A Reconfigurable Multicast Routing Protocol for Mobile Ad-Hoc Networks

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Abstract*: An infrastructure independent and self-organizing network where the mobile nodes are communicated with each other through wireless links is referred asMobile ad-hoc network. Amajor challenging task of mobile ad-hoc networks is Route maintenance due to some reasons such as frequent topological changes, packet collisions and bad channels which may cause some link breakages. Reconfigurable Virtual Backbone (RVB) construction and maintenance play a vital role, mainly in the multicast routing of mobile ad-hoc networks (MANETs). In this paper, the issues in providing a reconfigurable virtual backbone with the lower overhead are investigated and here we come up with a solution and propose a Reconfigurable Multicast Routing Protocol (RMRP) for constructing a virtual backbone and generating an alternate path during link failures. In comparison with the existing backbone and link recovery protocols like Backbone Group Model (BGM), Hierarchical Virtual Backbone Construction (HVBC) protocol and Local Link Failure Recovery (LLFR) protocol, the proposed protocol yields effective results in constructing a reconfigurable virtual backbone and generating an on-demand alternate path with the minimized overhead, increasing packet delivery ratio, throughput, minimizing delay of transmission, energy consumption, and with the improved routing performance significantly.

***Index Terms*:Bayesian classification, core node, link failure recovery, multicast routing, reconfigurable virtual backbone.**

I. INTRODUCTION

A set of independent mobile nodes form a self-configuring network to communicate one another by wireless links is referred as a mobile ad-hoc network (MANET) [1,2], in which every node acts as a router. These routers move arbitrarily and form dynamic networks, which make the wireless network topology unpredictable. It's a kind of network which operates stand-alone or can be linked to a larger network. MANET plays a vital role in providing communication to civilians, military and in disaster recovery applications. Since these applications demand proper communication and coordination among the mobile nodes, MANET is one particularly challenging environment for multicasting [2]. Multicast communication is very useful and efficient means of supporting group-oriented applications; it improves the wireless link efficiency when sending messages in multiple copies over a wireless transmission by exploiting the inherent broadcast property of the network. In MANETs, multicast routing has a great impact as it minimizes the overhead, delay, and bandwidth consumption when compared to multiple unicasts.

A Backbone [3] is referred as a set of interconnected core nodes of the network. Core nodes are an active subset of nodes serving the rest of the nodes in the network which are used for routing activities. The backbone aims to perform an efficient multicast routing and reduces the communication overhead, overall energy consumption, increases the bandwidth efficiency and guarantees the network connectivity. The virtual backbone (VB) [5] construction is classified into three types that are tree-based, cluster-based and dominating set-based virtual backbone. In tree-based, the spanning trees manage routing and security services over the network. The cluster-based method creates a portion of the communication graphs hence, every node belonging to a cluster participate only in it. In dominating set-based virtual backbone, a backbone construct with a set of clusters and every cluster-head keeps 1-hop distance with the corresponding members of the cluster.

The virtual backbone [6] can be constructed in any one of the two ways: static or dynamic. In static VB, core nodes are fixed to one location which results in the collapse of the entire backbone even if a single core node fails. To overcome the limitations of static VB, dynamic VB is adopted in which core nodes can be moved over the network.

In general, joining or leaving of nodes from the network leads to the reconstruction of the backbone twice. Reconstruction of the backbone results in increased overhead and degrades the network performance. Instead of reconstructing the backbone [6], reconfiguration of the backbone is a better choice to improve the network efficiency. Due to the mobility nature of MANET, there might be frequent topological changes occur and leads to link breakages and route invalidation in backbone networks. Hence, construction of reconfigurable virtual backbone and route maintenance are the crucial tasks of MANET.

Currently, many approaches have existed for the construction of virtual backbone [6] and route maintenance, but each of them is having limitations like the flooding of control packets, maximum consumption of energy and bandwidth, poor packet delivery ratio, increased packet delay and overhead on every node. Hence, none of these approaches providing effective solutions for the problems mentioned above.

In this paper, we are proposing a novel multicast routing protocol to construct a reconfigurable virtual backbone [7] and recover the link breakages. The proposed protocol utilizes the Bayesian classification [8,9] method to find an alternate path in case of link failure. The reason to choose Bayesian classification method for this protocol is as it provides an optimum solution for the problems mentioned above.

