Journal of King Saud University – Computer and Information Sciences (2018) **30**, 67–79

King Saud University

Journal of King Saud University – Computer and Information Sciences

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Minimizing Broadcast Expenses in Clustered Ad-hoc Networks

S. Zeeshan Hussain, Naeem Ahmad *

Department of Computer Science, Jamia Millia Islamia (A Central University), Jamia Nagar, New Delhi, India

Received 26 January 2016; revised 6 May 2016; accepted 8 May 2016
Available online 17 May 2016

KEYWORDS

Routing;
Clustering;
Congestion;
Propagation;
Broadcast

Abstract One way to minimize the broadcast expenses of routing protocols is to cluster the network. In clustered ad-hoc networks, all resources can be managed easily by resolving scalability issues. However, blind query broadcast is a major issue that leads to the broadcast storm problem in clustered ad-hoc networks. This query broadcast is done to carry out the route-search task that leads to the unnecessary propagation of route-query even after route has been found. Hence, this query propagation poses the problem of congestion in the network. In particular this motivates us to propose a query-control technique in such networks which works based on broadcast repealing. A huge amount of work has been devoted to propose the query control broadcasting techniques. However, such techniques used in traditional broadcasting mechanisms need to be properly extended for use in the cluster based routing architecture. In this paper, query-control technique is proposed for cluster based routing technique to reduce the broadcast expenses. Finally, we report some experiments which compare the proposed technique to other commonly used techniques including standard one-class AODV that follows TTL-sequence based broadcasting technique.

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1. Introduction

Self-configuring structures of randomly moving nodes set up Mobile Ad-hoc Networks (MANETs) in which moving nodes act as mobile-terminals as well as routing stations. These slave-less movements cause the change in the structure of the networks. In such scenarios, route establishment is the primary task to initiate the communication between resources which is very difficult due to their random movements (Yousefi et al., 2006). To achieve adaptability, several routing protocols have been proposed in which different strategies were adopted to acquire the requested route.

The route-query broadcast is the most traditional way of discovering the route in any routing protocol for data transmission (Perkins and Bhagwat, 1994; Perkins and Royer, 1999). This query covers a large area of the network to find the route and propagate even after the route has been discovered. This unnecessary propagation of route-queries in the network poses the problem of congestion. In order to

* Corresponding author.
E-mail addresses: szhussain@jmi.ac.in (S.Z. Hussain), naeemahmad.jmi@gmail.com (N. Ahmad).
Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jksuci.2016.05.001
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minimize such type of congestion, several query control broadcasting techniques came into existence. These techniques reduce the broadcast expenses, and also eliminate one of the causes of network congestion.

Such query broadcast techniques can be classified either as based on selective flooding or as based on bounded flooding (Hussain and Ahmad, 2014; Pu and Shen, 2010). The selective flooding based techniques rely on previously stored routing information to acquire desire route and also require up-to-date topological information. On one hand, the effectiveness of broadcasting increases as up-to-date topological information becomes available. On the other hand, collecting topological information needs periodic link-update broadcasts which are very costly in *ad-hoc* networks, where resources like bandwidth, energy, etc. are scarce. To prevent such periodic broadcast, bounded flooding based query broadcast (e.g. TTL-sequenced based ERS) is needed which reactively places the query control broadcast (Pu and Shen, 2010). Despite controlled broadcasting, some intermediate nodes are used unnecessarily that leads to the unnecessary energy consumption as discussed later in Section 3.

Apart from the single-type routing techniques whether proactive or reactive, hybrid routing techniques were proposed, for example CBRP (Rezaee and Yaghmaee, 2009), ZRP (Haas et al.), etc., which acquire the route proactively within the node proximity and reactively beyond the proximity of the node (Abolhasan et al., 2004). On the one hand, these routing techniques solve scalability issue. On the other hand, they are still prone to the unnecessary query broadcast like single-type routing techniques as discussed in Haas and Pearlman (2001); Park et al., 2006; Ahmad and Hussain. This is because a node may be a peripheral node of more than one node in accordance with ZRP. Consequently, a node may receive multiple copies of same query. In contrast, cluster based routing technique produces the clusters in distributed manner where route-query broadcast is done blindly in the absence of the previous communications. There is no query control mechanism that notifies the relay nodes to cease the query broadcast after the successful discovery of destination node.

Routing techniques, working either as proactively or reactively or as both, need a query control mechanism. The negligent query broadcast may be a major issue for ad-hoc networks, where resources are limited and topology changes frequently. Reactive approach in any routing protocol creates massive traffic by blind-query broadcast in the entire network. As the distance between communicating nodes increases, this overhead again increases. The combination of excessive traffic and larger distance in *ad-hoc* networks rules out the reactive routing technique for real-time communication. Intuitively, hybrid routing techniques inherit the same problem and likewise is not appropriate in such cases as they continuously use the reactive approach to carry out the route discovery. As a result, it becomes challenging to acquire the desired route at minimal cost. Although a large research community has worked and understood that query broadcast in a controlled manner helps improve the quality of the routing techniques in the *ad-hoc* network, no previous work has been done for such a hybrid routing technique. To the best of our knowledge, our work is the first effort to investigate the query control problem for cluster-based routing protocols in *ad-hoc* networks.

In our proposed method, a Distributed Weighted Clustering Algorithm (DWCA) (Choi and Woo, 2006) is devised to form clusters, and select cluster head and boundary nodes based on their metrics. It is free from ripple effect of clusters which works based on the combined weight metric of mobile nodes. In this technique, mobile nodes collectively form a cluster and choose a cluster head based on their weight metric. This cluster head takes care of all the routing decisions both proactively and reactively. Subsequently, a Modified-Blocking Expanding Ring Search (MBERS+) technique is employed for repealing the query broadcast from further propagation. Since broadcast repealing technique is implemented in clustered network, it is called Clustered Modified-BERS+ (CMBERS+) to define proposed technique. The preliminary version of this paper has been published in Hussain and Ahmad (2014). Here, we demonstrated the analytical study of the proposed technique. Now, more clear interpretation of mathematical modeling is presented along with simulation results to evaluate performance of the proposed technique.

