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Abstract

This paper presents heterogeneity ratio (HR) as a new routing metric for heterogeneous MANETs. This metric is the ratio of number of powerful nodes to hop count that is used to select the best path to destination. Node heterogeneity is modeled in terms of: types and number of different interfaces, power, and transmission ranges. Our proposed routing metric is based on developing route discovery algorithm that is implemented on the top of on-demand tree-based routing protocol (OTRP)[2] to accommodate nodes heterogeneity. Simulation results show that using HR with OTRP heterogeneity aware outperforms other metrics like minimal hop count and maximal number of powerful nodes.

Keywords

Routing, Metric, for, Multi, interface, Power, Aware, Nodes, Heterogenous, MANETs

Disciplines

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Abstract

This paper presents Heterogeneity Ratio (HR) as a new routing metric for heterogeneous MANETs. This metric is the ratio of number of powerful nodes to hop count that is used to select the best path to destination. Node heterogeneity is modeled in terms of: types and number of different interfaces, power, and transmission ranges. Our proposed routing metric is based on developing route discovery algorithm that is implemented on the top of On-demand Tree-based Routing Protocol (OTRP)[2] to accommodate nodes heterogeneity. Simulation results show that using HR with OTRP Heterogeneity Aware outperforms other metrics like minimal hop count and maximal number of powerful nodes.

1. Introduction

In MANETs, the main role of routing metrics is in selecting best path to route data between two nodes. Hop count is the simple routing metric that is used with homogeneous MANETs. Using this metric with heterogeneous MANET (HMANET) where there are nodes with different capabilities and resource, can degrade the performance of MANAET routing protocols. This is because minimal hop count considers shortest path with minimum number of hops to route data regardless of nodes heterogeneity and links quality. Different metrics have been proposed to select path according to link quality in HMANET and Wireless Mesh Networking (WMN) like expected number of transmissions (ETX) in [3] and [4], Received Signal Strength Indicator (RSSI) in [7], and maximum number of powerful nodes in [5]. In this paper, we are proposing a new routing metric to route data in HMANETs. The route quality is estimated according to the ratio of a number of powerful nodes to the hop count. This ratio is called Heterogeneity Ratio (HR). The term powerful nodes here refers to nodes that have more resources than the current node. Node heterogeneity for this metric is modeled by having nodes with different resources in terms of: types and number of different interfaces, power, and transmission ranges. HR metric is implemented on the top of enhanced

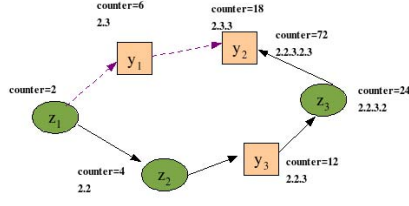
On-demand Tree-based Routing Protocol (OTRP)[2]. This protocol is developed to adapt node heterogeneity based on the issue of nodes connectivity and network scalability. This protocol is called OTRP Heterogeneity Aware (OTRP_HA). OTRP_HA utilizes node heterogeneity and optimizes route discovery to reduce overheads and ensures connectivities between different types of nodes with different interfaces. Few papers have considered multi-interfaces heterogeneity and issues of routing and scalability in HMANET [8] [1]. The rest of this paper is organised as follows. In section II, the description of OTRP_HA is given. The new routing metric is described in section III. The simulation parameters and scenarios that are used to investigate the performance of the proposed routing metric are given in section IV. Then the results of the simulation study are summarised in section V. Section VI concludes the paper.

Table 1: Types of nodes and their features

Type	Number of Radio Interfaces	Types of Interfaces	Types of Powers	Its prime number	i	w_i
Type1	2	IEEE 802.11 a/b	Continous Power	2	1	4
Type2	1	IEEE 802.11 a	Continous Power	3	2	3
Type3	1	IEEE 802.11 b	Continous Power	5	3	2
Type4	1	IEEE 802.11 b	Battery Power	7	4	1