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The backbone constructs with a minimal set of core nodes; and the core nodes election is processed based on three parameters traffic load, neighborhood density, and energy. In case of a link failure, the Bayesian classification [9] method elects an optimal core node among the nearest neighboring nodes and generates an alternate path towards the destination.

The organization of this paper is as follows: section 2, covers problem statement. Section 3, describes related work which includes recent existing protocols for backbone construction and link failure recovery. Section 4, gives the overview of proposed protocol and its algorithm. Section 5, provides the simulation results in comparison with the existing protocols and section 6, concludes of the paper.

II. RELATED WORK

In ad-hoc networks [10], the virtual backbone is utilized for supporting unicast, broadcast and multicast communications and also used in the fault-tolerant methods. This section briefly reviews the most recent existing schemes for the construction of virtual backbone and link failure recovery [11]. Few of them are discussed in the following subsections.

A. Backbone Group Model

Md. Amir KhusruAkhtar et al. proposed backbone group model [12], where a set of nodes is used to perform routing activities over the network. Cluster-head uses the least set of nodes for the network activities taken for a threshold time hence, every node of the locality group (LG) [12] equally takes the responsibility of routing. It does not consider the reachability constraints of single hop distant LGs. It comprises of two steps, selection of a cluster-head (CH) for the local groups and backbone construction. At the inception of the network, every node exchanges the information with its adjacent nodes and the node with the maximum energy and power is chosen as CH. Thereafter the adjacent nodes of the CH join together by sending a request to CH to form a local group. A node existing in the coverage area of two CHs is selected as border node (BN) [12] and keeps minimum distance with CHs; local groups may associate with one or more BNs. Here the greedy approach is adopted to evaluate a formulated linear problem to find the maximum number of nodes exists in the area of each LG. Though it minimizes the total control traffic overhead, the routing and computation overhead is more.

B. Hierarchical Virtual Backbone Construction Protocol

Bharti Sharma et al. have proposed hierarchical virtual backbone construction (HVBC) protocol [13] for MANETs. In HVBC protocol, a set of nodes with a predefined distance forms a cluster by using an efficient extreme finding approach. During the construction of backbone, the dominating nodes connect through multi-hop virtual links [13] using diameter algorithm. The major drawbacks of HVBC protocol are control overhead; in wide area networks this protocol is unable to retain the backbone and has no stability.

C. Local Link Failure Recovery Protocol

P.R. Jasmine Jeni et al. proposed local link failure recovery algorithm [15] to perform route recovery in MANETs. In this approach, LLFR deploys on each node and maintains RREP buffer table (RBT) stack [15] to collect the route replies (RREPs) from neighboring nodes in ascending order of their signal strength. Here RSSI (received signal strength indication) [15] is used to determine the stability of the link. During the link failure, the upstream node selects the topmost entry (RREP) with the highest signal strength to find an alternate path. Once the alternate path found, the upstream node updates the route cache and inform the source. If the RBT stack is empty, the upstream node generates a route error and initiates route discovery process. Though LLFR mechanism exhibit better efficiency in terms link recovery, it has limitations like RBT overhead as every node need to maintain RBT stack; control overhead, computation overhead, and delay.

III. RECONFIGURABLE MULTICAST ROUTING PROTOCOL

A. Overview

A reconfigurable multicast routing protocol (RMRP) is a hybrid protocol where a subset of nodes actively participates in the network and referred as core nodes. The core nodes communicate with each other to form a backbone and reconfigure due to the mobility. The RMR aims to provide a reconfigurable virtual backbone by embedding route maintenance mechanism. In following subsections, we describe how RMR protocol constructs virtual backbone with minimum overhead and link recovery.

B. Methodology

The RMR protocol consists of three major components: i) Core election process, ii) Backbone construction process, and iii) Route maintenance process. The core node election process is responsible to elect the core nodes by evaluating three parameters neighborhood density, energy, and traffic load using Bayesian classification method. The backbone construction process then uses the elected core nodes to form individual groups and thereafter the core nodes communicate with each other and form a virtual backbone. Due to the link failures, the upstream node uses the Bayesian classification [8,9] method to elect a nearby optimal node as a core node and generates an alternate path towards the destination. This is done by route maintenance process. The virtual backbone reconfigures itself based on either dynamism of the network (mobility) or lack of energy and so on. Figure 1 depicts the overall structure of reconfigurable virtual multicast backbone, where the black color nodes represent core nodes and rest of the nodes are group members. The three phases of RMRP are briefly discussed in the following sub-sections in sequence.

