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Research Article

Energy Optimization for Wireless Sensor Networks using a Novel Dynamic Multicast Routing Protocol

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Abstract: Minimization of energy consumption has always been the predominant factor deciding the acceptability of a routing protocol for wireless ad-hoc networks. In this study we have proposed a novel efficient multicast routing protocols in wireless mobile ad hoc networks is proposed. Due to the high mobility of nodes and highly dynamic topology, performing efficient and robust multicast in a Mobile Ad hoc Network (MANET) is a challenging task. Most of existing multicast protocols in MANETs discover the routing path by flooding message over the whole network, which result in considerable cost for routing discovery and maintenance. Moreover, the reliability of the discovered path cannot be guaranteed, since the stabilities of nodes along such path are unpredictable. Here an attempt is made to devise an algorithm combining the features of both energy efficient and low latency algorithms. The new algorithm is intended to do well in real-world scenarios where the energy capacities of the nodes are not uniform. It employs a mobility prediction based election process to construct a reliable backbone structure performing packet transmission, message flooding, routing discovery and maintenance. Several virtual architectures are used in the protocol without need of maintaining state information for more robust and scalable membership management and packet forwarding in the presence of high network dynamics due to unstable wireless channels and node movements.

Keywords: Load balancing, low latency, multipath routing, scalability, wireless ad-hoc networks

INTRODUCTION

An ad-hoc network is the cooperative engagement of a collection of mobile nodes without requiring intervention of any centralized access point or existing infrastructure. To provide the optimal communication ability, a routing protocol for such dynamic self-starting network must be capable of unicast, broadcast and multicast in a wireless ad hoc network environment some nodes may want to communicate with other nodes outside their maximum transmission range, thus requiring other nodes to forward packets on behalf of source nodes. In general, there will be none, one, or several intermediate forwarding nodes between source-destination pairs. Route-discovery is responsible for finding new routes between active source-destination pairs whereas route maintenance is responsible for updating existing routes in the presence of node mobility. Multicasting is a communication process in which the transmission of packets (message) is initiated by a single user and the message is received by one or more end user of the network (Chen and Wu, 2003).

A MANET is an autonomous collection of mobile nodes forming a dynamic network and communicating over wireless links. Users are allowed to communicate with each other in a temporary manner with no centralized administration and in a dynamic topology that changes frequently. Due to the limited propagation range of the wireless environment, routes in ad hoc networks are Multihop and mobile nodes in this network dynamically establish routing among themselves to form their own network "on the fly" (Broch *et al*., 1998). Each participating node acts both as a host and a router and must therefore be willing to forward packets for other nodes. Nodes in such a network move arbitrarily, thus network topology changes frequently, unpredictable and may consist of unidirectional links as well as bi -directional links. Moreover, wireless channel bandwidth is limited. The scarce bandwidth decreases even further due to the effects of signal interference and channel fading. Network hosts operate on constrained battery power, which will eventually be exhausted. MANETs strictly depend on radio links. Actually, a wireless link is the most variable and unpredictable communication

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channel. In addition, ad hoc networks are vulnerable to attacks and have limited physical security. The increased possibility of eavesdropping, spoofing and denial-of-service attacks should be carefully considered. Because ad hoc networks do not typically allow the same aggregation techniques that are available to standard Internet routing protocols, they are vulnerable to scalability problems. These drawbacks lead to define a set of underlying assumptions and performance concerns for protocol design (Tony and Nicklas, 1998).

Location aided routing is based on localization. Its purpose is to limit the route request packets broadcast. For this purpose it uses GPS localized information. Before launching any request, the source node acquires the destination's position information from the GPS and puts it in the request packet. The broad cast of this packet is limited to the nodes located within the smallest area covering the two nodes (source and destination). Nodes beyond this area will drop this packet if they receive it (Ko and Vaidya, 1998; Kuruvila *et al.*, 2004). Multipath protocols aim at providing redundant paths to the destination. Availability of redundant paths to the same destination increases the reliability and robustness of the network. Providing multipath is beneficial, particularly in wireless ad hoc networks where routes are disconnected frequently due to mobility of the nodes and poor wireless link quality. Minimum-energy routing algorithms in wireless networks typically select minimum-cost multi-hop paths. If the cost of each link is the transmission energy required, the energy-aware routing protocols select routes that minimize the total transmission power over all the nodes in the selected path. In scenarios where the transmission power is fixed, each link has the same cost and the minimum-hop path is selected. In situations where the transmission power can be varied with the distance of the link, the link cost is higher for longer hops; the energy aware routing algorithms select a path with a larger number of small-distance hops. Such a formulation based solely on the energy spent in a single transmission is misleading-the proper metric should consider the link error rates to account for the potential cost of retransmissions needed for reliable packet delivery.