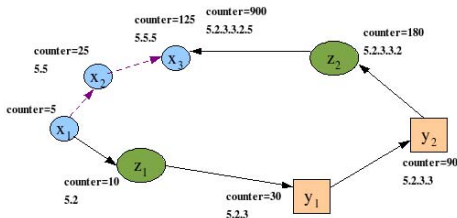
2. Description of OTRP_HA

The main idea of OTRP [2] is to minimise the number of rebroadcasting nodes in homogeneous MANETs when previous knowledge about destination is unreachable. The main criteria to select the rebroadcasting nodes was based on the node location. OTRP is extended to OTRP_HA to work with heterogeneous nodes. In OTRP_HA, the source node does not select rebroadcasting nodes, however the decision to rebroadcast is left to the relay nodes. The criteria of relay nodes which will rebroadcast depend on : node type, local density, node location, multi-interfaces, continuous power, and high transmission range. Relay node decides



Path	Counter	$\sum(w_i, t_i)$	HopCount	HR
$z_1 y_1 y_2$	18	$1.4+2.3=10$	2	5
$z_1 z_3 y_2 z_2 y_3$	72	$3.4+2.3=18$	4	4.5

Figure 1: Path with minimal hop count is selected.



Path	Counter	$\sum(w_i, t_i)$	HopCount	HR
$x_1 x_2 x_3$	125	$3.2=6$	2	3
$x_1 z_1 y_1 y_2 z_2 x_3$	900	$2.2+2.4+2.3=18$	5	3.6

Figure 2: Path with higher number of powerful nodes is selected.

its own type according to available resources as shown in Table 1. With OTRP_HA, Source node initiates RREQ packet when there is no route to destination. Source type, location information, and trial number to find route to destination are appended to the RREQ packet. The route discovery process goes through 4 trials to find the destination. In first trial, rebroadcasting nodes are chosen according to the conditions specified previously. In the next trial, the number of rebroadcasting nodes increases as the number of conditions is reduced. If the node receives RREQ packet then it checks if it satisfy conditions to be a rebroadcasting node. If yes then it forwards the packets otherwise drops it. It also keeps information about nodes type in TypeTable. OTRP_HA maintains TypeTable that stores information like: id, node type and the state of battery if it is a battery-powered single-interface node. Battery state value helps to avoid initiating any traffic or route request to dead nodes which therefore reduces redundant overheads. If there are unreachable nodes or no route was found through three trials, then all nodes will rebroadcast the RREQ packets. The route maintenance process and location updates are the same as a OTRP [2].

Table 2: Simulation parameters

Simulation Parameter	Value
Network size	$1000 \times 1000 m^2$
Number of nodes	200 and 400
Node distribution	randomly
Simulation time	200s
Traffic	30 data traffic flows, CBR, 4 packets/sec, 512 bytes/packet
Mobility model	random way point
Pause time	0s, 50s, 100s, 200s
Speed	from 0 to 20 m/s

Table 3: Simulation parameters for 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
Transmission bandwidth	6Mbps	2Mbps	6/2Mbps
Transmission power	20dbm	15dbm	20/15dbm

3. Description of Heterogeneity Ratio Metric

OTRP_HA selects nodes with more resources to rebroadcast. However, shortest paths with minimal hop count is preferred to route data regardless of links heterogeneity. Selecting paths according to minimal hop count may lead to poor performance in HMANET where there are different types of nodes which may provide a path with better performance and higher number of hops. On the other hand, routing data to nearby nodes with good links and less hop count is better than using path with higher hop count and more powerful nodes which may delay delivering of data. Therefore, our work here is based on answering the following questions:

- Which is the best path to use in HMANET with different types of nodes: path with high nodes heterogeneity or path with less hop count.
- How can we balance between the two metrics nodes heterogeneity and hop count to achieve good performance.