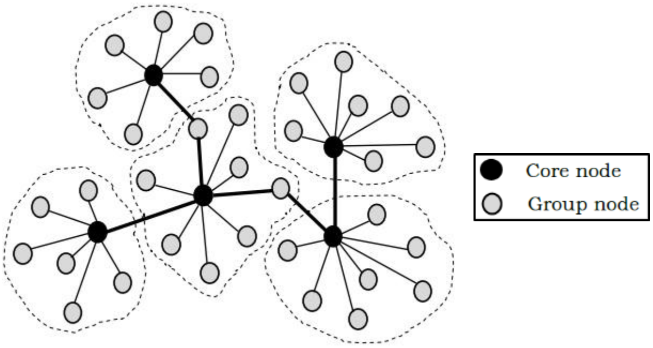

Figure 1.Reconfigurable virtual multicast backbone

a. Core Election Process

In RMR protocol, Bayesian classification method plays a key role to elect an optimal node as a core node. A method to find the probabilistic graphical model for a set of variables with the probabilistic dependencies is known as the Bayesian classification [8] method. The key parameters for selecting the core nodes are neighbor density, energy, and traffic load. The algorithm to perform core node election is illustrated below.

Algorithm:

1. Initially, for each node evaluate the values of parameters neighborhood density 'd', energy 'e', and traffic load 'l'.
2. Substitute the values in equation (1) i.e. Bayesian input matrix (BIM).

$$BIM = \begin{bmatrix} x_{d1} & x_{d2} & x_{d3} & x_{dn} \\ x_{e1} & x_{e2} & x_{e3} \ldots & x_{en} \\ x_{l1} & x_{l2} & x_{l3} & x_{ln} \end{bmatrix} \quad \ldots..(1)$$

where x_{d1} - the neighborhood density of node x_1,
x_{e1} - the energy of the node x_1,
x_{l1} - the traffic load of the node x_1.

3. For each parameter, compute the mean using equation (2)

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \ldots\ldots.. (2)$$

where μ - mean

4. Compute the variance using equation (3)

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(\mu - x_i)^2 \quad \ldots\ldots.. (3)$$

where σ^2 - variance

5. Compute the standard deviation using equation (4)

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mu - x_i)^2} \ldots\ldots.. (4)$$

whereσ - standard deviation

6. Compute the density function using equation (5) by substitute mean 'μ', variance 'σ^2' and standard deviation 'σ'

$$\varphi_{\mu,\sigma}(x_i) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x_i-\mu)^2}{2\sigma^2}} \quad \ldots (5)$$

7. Substitute the values in equation (6) i.e. Normal Distribution Matrix (NDM)

$$NDM = \begin{bmatrix} x_{nd1} & x_{nd2} & x_{nd3} & x_{ndn} \\ x_{ne1} & x_{ne2} & x_{ne3} \ldots & x_{nen} \\ x_{nl1} & x_{nl2} & x_{nl3} & x_{nln} \end{bmatrix} \quad \ldots (6)$$

Where x_{nd1} - normal distribution neighborhood density of node x_1,
x_{ne1} - normal distribution energy of the nodex_1,
x_{nl1} - normal distribution traffic load of the nodex_1.

8. Compute the distribution summation value 'D' using equation (7).

$$D += NDM \quad \ldots.(7)$$

9. The normal distribution matrix is translated into normal distribution probability matrix by dividing the matrix with distribution summation value as shown in equation (8).

$$NDPM = \begin{bmatrix} x_{nd1} & x_{nd2} & x_{nd3} & x_{ndn} \\ x_{ne1} & x_{ne2} & x_{ne3} \ldots & x_{nen} \\ x_{nl1} & x_{nl2} & x_{nl3} & x_{nln} \end{bmatrix} / D \quad \ldots. (8)$$