The more error-prone a link the higher will be the probability of retransmissions. Therefore, the cost of a link should be assessed based on both the transmission energy needed and the error rate. Re-transmission aware routing is significant irrespective of whether fixed or variable transmission power is used by the nodes to transmit across links. An improvement in energy efficiency is achieved by explicitly considering the impact of receiver noise on packet errors and by adjusting the transmission power to minimize the total energy spent in reliably forwarding a single bit. Energy-efficient algorithms rely on short-range communications thereby increasing the network latency. The load balancing property of these algorithms is also not good when there is no inherent load distribution in the traffic. The relay nodes close to the source node can become over-exploited. A variant of the energy-aware protocols considers the battery level of the nodes while assessing the cost of the links. This can avoid choosing an energy-efficient path with one or more nodes in the path having low battery levels as the best route. But, even this strategy cannot prevent overloading of a node with low battery level when the other nodes in the routes of which it is a part all have high battery levels (Ilias and Cyriel, 2008; Scott and Bamboos, 1996; Singh and Raghavendra, 1998; Banerjee and Misra, 2002).

Routing algorithms employing randomized algorithms inspired by the small-world phenomenon have also been proposed (De Couto *et al.*, 2003). Though the common attribute of these algorithms is excellent load balancing, there are a few in this category that provide low network latency and power consumption. Randomized algorithms can provide extreme decentralization and, therefore, very high robustness and scalability. Collaborative techniques employing randomized algorithms create little communication overhead as the decisions are locally made. Decision making is probabilistic in nature; therefore, the probability distribution functions used should be wisely chosen so as to make the overall effect of the local actions producing the desired system-wide result. The main idea is the use of two phases in the journey of a packet from its source to destination. The first phase, named expansion phase, is used to distribute the packets nearly uniformly across the network. The second phase, named contraction phase, directs the packets towards their respective destinations. If the algorithm relies only on short range communications for the routing load distribution, the resulting average network latency will be high. On the other hand, if proper mix of long range and short range communications are used the average network latency experienced by the packets can be reduced substantially (Kleinberg, 2000).

OVERVIEW OF MULTICASTING PROTOCOLS

RBMR: Reliable Backbone based Multicast Routing (RBMR), to improve the robustness and efficiency of multicast routing and delivery in high speed scenario. Different to other famous multicast protocols for MANETs, in RBMR, in order to achieve efficient and reliable packet forwarding, the most stable nodes are elected to be cluster leader forming a Reliable Backbone Structure (RBS) to manage the content delivery, routing discovery and maintenance. Hence, in RBMR, routing discovery never suffers from the considerable cost aroused from flooding message over the whole ad hoc network either implicitly or explicitly. Moreover, unlike previous works, a stability

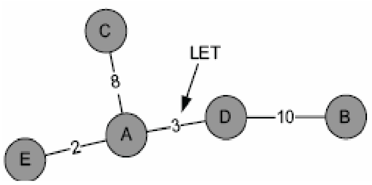

Fig. 1: Example of node stability

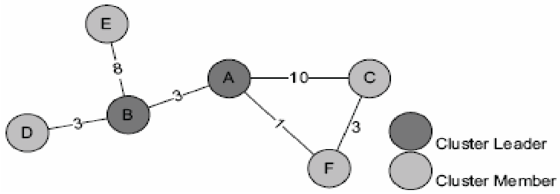

Fig. 2: Example for leader election

Table 1: Notations are used to describe RBMR

ID (i)	The unique ID of mobile node i, for instance, IP addresses
CID (i)	The unique cluster ID of mobile node i, it should be equal to the ID of cluster leader. If node i join no cluster, it equal to ID $_{\text{Invalid}}$
l (i, j)	The link between a pair of 1-hop neighbour nodes i and j if existed
NS (i)	Stability level of node i
$T_{\text{Stability}}$	A constant number to denote the cycle to update NS (i) factor by mobile node i
LET (i, j)	Link expiration time which indicate how reliable is the link between node i and j
RET (l)	Route expiration time of the route path l
Hop (l)	Hop count along route path l

metric based upon mobility prediction is proposed to evaluate the reliability of nodes. Since the RBS is formed from these most relatively reliable nodes, the influence of nodes mobility is alleviated. Existing multicast protocols can take advantage of RBS by cooperating with it. An example about node stability is depicted in Fig. 1. There are three links between node *A* and its 1-hop neighbors (Table 1):