The obtained results corresponding to the proposed technique showed better performance against the DWCA (Choi and Woo, 2006), BERS+ (Al-Rodhaan et al., 2008), and TTL-sequence based broadcasting technique (TTL-ERS) that the Ad-hoc On-demand Distance Vector (AODV) (Perkins and Royer, 1999) follows. We noted that like most state-of-the-art broadcasting techniques such as BERS, BERS+, for a communicating pair of nodes, the proposed work followed more or less the same low-cost path in each set of simulation trials and give same results for some other performance metrics. To help avoid such repeated situations used in the previous work, we are currently investigating query forwarding and energy consumption extensions to the technique presented in this research work. This performance analysis is done using 5 performance metrics: average latency, throughput, energy-exhaustion ratio, retransmission ratio, and query-forwarding with varying hop count between resources, and network coverage.

Rest of the papers is summarized as follows: Section 2 describes the previous work related to controlled broadcasting techniques. Section 3 highlights the need for modification in BERS+ and demonstrates the mathematical comparison with this technique. Section 4 represents the design mechanism of clustering used, routing packets, and tables. In Section 5, we discuss the methodology used in route discovery phase, route maintenance technique and also describe the query-control technique. In Section 6, simulation and result of proposed technique are presented and we then conclude our work in last Section 7.

2. Related work

Connecting call at first attempt and smooth communication without interference are always desirable in real world scenarios. It is only possible in congestion free network where one of the communication lines is continuously free for transmission without any interference. In traffic analysis of such networks, it is found that multiple classes of congestion exist in the network (Karenos et al., 2005). It can be either due to heavy data transmission or negligent circulation of route-query. In order to make collision and congestion free networks, several query control broadcasting techniques pertaining to the selective and controlled flooding have been proposed. The primary objective of these techniques is to transmit the route-query to all the nodes with minimum conveying nodes so that the retransmission ratio as well as forwarding of route-query can be curtailed. Moreover, it also minimizes the energy consumption of intermediate nodes incurred by negligent circulation. A combination of accurate estimation of query-control technique and broadcast-avoidance technique is essential for acceptable communication network. *An accurate estimation of query-control broadcasting technique can lead to maximum network life by exploiting the inherent congestion free network using efficient route discovery*.

Over the past decades, a number of reliable and unreliable query-control broadcasting techniques have been proposed (Ahmad and Hussain). In early stage of this field, reliable techniques were proposed to lessen the broadcast expenses of route discovery process. Flooding and all self-pruning techniques belong to this category. FResher Encounter SearcH (FRESH) (Dubois-Ferriere et al., 2003), Distance Routing Effect Algorithm for Mobility (DREAM) (Basagni et al., 1998), probabilistic technique (Preetha et al., 1820), Query Localization Technique (Castaneda et al., 2002), Location Aided Routing (Ko and Vaidya, 2000), Hop-Wise Limited broadcast (HoWL) (Minematsu et al., 2005), Multipoint Relays (MPRs) (Qayyum et al., 2002), Weighted Rough Set based broadcast (WRS) (Aitha and Srinadas, 2009), all are self-pruning techniques (also called selective-flooding techniques). In MPRs (Qayyum et al., 2002), only neighbor nodes which belong to the multipoint-relay set retransmit the route-query and others discard it. This technique is somewhat better than flooding. Like MPRs (Qayyum et al., 2002), WRS (Aitha and Srinadas, 2009,Preetha et al., 1820) are also selective-flooding based techniques which select the set of neighbor nodes based on some metric. But these techniques require a large storage space at each node of the network and also prone to unnecessary circulation of route-query.

In Dubois-Ferriere et al. (2003), FRESH technique was proposed in which a route was found using anchor nodes. Due to repeated use of the overlapping nodes between anchor nodes, it consumes too much energy of nodes. It is also a time-taken practice which consumes an unnecessary amount of time to search the anchor node. Furthermore, connected-dominating-set based solutions is proposed to remove the redundancy at each intermediate node during query broadcast as in Lou and Wu (2003); Stojmenovic et al., 2002; Wu and Li, 1999. These are heuristic approaches and not suitable where previous communication does not exist. This is because routing information in advance is always desirable to make the heuristic approach.

On the other hand, various bounded broadcasting techniques have been proposed to reduce the forwarding of the route-query. Limited Broadcast Algorithm (LBA) (Gargano and Hammar, 2004), Limited Hop Broadcast Algorithm (LHBA) (Zhang and Jiang, 2005), TTL sequence based ERS (TTL-ERS) (Chang and Liu, 2004), Blocking-ERS (BERS) (Park et al., 2006), Blocking-ERS+ (BERS+) (Al-Rodhaan et al., 2008), and Enhanced-BERS (BERS*) (Pu and Shen, 2009) belong to this category. All these techniques (except Chang and Liu, 2004) are based on chasing strategy. They allow the route-query within the limited area of the network. LBA (Gargano and Hammar, 2004) is a channel capacity based technique in which chase-packet has higher priority than route-query. It causes larger end to end delay. This flaw of LBA (Gargano and Hammar, 2004) was overcome in LHBA (Zhang and Jiang, 2005) by issuing the chase-packets at destination node. Due to partial diffusion of chase-packets, LHBA (Zhang and Jiang, 2005) controls route-queries of only one part of the network. This technique is still prone to the unnecessary propagation of route-queries.

To overcome the flaw of LHBA, a TTL sequence-based ERS algorithm is proposed. This technique does not use any chase-packet to cease the query broadcast. In this technique, source node floods the specific portion of the entire network with route-query based on predefined TTL value. Only intermediate nodes which lie within this searching ring[1] of TTL value participate in the route discovery. If intermediate nodes fail to find path, source node again broadcasts the route-query with increased TTL value. Likewise, at each failure, it expands its searching area as ripple across the water. Like FRESH (Dubois-Ferriere et al., 2003), it also consumes too much power of intermediate nodes.