In this paper, we extend OTRP_HA to select path according to heterogeneity ratio of hop nodes along the path. Heterogeneity Ratio (HR) depends on number of nodes of each type on the path to hop count and is defined as:

$$HR = \frac{\sum_{i=1}^4 (w_i, t_i)}{HopCount}$$

where $w_4 \leq w_i \leq w_1$, $\sum_{i=1}^4 t_i = HopCount$, and t_i represents total number of nodes of type i and w_i refers to node type weight as shown in Table 1. The node type with more resources has higher weight value. The value of t_i is calculated as following. A counter is appended to the RREQ and RREP packets to calculate number of nodes of each type that packet has visited. To avoid creating a counter for each type which increases the size of control packet as number of node types increases and consequently increases overheads,

we use Unique Factorization Theorem [6] to create only one counter for all types. This is done by assigning different prime number to each node type (see Table1). Then, the value of the counter is the product of prime numbers of node types that packet has visited. Therefore, based on Table1 the counter value must be in the form of:

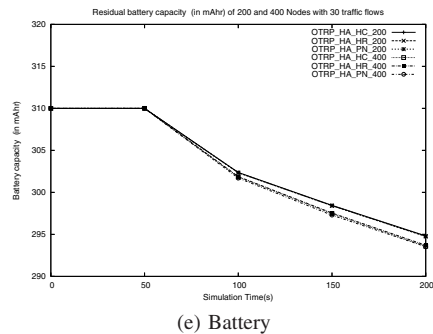
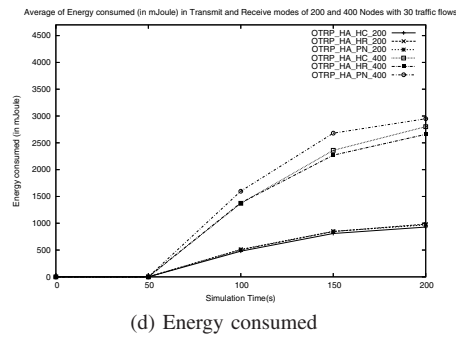
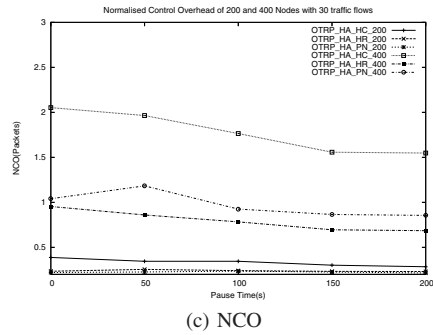
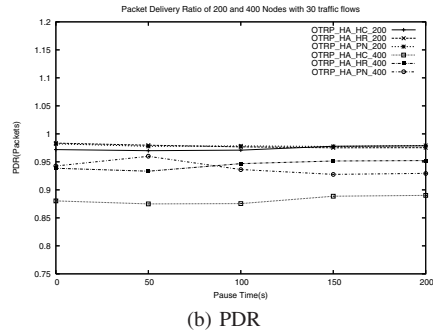
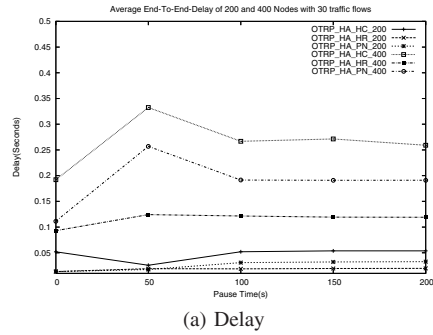
$$counter = 2^{\alpha_1} 3^{\alpha_2} 5^{\alpha_3} 7^{\alpha_4}$$

where α_i is integer, i is node type number, and $\alpha_i \geq 0$. The value of α_i represents the number of node in each type.

Source node sets initially the counter in RREQ packet to the prime number of its type. Each rebroadcast node updates the counter by multiplying it by the prime number of its own type. Each node receives the control packet, add the counter to the route entry to source/destination in routing table. Route to a destination in the routing table can be replaced by new path if new path has higher HR than the route that is in routing table. The number of each type of the nodes that are included in the path is calculated by decomposing the counter value to its prime factors and then count the frequencies of each prime number. Figure1 and Figure2 are examples of using HR. In Figure1 and Figure2, $z_i \in Type1$, $y_i \in Type2$, and $x_i \in Type3$. In Figure1, there are two paths from z_1 to y_2 . Node z_1 chooses $z_1y_1y_2$ as a path to destination y_2 with higher HR where this path has a sufficient number of powerful nodes to the number of hops comparing to the path $z_1z_2y_3z_3y_2$. This is because both paths may have similar packet delivery ratio but $z_1y_1y_2$ has less delay. While in Figure 2, node x_1 chooses the longest path $x_1z_1y_1y_2z_2x_3$ where it is worth to have long path with more powerful nodes.