> *LET* (*A*, *C*) = 8, *LET* (*A*, *D*) = 3 and *LET* (*A*, *E*) = 2. Hence, the node stability *NS* (*A*) = *LET* (*A*, *C*) + *LET* (*A*, *D*) + *LET* (*A*, *E*) = 13

Mobility-aware cluster leader election: In this mechanism, each node is either a cluster leader or a cluster member within a cluster after the process of cluster leader election (Fig. 2).

In RBMR, each cluster is formed from the 1-hop neighborhood of the cluster leader. All the nodes elect the highest stable mobile node in their neighborhood only by using 1-hop neighborhood information. In order to react to changes of network topology, each node, e.g., node *j*, need to broadcast a 1-hop broadcast message, named CHELLO, periodically, e.g., every one second. In order to employ the motion information provided by GPS, as long as mobile node *j* sends a CHELLO packet, its location, direction and speed are appended to the packet. Hence, such message includes the fields (*NS* (*j*), *ID* (*j*), *CID* (*j*), *xj*, *yj*, *vj*, *θj*). All the 1-hop nodes receive CHELLO messages and update information of their neighbors for management. Once a 1-hop neighbour node, say mobile node *i*, received this message, it update the *NS* (*j*) for node *j* and the link reliability *LET* (*i*, *j*) between them is predicted by applying Eq. (1). Each mobile node also updates its own stability factor periodically by applying the Eq. (3) with the cycle of *TStability*. With all the node stability factors of all the nodes in the neighborhood, nodes can easily elect a node in their leader, with the comparison metric in lexicographical ordering: (*NS* (*i*), *ID* (*i*)). In case two nodes in the neighborhood take the same highest node stability, node prefers to elect the node with highest ID to be its cluster leader. Such a node then transmits a CJOIN packet to its elected leader and update the *CID* (*i*) to be the ID of the leader.

Mobility-aware gateway selection: A node is called a boundary node once it links to not only the nodes within the same cluster but also the nodes of the adjacent clusters. Note that a cluster header may also be a boundary node, since a cluster may have a link to a node which is also elected to be a leader by its neighbour or join another cluster leader with higher stability, ID. There only can exist four different situations as following:

- Cluster leader directly link to cluster leader j
- Member node in cluster i directly link to cluster leader j
- Member node in cluster j directly link to cluster leader i
- Member node in cluster i link to member node in cluster j

In order to achieve mobility-aware communication between two cluster and maintain a low overhead lever level, each cluster leader employ a detect process to discovery in an event driven manner An example is shown in Fig. 3, there exist four routing paths between leader *A* and *B*: *lADB*, *lAFB lADFB* and *lAFDB*.

It's clearly that the gateway routing cannot be selected from both of *lADFB* and *lAFDB* even *lAFDB* take the highest route expiration time of 4, since both of them are 3-hops links. Among path *lADB* and path *lAFB*, the route expiration time of path *lAFB* is higher than the one of path *lADB*. As a result, path *lAFB* become the routing path between leader *A* and leader *B*. Eventually, after cluster leaders select their routing paths to the adjacent clusters, the RBS is formed.