BERS (Park et al., 2006) and BERS* (Pu and Shen, 2009) are improved versions of (Chang and Liu, 2004). These techniques show higher energy saving and lesser end to end delay. They also eliminate repeated broadcast by introducing the slight delay in the propagation of the route-queries allowing TTL value accounted in previous attempt instead of starting from predefined TTL value. However, the main drawback of BERS and BERS* is that these techniques are not adaptive with the sudden movement of the destination node because of the limited journey of route-queries.

This shortcoming was addressed in Al-Rodhaan et al. (2008). Here, BERS+ was proposed that enabled the route-query to travel beyond the searching ring in this technique, route-query is broadcasted by the intermediate nodes without waiting for chase-packet. It introduces added delay after the maximum hop count rather than within the searching ring. This technique has many benefits over aforementioned techniques such as, minimum end to end delay, and maximum reception ratio. However, broadcast repealing is source initiated whereas to speed up the broadcast repealing, control packet must be destination initiated. In destination initiated broadcast repealing, replying and chasing events occur concurrently that makes the broadcast repealing time efficient.

In contrast, cluster-based routing protocols, for example WCA (Choi and Woo, 2006) and DWCA (Chatterjee et al., 2002), are based on the idea that querying can be done in a way of directing the route-query to gateway nodes. It is an effective method of query broadcast than flooding the entire network with route query. However, because neighboring cluster heads, the relaying nodes of route-query, continue query even after route has been discovered, resulting in unnecessary propagation of route-query. In such cases, the query-control techniques used in traditional broadcasting mechanisms need to be properly extended for use in the cluster based routing architecture. In this research work, a similar query control broadcasting technique is proposed for cluster based routing in which the chase-packet, to cease the query broadcast, is issued from destination node. It speeds up the broadcast repealing in such routing techniques. The efficiency of our

[1] One hop away neighbor nodes form first ring, two hop away nodes form second ring and so on.

technique can be measured mathematically which is discussed in next the section.

3. Analytical study of the proposed technique

Broadcast repealing and clustering are two measures which reduce the query-forwarding and, thus, its consequences. Broadcast repealing ceases the unnecessary propagation of packets, and achieves scalability using clustering which minimizes the number of participating nodes. Based on this assumption, an analytical comparison is done to show the comparative advantage between proposed technique and BERS+.

3.1. Broadcast repealing and its model

Broadcast repealing is query broadcast cancelation procedure. Fig. 1 shows the complete process of broadcast repealing and how the route-query changes its velocity at different rings. Source node broadcasts route-query with predefined TTL value (H_M in this case). Each inlying node, whose distance from the source node is less than H_M hops, normally forwards route-query without any delay to find the route as shown by black circles in Fig. 1. As TTL-value of route-query reaches maximum hopcount H_M, node introduces added delay to process route-query as shown by red circles. These are $waited - relay$ nodes where route-query changes its velocity. As the destination node receives route-query, it sends back a reply-packet (shown by green arrows in Fig. 1) to the source node and broadcast a chase-packet (shown by blue arrows in Fig. 1).

There is a case of searching for a single destination node which is assumed to exist in the network. In order to accomplish this searching, a chase based broadcast repealing strategy is used as in CMBERS+ and BERS+. Here, query broadcast creates 3 rings which are obtained at the nodes where TTL value reaches maximum threshold, destination node and the nodes where packet broadcast is repealed as shown in Figs. 2 and 3. These 3 rings are measured in number of hops considering that neighbor nodes being one hop away represent the ring of TTL value 1. The term H_r denotes the minimum TTL value required to reach destination node in the network.

Assume that H_M be the predefined TTL value of broadcasting technique at which query packets slow down their velocity. After this specified ring, control packets get higher priority than query packets. Suppose query packets travel with velocity of v_1 before TTL value reaches maximum threshold and with velocity of v_2 after the maximum limit of TTL value. H_C be the ring at which query broadcast is repealed. There are two cases as shown in both Figs. 2 and 3. The case one i.e. $H_M > H_r$ implies that destination node is located within the H_M hops and case 2 i.e. $H_M < H_r$ is equivalent to not finding the destination node within the H_M hops. Searching techniques of CMBERS+ and BERS+ are same except broadcast repealing mechanism. The main concern of this section is to show the gain of destination initiated broadcast repealing as in CMBERS+ over source initiated broadcast repealing as in BERS+.

Broadcast repealing in CMBERS+ is destination initiated. According to the case 1 drawn in Fig. 2(a), the time taken by the chase-packet to repeal the query broadcast in v_1 is equal to

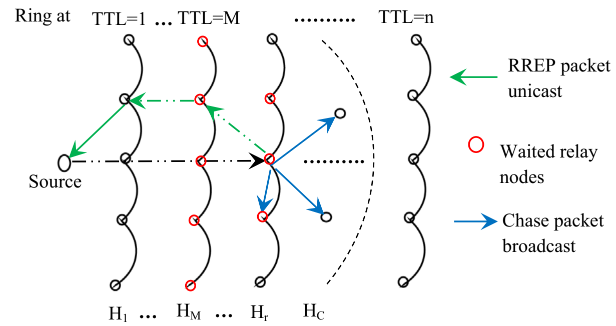

Figure 1 Forming rings and effects of velocity at different ring.

the time taken by the route-query to reach the node of H_C hops. Referring to Fig. 2(a), we get

$$\frac{H_C}{v_1} = \int_{H_r}^{H_C} \frac{dh}{v_2} \tag{1}$$

By putting $v_1 = 1$ and $v_2 = \frac{H_M}{h}$, we have

$$H_C = H_M + \sqrt{H_M^2 + H_r^2} \tag{2}$$

whereas in case 2, time taken by the chase-packet is equal to the time taken by the query broadcast which propagates with both velocities of v_1 and v_2. Referring to Fig. 2(b), we get

$$\frac{H_C}{v_1} = \frac{H_M - H_r}{v_1} + \int_{H_M}^{H_C} \frac{dh}{v_2} \tag{3}$$

After solving given equation, we get

$$H_C = H_M + \sqrt{2H_M H_r} \tag{4}$$

From Eqs. (2) and (4) we have

$$H_C = \begin{cases} H_M + \sqrt{H_M^2 + H_r^2} & : H_M < H_r \\ H_M + \sqrt{2H_M H_r} & : H_M > H_r \end{cases}$$

At $H_M = H_r$, result is identical for both the cases which is equivalent to $2.414H_r$.