10. Compute Predicator using equation (9)

$$p\_s += NDPM \quad \ldots.. (9)$$

11. Compute Prior probability of predictor using equation (10)

$$p\_a[j] = \sum_{i=1}^{n} NDPM[i][j] \quad \ldots\ldots (10)$$

12. Compute Likelihood using equation (11)

$$p\_s\_a[i] = \sum_{j=1}^{m} NDPM[i][j] \quad \ldots\ldots (11)$$

13. Compute Posterior probability using equation (12)

$$p\_a\_s[i][j] = \frac{(p\_s\_a[i])(p\_a[j])}{p\_s} \quad \ldots\ldots.. (12)$$

14. From the contribution probability of the parameter, the maximum parameter is computed to calculate the contribution probability of the each node by taking the summation of each node and its parameters using equations (13, 14).

$$max\_p = 1 - p\_a\_s[i][j] \quad \ldots\ldots.. (13)$$

where i = 1 to n, j = 1 to m

$$pas[i] = \sum_{i=1,j=1}^{nm} pas[i] + [(max\_p[i])(p\_a\_s[i][j])]..(14)$$

15. This final contribution probability is termed as the naive Bayes probability of the node to become the core node.

b. Backbone Construction Process

The elected core node announces itself as a core node. After receiving the core_announcement packet, the neighboring nodes send group_join_req packet. If the core node accepts the request it replies back with group_join_rep packet to them. Then the neighboring nodes become the corresponding core group members, the formed groups are referred as multicast groups. The core node knows the ids of the members of the group. The core node can communicate with its neighboring core nodes by sending a core_req packet. In response, neighboring core nodes reply with a core_rep packet, hence communication path is established among core nodes and finally a virtual backbone will be formed over the network. In case if a core node is not reachable to another core node, an intermediate node involve between two core nodes. Here an intermediate node can be any member node of the group.

c. Route Maintenance Process

If a source is having a packet to transmit it to the destination, initially it checks the route cache to find the route. If a route found, transmission takes place. Otherwise, it initiates the route discovery process by using Dynamic Source Routing (DSR) [16] scheme. During the packet transmission, if any link fails, the upstream node initiates route recovery process by reconfiguring the backbone. The route recovery process is described by considering three scenarios as discussed below.

During link failure, the upstream node keeps the data packet in the queue until it finds an alternate path to the next core node which in turn leads to the destination. Let us consider a virtual backbone where core nodes are elected based on Bayesian classification [] method; that are CN1, CN2, CN3 and CN4 as shown in figure 2.

Scenario 1: Link failure between core node and intermediate node (CN - IN)

In this scenario, an intermediate node involves maintaining the communication between two core nodes. Let us assume that a link failure occurred between core node 'CN3' to intermediate node 'r' as shown in figure 2, means node 'r' might be reachable to any adjacent core node(s) nearby (either CN2 or CN4). In this case, either CN2 or CN4 reconfigures itself and makes the unreachable intermediate node 'r' as its group member. In order to place the communication between CN3 and group 4, Bayesian classification method works as discussed in section 4.2.1. It elects an optimal node as a core node in group 4 to retain the backbone.

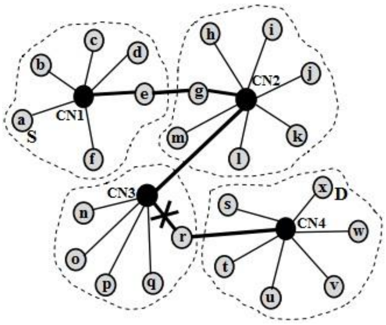

Figure 2. Schematic representation of link failure between a core node and an intermediate node (CN - IN)

Scenario 2: Link failure between two core nodes (CN - CN)

Let us assume that a link failure occurs between two core nodes CN2 and CN3 as shown in figure 3. The core node with mobility becomes the group member of its adjacent core. Bayesian classification [9] method elects an optimal node as a core node of the group from which earlier core node left and retains the backbone.