Multicast routing discovery: The routing discovery process and multicast packet transmission is designed based upon ODMRP. Whenever a multicast source

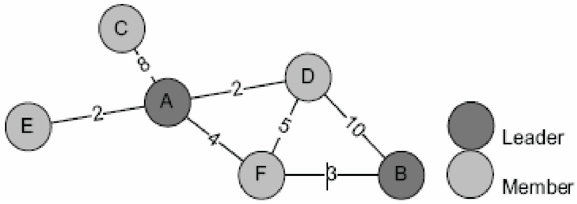

Fig. 3: Example of routing path selection between two adjacent clusters

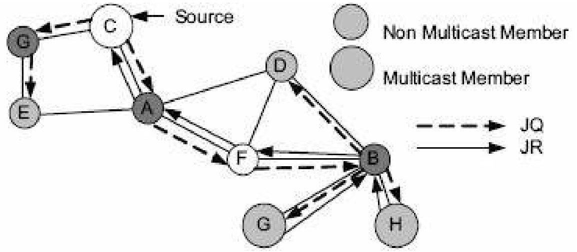

Fig. 4: Routing discovery

wishes to multicast data to the multicast group, it initiates the routing discovery process. Unlike the process in ODMRP, Join Query (JQ) messages only be broadcasted by RBS. Once the JQ message arrives at a multicast member, such member replies a Join Reply (JR) message. By the time the JR message arrives at a cluster leader, such leader become a forwarding node as well as its upstream cluster leader and the gateway nodes between them. The multicast route discovery mechanism is shown in Fig. 4.

ODMRP: An ad hoc network is a dynamically reconfigurable wireless network with no fixed infrastructure or central administration. Each host is mobile and must act as a router. Routing and multicasting protocols in ad hoc networks are faced with the challenge of delivering data to destinations through Multihop routes in the presence of node movements and topology changes. It presents the On-Demand Multicast Routing Protocol (ODMRP) (Lee *et al*., 2002) for wireless mobile ad hoc networks. ODMRP is a mesh-based, rather than a conventional tree-based, multicast scheme and uses a forwarding group concept; only a subset of nodes forwards the multicast packets via scoped flooding. It applies on-demand procedures to dynamically build routes and maintain multicast group membership. ODMRP is well suited for ad hoc wireless networks with mobile hosts where bandwidth is limited, topology changes frequently and power is constrained. We evaluate ODMRP performance with other multicast protocols proposed for ad hoc networks via extensive and detailed simulation (Royer and Perkins, 1999).

ODMRP builds and maintains a mesh for each multicast group. Providing multiple paths by the formation of mesh configuration makes the protocol robust to mobility. Alternate routes enable data delivery in the face of mobility and link breaks while the primary route is being reconstructed. The protocol does not yield excessive channel overhead in highly mobile networks because no control packets are triggered by link breaks. ODMRP also applies demand-driven, as opposed to periodic, multicast route construction and takes soft state approach in membership maintenance.

METHODOLOGY

Proposed routing algorithm: The proposed, randomized, decentralized routing algorithm that uses collaboration of all the nodes in the network. In this algorithm, a new routing path is generated from source to destination for each batch of transmissions. Moreover, local and independent decisions at the node level are used to construct each new routing path.

The proposed algorithm has two phases namely expansion phase and the contraction phase, which aims load balancing, low network latency and energy efficiency. During a packet's expansion phase, the set of probable nodes to which the packet can be forwarded to is relatively large. The probability distribution function is such that the nodes farther from the source have a fair chance of becoming relay nodes unlike in many routing algorithms where the nodes closer to the source are overloaded for the packets emanating from that source and in such algorithms any chance of achieving uniform load sharing depends on the uniform nature of the traffic distribution in the network. A good litmus to test the uniform load sharing for the routing task is to apply the algorithm for the routing of a multicasting application with one source and a finite number of receivers which is a proper (and small) subset of the set of nodes in the ad-hoc network. Such applications usually emit long streams of packets which provide an opportunity to test the load balancing property of a routing algorithm without relying on the inherent uniform traffic distribution found in many networks.

The contraction phase serves to direct the packet to the destination node. The next hop for a packet in its contraction phase is probabilistically chosen so that there is a chance for long-range transmissions to take place. The probability of a long-range node (a potential shortcut to the destination) getting selected as the next hop depends on its distance from the current node-more the distance lower the probability. As with other ad-hoc routing methods, the requirement that each forwarding action should take the system closer to the destination (greedy strategy) is realized by following the rule that the selected shortcut is used only if taking the shortcut gets the packet closer to the destination than moving to any of the immediate neighbors. If the distance between selected shortcut and the destination is not less than that between the best (in terms of the distance to the destination) of the immediate neighbors of the current node, the next hop will be to the best immediate neighbour. The probabilistic nature of choosing the shortcut contributes to the overall load balancing which is the main emphasis of the expansion phase. Since the probability distribution dictating the choice of a shortcut to the destination tends to pick nearer nodes more often than the farther nodes, the energy efficiency aspect is also taken care of.