Broadcast repealing in BERS+ is source initiated that indicates replying and unicasting events are not concurrent. When destination node unicasts the reply-packet in the meanwhile route-query propagates as shown in Fig. 3. Thus it increases extra query-forwarding over the network. Following the same mathematical calculation based on Fig. 3 for chasing efficiency of BERS+, we get

$$H_C = \begin{cases} 2H_M + H_r & : H_M < H_r \\ H_M + 2\sqrt{H_M H_r} & : H_M > H_r \end{cases}$$

At $H_M = H_r$, result is identical for both the cases which is equivalent to $3H_r$. Major disadvantage with the BERS, BERS*, and BERS+ is that broadcast repealing is source initiated. It takes extra H_r unit time which is utilized to unicast the reply-packet to source node. CMBERS+ are more chasing efficient than BERS+ and have difference of 0.586 unit time in chasing when destination is found at maximum hops exactly. This difference can be examined from Table 1 which depicts the chasing of said techniques in both the cases.

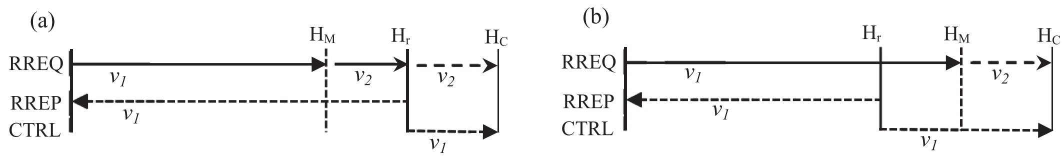

Figure 2 CMBERS+ in both cases.

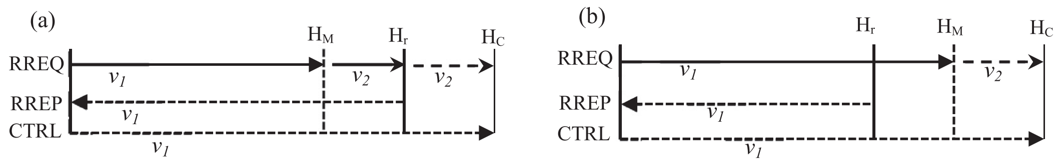

Figure 3 BERS+ in both cases.

Table 1 Comparison of chasing efficiency.

Cases	Broadcast repealing for	
	BERS+	CMBERS+
$H_M < H_r$	$2H_M + H_r$	$H_M + \sqrt{H_M^2 + H_r^2}$
$H_M > H_r$	$H_M + 2\sqrt{H_M H_r}$	$H_M + \sqrt{2H_M H_r}$
$H_M = H_r$	$3H_r$	$2.414H_r$

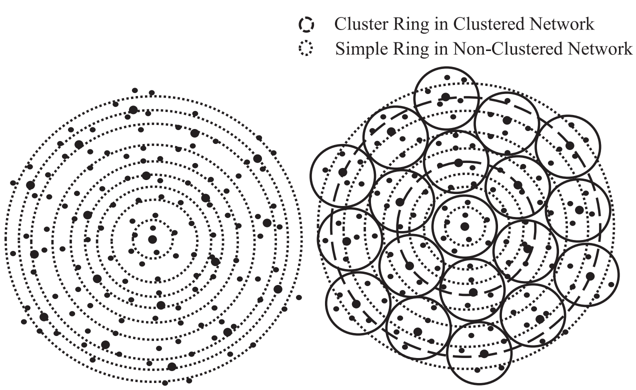

Figure 4 Clustered and non-clustered network.

3.2. Network scalability

Network scalability is one of the aspects to reduce the query-forwarding which is achieved by dividing the network into clusters. Assuming a distributed clustered network as shown in Fig. 4, let H_r denote the hops between source and destination nodes that contain k clusters of H_C radius as shown in Fig. 5. Clearly, the value of k is equal to H_r/H_C. An example shown in Fig. 5, where circular area of radius H_r is πH_r^2 and area covered by one cluster of radius H_C is πH_C^2. Thus total number of clusters covered in route discovery is $(\pi H_r^2)/(\pi H_C^2) = (2k)^2 = 4k^2$. Assume that x be the number of nodes contained in a cluster and y be the number of non-boundary nodes in that cluster. Thus total number of nodes contained by $4k^2$ clusters is $4k^2x$ which is equal to $\Sigma_{i=1}^{H_r-1} n_i$.

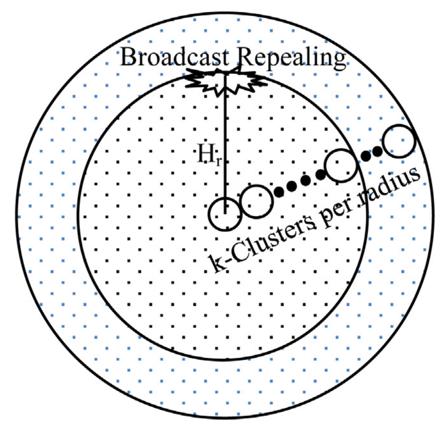

Figure 5 Query broadcast repealing.

Let each broadcast and unicast consume 1 unit of energy, total energy consumed in route discovery phase is as follows:

$$\begin{aligned} E_{CMBERS+} &= 2(1 + k^2(x - y) + 4k^2) + E_{RREP} \\ &= 2(1 + 4k^2x) - 2k^2(y - 1) + n_r H_r \end{aligned} \tag{5}$$

By putting the value of $4k^2x$ in Eq. (5), we have

$$= \underbrace{\left[2\left(1 + \Sigma_{i=1}^{H_r-1} n_i\right) + n_r H_r\right]}_{\text{Energy consumed in BERS+}} - 2k^2(y - 1) \tag{6}$$

where E_{RREP} is consumed energy in unicasting the reply packet. From Eq. (6), it is clear that controlled flooding over clustering saves energy of $2k^2(y - 1)$ nodes. It becomes more beneficial when neighbor nodes are in dense within the transmission of the node. On the basis of this analysis, it is observed that CMBERS+ performs better than BERS+ in terms of query-forwarding and energy consumption. In the support of this analytical study, simulation results are given in Section 6.