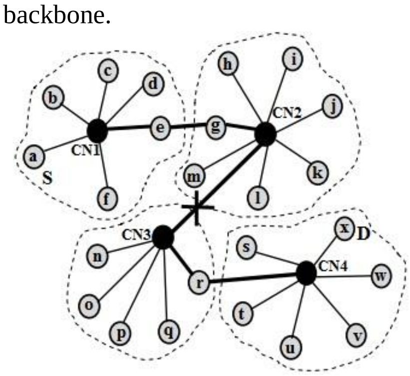

Figure 3. Schematic representation of link failure between two core nodes (CN - CN)

Scenario 3: Link failure between two intermediate nodes (IN - IN)

Let us assume that a link failure occurs between two intermediate nodes 'e' and 'g' of adjacent core groups CN1 and CN2 as shown in figure 4. In this case, either of the intermediate nodes with mobility becomes the group member of its adjacent group. In case if two core nodes are still not reachable without any intermediate node then Bayesian classification method elects an optimal node as an intermediate node between CN1 and CN2 and retains the backbone.

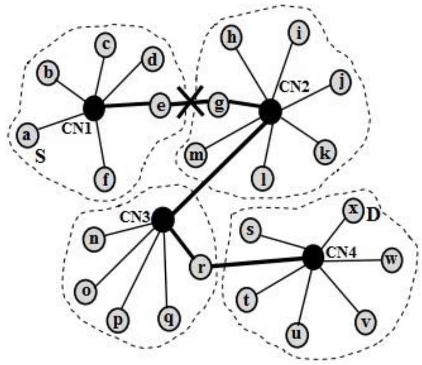

Figure 4.Schematic representation of link failure between two intermediate nodes (IN-IN)

IV. SIMULATION RESULTS

The performance of proposed RMR protocol is simulated using network simulator (NS2) tool. The protocol is compared with most recent existing backbone protocols backbone group model [12] and hierarchical virtual backbone construction protocol [13]; and route recovery protocol local link failure recovery protocol [15]. The simulation runs under the following simulation environment: The confined working space is 1000m × 1000m. Nodes are randomly located in this area. Each node has the same transmission range, and the link between every pair of nodes is bidirectional. The simulation parameters are summarized in table 1. The simulation is carried out by varying the network size and traffic in terms of the selected evaluation metrics such as packet delivery ratio, normalized overhead, delay, and throughput.

Table 1. Simulation configuration

Parameter	Value
Simulation tool	NS2 (version 2.34)
Simulation area	1000 m × 1000 m
Number of nodes	50, 60, 70, 80, 90, 100
MAC type	IEEE 802.11
Simulation time	200 s
Initial node energy	100 Joules
Antenna model	Omni antenna
Channel type	Wireless channel
Mobility model	Random way point
Traffic type	UDP

A. Result Analysis

The simulation results of RMR protocol are analyzed by using the performance metrics like packet delivery ratio, throughput, normalized overheads and delay by varying size of the network and traffic. It is noticed that RMR protocol yields better results and improves the network efficiency with respect to the parameters as shown in figure 5, 6, 7, 8, 9, 10, 11 and 12.