4. Simulation Models

We compare the performance of OTRP_HA with three different routing metrics that are used to select path to a destination: minimal Hop Count (HC), maximal Heterogeneity Ratio (HR), and maximal number of Powerful Nodes (PN). The node selects the path according to PN means that this path includes higher number of powerful nodes which have more resources and features than this node. The performance is evaluated using the QualNet4.5 package. The simulation parameters are shown in Table2 and Table3. 50 nodes out of total number nodes with IEEE 802.11b interface only are battery-constrained nodes. The traffic load was constant for both 200 and 400 nodes. The performance of the protocol with three metrics is 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 nodes. Energy model and battery model with QualNet4.5 are used to get energy consumed and battery capacity.



374 Figure 3: Compare the performance of different routing metrics with OTRP_HA with 200 and 400 nodes and 30 traffic flows.

5. Results

Figure 3 compares the performance of OTRP_HA with different routing metrics with 200 and 400 nodes and 30 Traffic flows. OTRP_HA with hop count has the highest delay within 200 and 400 nodes respectively, see Fig 3(a). This can be explained that using HC ignores the types of nodes that are involved in the path. Selecting path according to PN reduce more delay comparing to hop count but it is not the best. Using HR can significantly decrease delay within 200 and 400 nodes comparing to HC and PN. This is because it balances the advantages of using shortest path and having powerful nodes which provides links with high quality to deliver data.

The PDR of OTRP_HA are similar with 200 nodes and different metrics with slight increase with HR, (see Fig 3(b)). With 400 nodes, PDR of HC is no more than 90% where using HC may result in a path with some links with low performance which affects PDR. Routing data with more PN can provide links with high quality but it may have long path which delay the delivery of data. However, OTRP_HA with HR has the highest PDR where it delivers more than 92% of data where long path are avoided and simultaneously good links are used.

As scalability and reducing COH are the main aim of OTRP_HA in HMANET, using HR can increase the efficiency of this protocol as it highly eliminate COH as shown in Fig 3(c). Using HC to select path in HMANET reduces the performance of OTRP_HA. Similarly, focusing only on high number of powerful nodes that may have more than one interface can increase COH. HR outperforms both metrics HC and PN. Moreover, using only one counter to count all types of hop nodes improves the performance of OTRP_HA and reduce COH.

To test the energy efficiency of the three metrics we captured the energy consumed for transmitting and receiving modes and residual battery capacity of battery nodes during 5 intervals of simulation time (0s, 50s, 100s, 150s, 200s) with pause time =100s. In all metrics, nearly the same amount of energy with 200 nodes are consumed as shown in Fig 3(d). However, using PN more energy is consumed as time increases with the 400 nodes scenario. This is because more powerful node are used, which may have more than one interface, then more power is consumed in receiving and sending. By using HC and HR, similar rates of energy are consumed with slight increase with HC for 400 nodes. This is can be attributed to the fact that using HC creates more overheads than HR as explained before. Therefore, the HR is an efficient power-aware metric.

Battery-powered nodes with PN consumed slightly less battery than using other metrics as shown in Fig 3(e) because battery-powered nodes are avoided in selecting the path. Although OTRP_HA with HR has the highest PDR, it has the similar battery capacity to HC. This prolongs the lifetime

of the network.

6. Conclusion

In this paper, heterogeneity ratio is proposed as a new routing metric for heterogeneous MANETs to utilize node heterogeneity to route data efficiently. Heterogeneity ratio balances the use of shortest path with minimal hop count and path with the best quality with high number of powerful nodes. This metric is implemented on the top of OTRP_HA where rebroadcasting nodes are selected according to their resources and locations. The performance of OTRP_HA with three metrics that are heterogeneity ratio, hop count, and number of powerful nodes were compared on a variety of network conditions like mobility and node density. Simulation results show that OTRP_HA with heterogeneity ratio significantly reduces routing overheads and achieves higher levels of data delivery than the other routing metrics. In the future, we plan to further investigate the effects of using OTRP_HA with heterogeneity ratio on lifetime of the network over sparse network.

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