4. Design mechanism

In the proposed technique, fundamental prerequisites for the route discovery phase are clustering of the network, routing packets, and routing tables. These three are important outfits to make routing easy. In this section, we discussed the design mechanism of these outfits.

4.1. Cluster formation

We used DWCA (Choi and Woo, 2006) clustering technique to cluster the whole network. It is an energy efficient clustering technique which is free from ripple effect of clusters. It has a high cluster stability and constant convergence time of O(1) (Abbasi and Younis, 2007). In DWCA, we divide the whole network into distributed clusters. Cluster-head is chosen provisionally with maximum battery power, strong connectivity, and low mobility. This cluster formation process is very similar to Choi and Woo (2006). Initially, each node computes its weight using attributes parameters like degree of the node, closeness, residual energy of a node, and mobility. When each node has done this computation, each node starts competition with its neighbors to be the cluster-head. This competition is done up to m-hop away neighbor nodes. Maximum weighted node among them is chosen as a cluster-head and remaining nodes become ordinary nodes. To continue the clustering, uncovered weighted node starts competition with its neighbors to be a cluster-head of the next cluster. This clustering process is continued until each node belongs to exactly one cluster. After the clustering process, each cluster-head gathers the information about local topology, and gateway nodes, etc. that is maintained proactively.

4.1.1. Model

In order to decide which node will be the best suited node for cluster-head, there are four parameters, i.e. degree, distance, residual energy and mobility of node, are taken together. Degree of any node indicates the neighbor nodes and it helps determine the degree difference as denoted by $\triangle_v$. D_v denotes the distance to measure the closeness of the adjacent nodes. These two metrics collectively form the strong connection with the adjacent nodes which is highly desirable in dynamic networks. $M_v$and E_v are assumed to be mobility and residual energy of node in current time T. Each parameter combines with weighing factor form a weight metric. Let w_1, w_2, w_3 and w_4 be the weighing factors, weight metric can be defined as

$$W_v = w_1 * \triangle_v + w_2 * D_v + w_3 * M_v + w_4 * E_v \tag{7}$$

First part (i.e. $w_1 * \triangle_v$) determines how many number of nodes will get a membership of a cluster. Larger number of node in a cluster may cause the imbalance clusters and lead to the frequent re-clustering problem. It is always desirable to save energy of node. This would save the energy by choosing the appropriate number of closer nodes to form a cluster. Therefore, the second part (i.e. $w_2 * D_v$) helps improve the network life by authenticating the membership of closer nodes. Mobility is an important factor to avoid frequent cluster-head changes. High mobility of cluster-head increases affiliation and re-affiliation problem (Choi and Woo, 2006). In such cases, information exchange takes place that again increases clustering overhead. Therefore the third part (i.e. $w_3 * M_v$) of W_v is measured as the running average of the speed for every node till current time so that lesser movable node can be chosen as cluster-head (Choi and Woo, 2006). The last part (i.e. $w_4 * E_v$) is residual energy requires for a node work as an cluster-head, indicates that the power of any cluster-head must be more than usual nodes. The meanings of metrics used in calculating weight metric are given in Table 2.

4.1.2. Cluster head selection

Steps are shown in Algorithm 1 that are performed by a node during the clustering procedure. Whenever a node starts the clustering, initially it is assumed to be an uncovered node (Line 1). This node checks its adjacent neighboring nodes whether any of them is a cluster head or if they have the membership in any of the clusters. If a cluster head is available, it simply finds its membership with that cluster head. This corresponds to the lines from 2 to 4 in Algorithm 1. Otherwise, this node computes all the necessary metrics for calculating its combined weight metric (CWM). This implies to self assessment of node which includes degree difference ($\triangle_v$), sum of distances with adjacent neighbor nodes (D_v), average speed till present time (M_v), residual energy (P_v) which implies consuming energy of node during its cluster headship as discussed in a previous section. As node identifies the values of ($\triangle_v$), (D_v), (M_v), and (E_v), it computes its combined weight metric that consists of four components. For every component, weighing factors are selected as the best arbitrarily such that the sum of these weighing factors is 1.0. It is observed that lesser number of neighbors within the node proximity is more suitable serving by the cluster head. Thus ideal degree of δ is 3 in such cases (Choi and Woo, 2006).

Afterward, it starts competition with its neighbors to be the cluster head. If the present node has maximum combined weight metric among all neighbor nodes, it declares itself as cluster head and neighbor nodes become ordinary nodes of that cluster (Lines 5–9). If result is opposite, its neighbor nodes compete with 2-hop away neighbor nodes to be the cluster head. In both the cases (cluster head is 1-hop or 2-hop away neighbor node), the remaining nodes become ordinary node. This corresponds to lines from 10 to 18.

Algorithm 1: Cluster formation competition algorithm

```
1  if Node is uncovered node then
2      if 1-hop or 2-hop away neighbor node is a cluster head then
3          Find its membership;
4      end
5      else
6          Calculate combined CWM;
7          if CWM is maximum then
8              Declare its headship;
9          end
10         else
11             if 1-hop neighbor node has maximum CWM then
12                 Declare its headship;
13             end
14             else
15                 Declare the headship of 2-hop away neighbor node;
16             end
17         end
18     end
19 end
```

4.2. Packets used in route discovery

Packet formation is an essential course of route discovery phase. Different types of packets are designed for different purposes. Route discovery phase of our technique is very similar to BERS+. But design mechanism of packet is different. We used two in one strategy of LHBA (Zhang and Jiang, 2005) to design the route-reply and control-packet. One packet

Table 2 Metrics and their descriptions.