Enhanced expansion random walk algorithm: Let *u* be the current node, *s* the source, *d* the destination, B_{high} a predefined high threshold, B_{low} a predefined low threshold and $B_{current}$ be the current battery level.

Every node that a data packet visits during its expansion phase executes the following sub-algorithm:

- If $B_{current}<B_{low}$, pass the packet to the first neighbour that is furthest from *s*
- If $B_{current}>B_{high}$ Choose a random long-range node, *v*, uniformly from the set of all nodes with in distance of *u*. Let *r* be the distance between *u* and *s* and *r' be* the distance between *v* and *s*
  If *r'>r*, pass the packet to *v else* pass the packet to the first neighbour that is furthest from *s*
- If $B_{low}\le B_{current}\le B_{high}$:

  Let p = $(1/(B_{high} - B_{low})) * (B_{current} - B_{low})$

Choose the next hop as in the case when $B_{current} > B_{high}$ with a probability of p or as in the case when $B_{current}<B_{low}$ with a probability of 1-p.

Enhanced contraction random walk algorithm: Let *u* be the current node, *s* the source, *d* the destination, B_{high} a predefined high threshold, B_{low} a predefined low threshold and $B_{current}$ be the current battery level.

Every node except the ultimate destination that a data packet visits during its contraction phase executes the following sub-algorithm:

- If $B_{current}<B_{low}$, pass the packet to the first neighbour that is nearest to *d*
- If $B_{current}>B_{high}$, Choose a random long-range node, *v*, uniformly from the set of all nodes. Let *r* be the distance between *u* and *d* and *r′* be the distance between *v* and *d*. If *r′<r*, pass the packet to *v else* pass the packet to the first neighbour that is nearest to *d*
- If $B_{low}\le B_{current}\le B_{high}$, Let p = $(1/(B_{high} - B_{low})) * (B_{current} - B_{low})$

Choose the next hop as in the case when $B_{current} > B_{high}$ with a probability of p or as in the case when $B_{current}<B_{low}$ with a probability of 1-p.

For routing, an expansion phase starts from the source node and continues for T = O (log N) steps until it stops at a relay node v, where N is the distance between the source and the ultimate destination. A contraction walk then starts from v towards the destination. The extension to the case of multiple receivers (multicast scenario) is straightforward. To feed M receivers, simply M, contraction random walks start, in parallel, from the relay node v. If the routing algorithm can successfully accommodate a single contraction phase, it will also be able to accommodate multiple phases at the same time. Since the creation of the shortcuts at individual nodes in the contraction phase is independent of the position of the destination, the same set of links can be used to relay messages to multiple destinations in the contraction phase of a multicast.

RESULT ANALYSIS

The performance evaluation is carried out as a simulation study using NS2. We use the following metrics in evaluating the performance of the different multicast routing protocols. The packet delivery ratio is computed as the ratio of total number of unique packets received by the receivers to the total number of packets transmitted by all sources times the number of receivers.

Routing overhead is the ratio between the numbers of control bytes transmitted to the number of data bytes received. The simulation results of our proposed protocol are compared to other leading protocols ODMRP and RBMR. In these simulations, we use synthetic MANET scenarios, in which we subject the protocols to a wide range of mobility, traffic load and multicast group characteristics (i.e., group size and number of sources). Figure 5 shows the packet delivery ratio as a function of traffic load. It is observed that all protocols are affected by the increase in network traffic. For the traffic loads