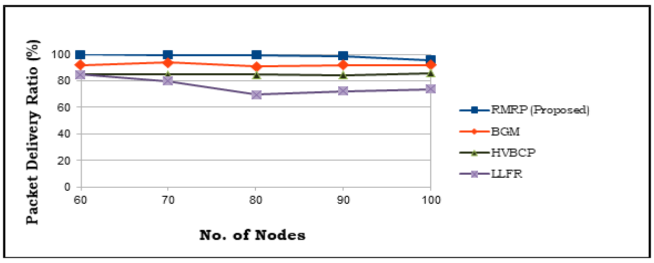

Figure 5.Number of nodes versus packet delivery ratio

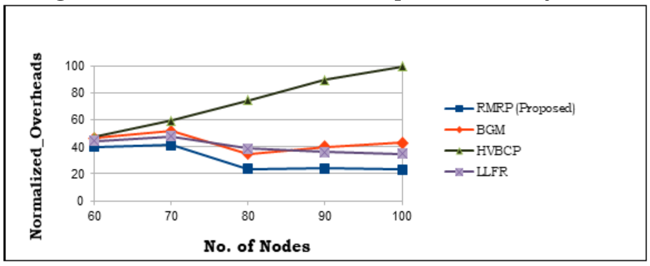

Figure 6.Number of nodes versus normalized overheads

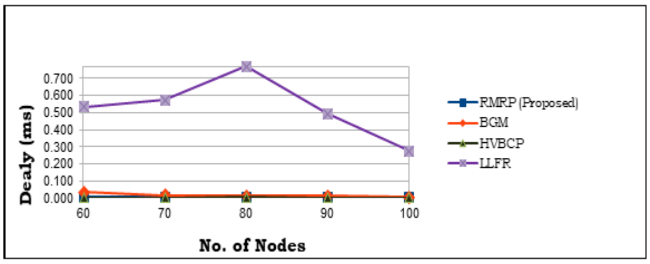

Figure 7.Number of nodes versus delay

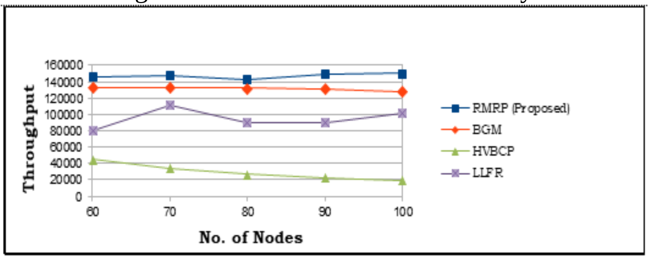

Figure 8.Number of nodes versus throughput

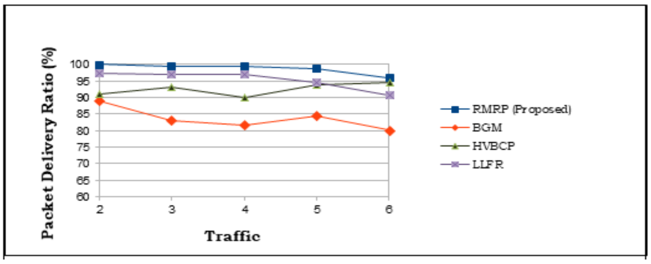

Figure 9. Traffic versus packet delivery ratio

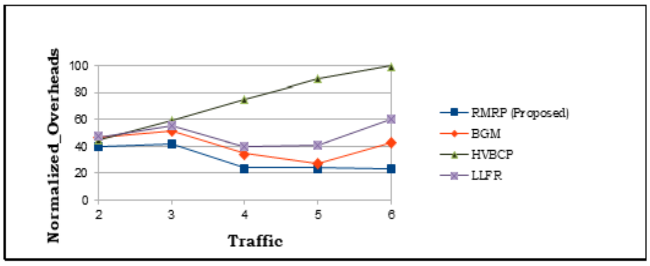

Figure 10. Traffic versus normalized overheads

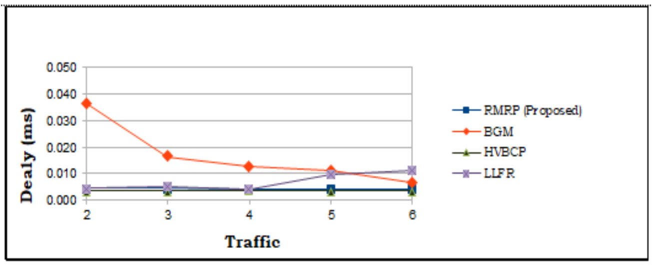

Figure 11. Traffic versus delay

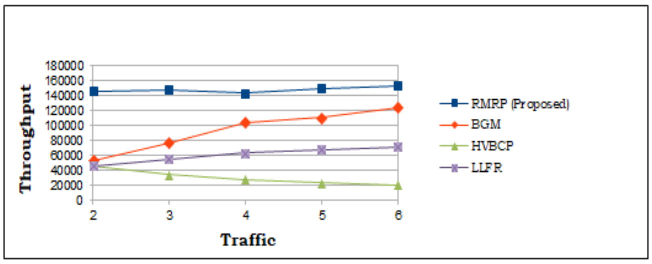

Figure 12. Traffic versus throughput

V. CONCLUSION

In this paper, a novel hybrid protocol is proposed to recover the link failures by reconfiguring virtual backbone in MANETs. We describe the construction of reconfigurable virtual backbone and finding an on-demand route in case of link failures. The main objective of the proposed protocol is to minimize the routing overhead and maintenance cost. Based on the simulation results, we can conclude that the proposed RMR protocol yields better results in terms of packet delivery ratio, throughput, normalized overheads, delay, dropping ratio and overall residual energy by varying size of the network and traffic in comparison with existing protocols. In the future, we would like to enhance the proposed protocol by incorporating the security concepts to increase the reliability and confidentiality of the network.

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