Metrics	Descriptions
d_v	$\sum_{v' \in V, v' \neq v}\{dist(v, v') < tx_{range}\}$, tx_{range} is transmission range of node v
$\triangle_v$	$\lvert d_v - \delta \rvert$, δ is overloading factor
D_v	$\sum_{v' \in N(v)}\{dist(v, v')\}$
M_v	$\frac{1}{T}\sum_{t=1}^{T}\sqrt{(X_t - X_{t-1})^2 + (Y_t - Y_{t-1})^2}$, (X_t, Y_t) and (X_{t-1}, Y_{t-1}) are coordinates at time t
E_v	Residual battery capacity of node when it competes to be a cluster head

Table 3 Notations and their meanings.

Packet	Notation	Meaning
Type 0	T_0	Intra-cluster route-query
Type 1	T_1	Inter-cluster route-query
Type 2	T_2	RRCL (reply + control) packet
Type 3	T_3	Notification packet
Type 4	T_4	Error packet

is used for both purposes. The data structure of packet contains source ID, destination ID, Type, Sequence number, hop count and path. The pair of source ID and sequence number is used to uniquely identify the packet. Sequence number is generated by source and destination node incrementally to check the freshness of route. In our approach, there are 5 types of packets in route discovery phase that are specified by the type field of packet. Type 0 is for internal route-query which is used for proactive process of intra-cluster routing. Hop-count field of Type 0 packet is initialized by cluster radius. Type 1 is for external route-query which is used for reactive process of inter-clusters routing and its hop-count field initialized by specified TTL value. Since reactive approach of route discovery gives the broadcast storm problem (Tonguz et al., 2006), it needs attention to control the query from unnecessary circulation in the network. So, Type 2 is for RRCL which is a combination of two packets. This packet works as a route respond packet as well as control-packet. Type 3 is for notification-packet, and type 4 is for route-error packet. In Table 3, we notified packets and summarized their meanings.

4.3. Routing tables

To balance the memory requirements at each node in the networks, we used two routing tables. First, IntraCRT which is an intra-cluster routing table. It is maintained proactively within the cluster. Each cluster head updates intra-cluster routing table as topology changes. It contains all topological information of the cluster. This routing table provides routing information quickly within the cluster as any ordinary node needs. Second, InterCRT is an inter-cluster routing table. It is maintained reactively by the cluster-head. This table employs a routing path when node needs to send the data outside the clusters.

5. Clustered modified-BERS+ (CMBERS+)

In this section, we will discuss the working model of proposed broadcasting technique. The proposed approach is an extension of the query-control technique for using in cluster based routing protocol. In other words, it is an implementation of broadcast repealing over clustered network. Packet controlling feature of the modified-BERS+ is used to repeal the query broadcast and network scalability aspect of cluster based routing is used to minimize the query forwarding. In order to carry out this technique, 5 types of packets are used in the route discovery phase which work based on the flag type. This process contains two tasks: First, route discovery and second, route reconstruction. These are discussed in next two sections.

5.1. Route discovery technique

Primary task of the routing protocol is route discovery phase. In the proposed approach, this is done at two levels: First, *route discovery within the cluster* that has pure proactive approach, and second, *route discovery between clusters* that has pure reactive nature.

5.2. Route discovery within a cluster

This is a pure proactive level. Each ordinary node of the cluster has routing information within the intra-cluster routing table. This routing information is updated periodically by the cluster head of the cluster. Since each node knows about other ordinary nodes, every node can send data without interacting with the sentinel node. It is as usual as previous cluster based routing strategies used as in Choi and Woo (2006). It also does not require any controlling technique for route-query.

Algorithm 2: Processing of Type 1 Packet

```
if Type 2 packet received Or Type 1 packet is Duplicate then
    Discard the Type 1 packet;
end
else if Present node is Destination cluster head then
    Create Type 2 reply-packet;
    Broadcast it;
end
else
    if hopcount ≤ MaxCount then
        Broadcast the Type 1 packet;
    end
    else
        while waiting for h unit time do
            if Type 2 packet received then
                Discard Type 1 packet;
            end
        end
        Broadcast the Type 1 packet;
    end
end
```

5.3. Route discovery between clusters

This is a pure reactive level. At this level, broadcast repealing technique with destination initiated controlling feature is used to cease the packet broadcast. Whenever source node wishes to send the data outside of the cluster, it sends a T_1 external route-query to the cluster-head. Upon receiving route-query, cluster-head immediately starts the route discovery phase. First, it checks its InterCRT table to initialize the hop-count field in the T_1 packet and forward it to the adjacent cluster-heads via gateway nodes (that connects two adjacent clusters). Adjacent cluster-heads receive the route-query and search the desirable route in their InterCRT table.

If the cluster-head fails to find the route, it caches the route travelled by the T_1 packet in its InterCRT table and continues the searching process. At each failed attempt, intermediate cluster-heads expand the searching area as ripple across the water shown in Fig. 4. If hop-count field exceeds, intermediate cluster-heads introduced the added delay of h unit time in the processing of T_1 packet to slowdown the propagation of T_1 packet. This practice is continued until the route is found. Upon receiving T_1 packet, cluster-head takes action defined in Algorithm 2. If any intermediate cluster-head finds the route, it sends out a T_2 reply packet back to the source cluster-head following the reverse route. Source cluster head receives the T_2 packet from the destination cluster head that has destination node in its IntraCRT table. It caches all routing information in the InterCRT table before sending the reply-packet to the source node. Due to dynamic change in local topology during route discovery, reflected in intra-cluster routing table, source node can manipulate the received route accordingly to reduce the route length if it is needed. It transmits data following this given route.

5.4. Packet broadcast repealing technique

Each intermediate cluster-head expands the searching ring as its attempt fails. When TTL field of T_1 packet reaches to maximum threshold, next intermediate cluster-heads introduce the added delay of h unit time in the processing of T_1 packet to slowdown the propagation of T_1 packet. This delay helps T_2 packet to catch them on completion of route searching phase. This T_2 reply-packet is used for dual purpose. First, it informs the sender about the path. Second, it controls the unnecessary propagation of the T_1 packet in the network.

