery-powered nodes lifetime avoids initiating traffic to overlow power nodes, which reduces overheads.

5) Each node incorporates self-selection mechanism to select itself as rebroadcasting node. This helps in eliminating the dependency on location information only,, which the relay nodes must receive to rebroadcast as is the case in OTRP. At the same time, it reduces the size of RREQ packet that have four addresses of rebroadcasting nodes in OTRP.

To investigate the energy efficiency of three protocols we captured the energy consumed for transmitting and receiving and residual battery capacity of the battery-powered nodes during 5 intervals of simulation time (0s, 50s, 100s, 150s, 200s) with pause time =100s. In all protocols, nearly the same amount of energy with 200 nodes were consumed as shown in Figure 4(d). However, in AODV more energy is consumed in the 400 nodes scenario. This is because more nodes are rebroadcasting. In OTRP and OTRP_HA similar rate of energy are consumed with slight increase with OTRP for 400 nodes. This is can be attributed to the fact that OTRP creates more overheads than OTRP_HA as explained before. Therefore, OTRP_HA is an efficient power-aware protocol.

Battery-powered nodes with AODV consumed more power than OTRP and OTRP_HA as shown in Figure 4(e) because all nodes are rebroadcasting regardless of node type. OTRP selects finite number of nodes to rebroadcast regardless of limited nodes and hence it has lower residual battery capacity than OTRP_HA. Although OTRP_HA has the highest PDR, it has the highest battery capacity because it avoids the participation of battery-powered nodes in route discovery process. This prolongs the lifetime of the network.

VI. CONCLUSION

In this paper, a new routing discovery strategy for heterogeneous MANETs is proposed to reduce routing overheads and adapt to node heterogeneity. Rebroadcasting nodes are selected according to their resources and locations. Powerful nodes with multi-interfaces have been used to link between two different types of nodes. The performance of OTRP_HA, OTRP, and AODV were compared on variety of network conditions like mobility and node density. Simulation results show that OTRP_HA significantly reduces routing overheads and achieves higher levels of data delivery than the other protocols. Moreover, the simulation results show that OTRP_HA is power efficient and a battery-aware protocol. In the future, we plan to further investigate the performance of OTRP_HA over sparse networks and develop new route metric, which further optimises its performance in such scenario.
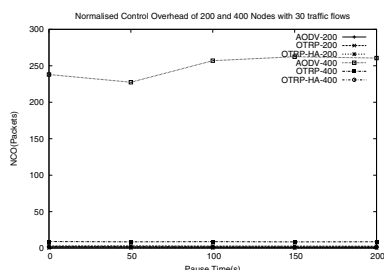
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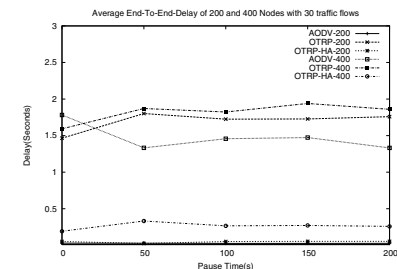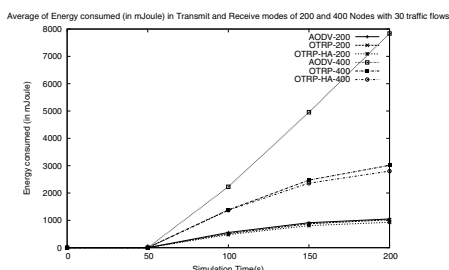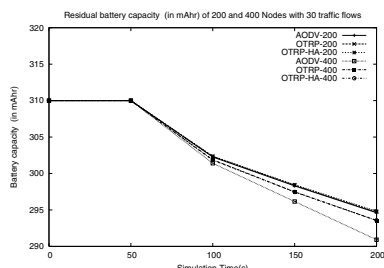
(a) Delay
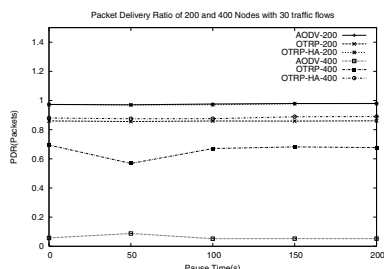
(b) PDR

(c) NCO

(d) Energy consumed

(e) Battery

Figure 4: Compare OTRP_HA to AODV and OTRP with 200 and 400 nodes and 30 Traffic Flows.

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