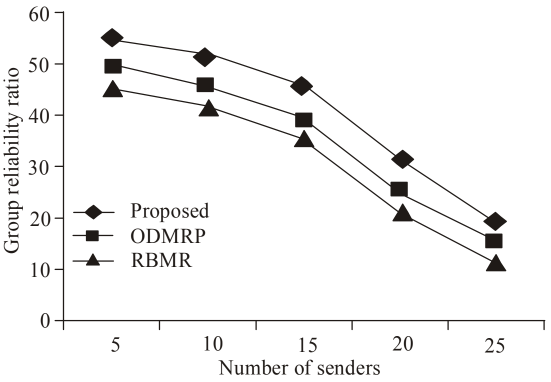

Fig. 5: Packet delivery ratio as a function of traffic load

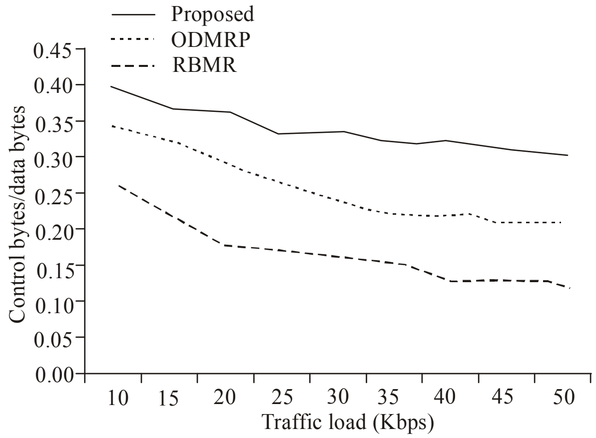

Fig. 6: Routing overhead as a function of traffic load

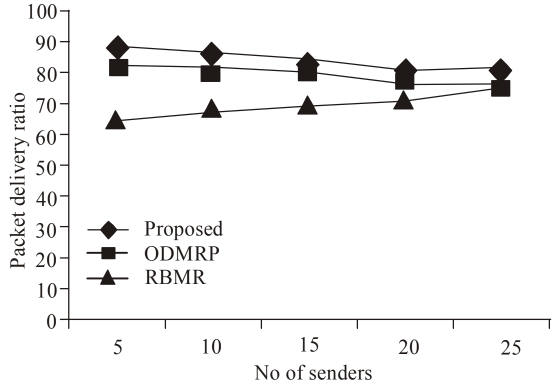

Fig. 7: Packet delivery ratio as a function of number of traffic sources

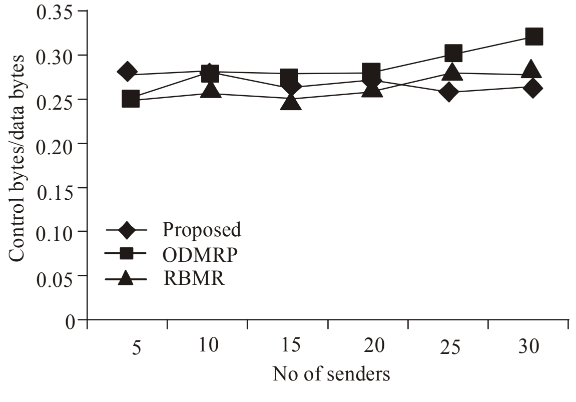

Fig. 8: Routing overhead as a function of traffic sources

considered, MTMP still out performs ODMRP and RBMR in terms of delivery ratios. The performance proposed protocol is much more better to ODMRP and RBMR as traffic load increases on account of the great number of redundant transmissions.

Figure 6 depicts the control overhead per data byte delivered as a function of traffic load. It can be seen that proposed system control overhead remains almost constant with increasing load. The high routing overhead seems to suggest that proposed system can be quite expensive at higher traffic loads and, hence, not scalable with increased traffic loads.

Figure 7 shows the packet delivery ratio as a function of the number of senders. Note that both the proposed and ODMRP packet delivery ratios remain fairly constant with the number of senders; thus, they do not suffer from increased contention except at a higher number of sources, where a slight drop off can be observed and is attributed to data packet loss due to collisions. Figure 8 depicts how control overhead varies with the number of traffic sources.

CONCLUSION

In this study, we focus on, randomized, decentralized routing algorithm that uses collaboration of all the nodes in the network. In this algorithm, a new routing path is generated from source to destination for each batch of transmissions. Moreover, local and independent decisions at the node level are used to construct each new routing path. The proposed algorithm has two phases namely expansion phase and the contraction phase, which aims load balancing, low network latency and energy efficiency multicast routing protocol. Routing requirements are reviewed. It can detect broken tree branches rapidly, with the support from the passively participating neighbouring nodes around the active branches and then repair the broken links. The comparative analysis was that our proposed algorithm, which is the simplest routing mechanism, achieves less energy dissipation by eliminating the redundant data receptions, provides higher delivery guarantees than RDMR and ODMRP because all the nodes are continuously relaying all the packets.

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