Algorithm 3: Processing of Type 2 Packet

```
if Type 2 packet is Duplicate then
    Discard it;
end
else if Present node is Source cluster-head then
    Send Reply-Packet to Source Node;
    Update MaxCount field in IntraCRT;
    Broadcast Type 2 packet;
end
else
    if Present cluster-head in the header of the packet then
        Update MaxCount field in IntraCRT;
        Broadcast Type 2 packet;
    end
    else if Type 1 packet received And Broadcasted it then
        Broadcast Type 2 packet;
    end
    else
        Discard it;
    end
end
```

5.5. Route reconstruction

Route can be no longer valid due to the mobility of nodes. So we require a route repair strategy. Route reconstruction within the cluster is very simple because of periodic messaging. Route is recovered through proactive information sent by cluster-head. On the other hand, this strategy is very cumbersome between clusters due to reactive approach. In this strategy, we used bypass technique to recover the route and to continue the data sending process. Whenever link break happens during the transmission, the node that finds the link break immediately uses a bypass technique of Castaneda et al. (2002) to find the alternate route. This node also sends back T_3 notification packet to the source node about the new path. As source node receive T_3 packet, it drops the previous route. Now it uses new alternate path for data transmission. If bypass technique fails, the node sends back a T_4 error packet to the source node to inform about link break. If source still has some data for transmission, it again starts the route discovery phase. The major advantage of the proposed route-repair technique is clustering. Every ordinary node knows about other ordinary nodes within the cluster. So, alternate route is always available due to proactive nature of ordinary nodes which makes route recovery faster than conventional techniques like BERS (Park et al., 2006), BERS+ (Al-Rodhaan et al., 2008), etc.

6. Simulation and result analysis

In order to better measure the performance of the proposed technique against BERS+ and TTL-sequence based ERS (TTL-ERS), a set of simulations were done in NS-2.34 (Network Simulator-2.34). In our simulation, we created a topology of 500 nodes over a grid of $1500 \times 1500\,\mathrm{m}^2$ for hop-count metric. The distance, in hop-count, between communicating nodes may vary. Therefore, simulations for different hop-counts were run to demonstrate the query-diffusion cost. We also set the simulation on different sizes of the network to show the effect of the network coverage on the performance of techniques. In this case, size of the topologies varies between 50 and 400 nodes for the different network sizes. The nodes, in each case, were scattered in all directions with maximum speed of 10 m/s randomly that followed the random way point mobility model. Each node is installed with radio range of 250 m, and bandwidth was set to 2 Mbps.

MAC layer of each node was set at 802.11 protocols with RTS/CTS, which requires an additional field of separate buffer to perform the delay on query before enqueuing the packet for services, as needed to slow down the speed of query, when query travels beyond the maximum boundary of the ring (Al-Rodhaan et al., 2008). In order to simulate best effort traffic, each node sends constant bit rate (CBR) traffic through UDP which is set on a rate of 4 packets per second with data payload of 512 bytes. In this simulation, we put 10 pairs of communicating nodes as required number of hops away while moving, and assigned 20 s of simulation time for each pair to communicate one by one with interval of 5 s. Obtained results were averaged over each set of trials. Each simulation was run for 200 s.

DWCA was set as an underlying protocol to cluster the network along with broadcast repealing technique and compared with BERS+ and TTL sequence-based ERS over AODV. In our simulation, we used value of all weighing factors given in Chatterjee et al. (2002). $w_1 = 0.7$, $w_2 = 0.2$, $w_3 = 0.05$, and $w_4 = 0.05$ are calculated weighing factors, used to cluster the whole network. According to the notion of Chatterjee et al. (2002), cluster head can handle number of nodes ideally which is set to 3. To calculate degree difference in our simulation, ideal degree was set for each cluster head.

To evaluate the performance of our proposed technique against the existing techniques, we acknowledged 5 metrics that are accounted with varying hop-count and network coverage:

Average latency (AL) is the average end to end delay that is taken by the route-query to search the path in the entire duration of route discovery. It can be defined as

$$AL = 2 * N_r * T_n \tag{8}$$

where N_r is number of nodes available on the desired route and T_n is route-query traversal time per node. Right hand side is multiplied by 2. This is because said delay is the total time in carrying the route-query to the destination and sending reply-packet back to the source node.

Energy exhaustion ratio (EER) is deduced from energy consumption that affects the network life. It is the ratio of the total energy used in the route discovery, and total energy of whole network before route discovery.

$$EER = \frac{\left[2\left(1 + \Sigma_{i=1}^{H_r-1} n_i\right) + n_r H_r\right] - 2k^2(y-1)}{E} \tag{9}$$

where E is the total energy before route discovery is initiated. In order to scale the result, we multiplied the obtained results by 5.

Retransmission ratio (RR) indicates participation of intermediate nodes during route discovery. It is the ratio of the total relaying-nodes in route discovery to the total number of nodes in the network. This is because higher participation of intermediate nodes increases routing overhead and as a consequence higher energy consumption. It affects the network life.

$$RR = \frac{N_p}{N} \tag{10}$$

Query forwarding (QPF) is overall forwarding of route-query in route discovery. It is the ratio of the total forwarded query and total number of nodes in the network. This is expected since higher propagation of route-query implies the flooding and as a consequence higher traffic over the network life.

$$QPR = \frac{RQ_{sum}}{N} \tag{11}$$

where RQ_{sum} is the total sum of route-query forwarded by the relaying-nodes.

Throughput is the average number of packets received at destination till simulation end. It is the amount of data send per simulation time.

$$Throughput = \frac{PR}{SE} \times SZ \tag{12}$$

where PR is packet received per second at destination node, SE denotes simulation time and SZ is size of the packet.

Every time route-query is broadcasted as source node needs to establish the route for data transmission. This query broadcast leads to the query forwarding as well as retransmission ratio. Again, these metrics create the traffic and affect the network life. Participating nodes exhaust their energy to process the route-query during route discovery. Lower values of the aforementioned metrics are always desirable to acquire the route at minimal cost. In order to prolong the network life, network affecting metrics like retransmission ratio and query forwarding need to be minimized. So, these five performance metrics are studied against the distance between resources (in hop-count), and network coverage. According to the notion, at higher hop-count latency is too high for network usability whereas at larger number of node, node density is too high for clustering usability. Therefore in our simulation distance varies between 1 and 8 hop-count, and network coverage between 50 and 400 nodes.

6.1. Experimental results of average latency

Figs. 6 and 7 demonstrate the average latency with respect to the hop-count and network size in clustered and non-clustered network. Average latency is the time spent by the route-query to establish required route between resources. Average latency increases as distance between source and destination nodes increases. As we can see in Fig. 6, proposed technique outper-

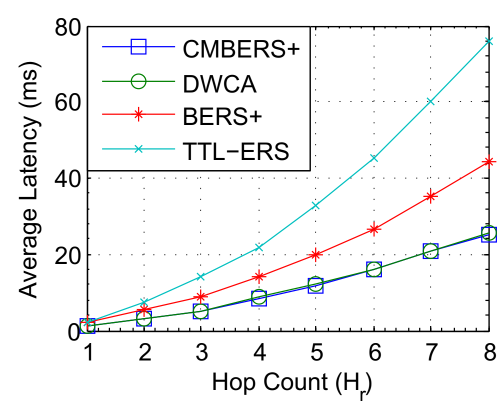

Figure 6 Average latency (ms) Vs hop count.

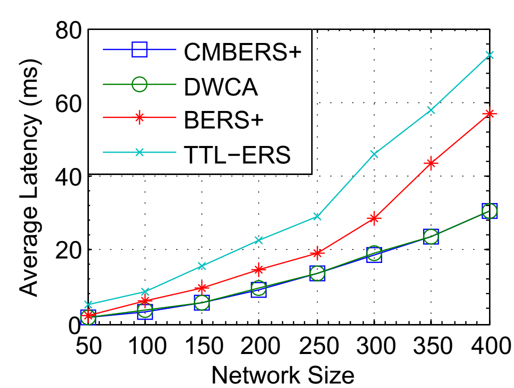

Figure 7 Average latency (ms) Vs network size.

forms than other two (BERS+ (Al-Rodhaan et al., 2008), and TTL-ERS (Perkins and Royer, 1999)) in both the cases but gives almost same results corresponds to DWCA (Choi and Woo, 2006). However, CMBERS+ improves the average latency up to 4.4% with varying hopcount and 9.3% in case of varying network size corresponding to DWCA. Proposed technique CMBERS+ reduced the average latency 38–57% in case of hop count and 32–46% in case of network coverage corresponding to BERS+.

6.2. Experimental results of throughput

In Figs. 8 and 9, obtained results of throughput are shown. Throughput is a measure of how many packets a destination can receive in a given amount of time. It is used to measure the performance of any routing technique. Related measure include, the packets received at destination which carry information, simulation time how long it takes to complete the simulation, and packet size. In Figures, one can see that throughput increases as hop-count and network coverage increases, which means expected number of packets at receiving end is increasing. If obtained results are compared to the DWCA, BERS+ and TT-ERS, we conclude that proposed work i.e. CMBERS+ is outperforming. Throughput increases 2.2–5.7% in case of hop-count and 4.4% in case of network size corresponding to DWCA. Proposed technique CMBERS+ improved the throughput 12.04–25% with

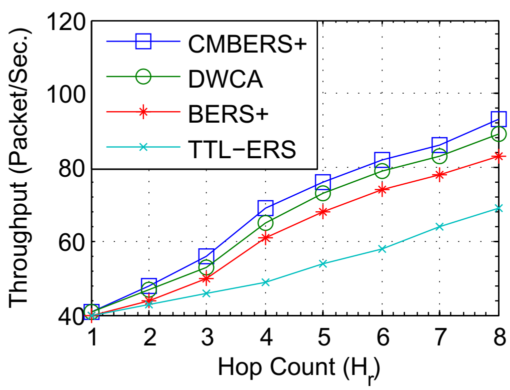

Figure 8 Throughput Vs hop count.

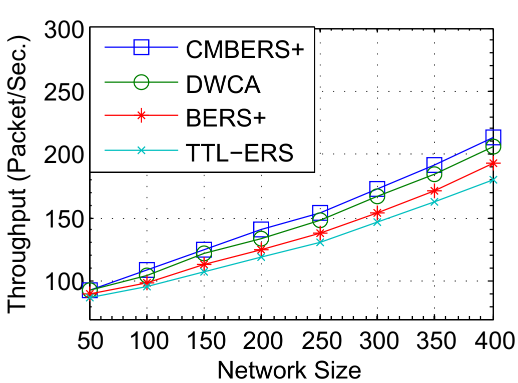

Figure 9 Throughput Vs network size.

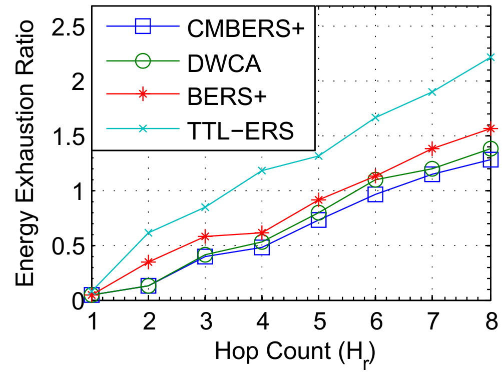

Figure 10 Energy exhaustion ratio Vs hop count.

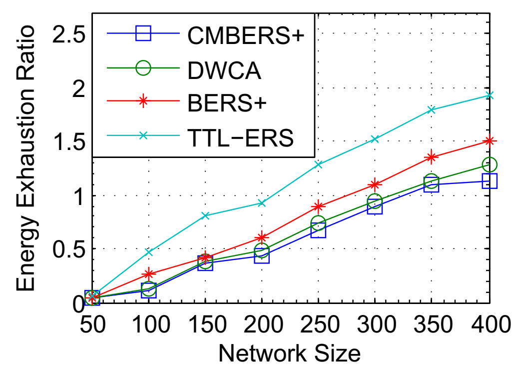

Figure 11 Energy exhaustion ratio Vs network size.

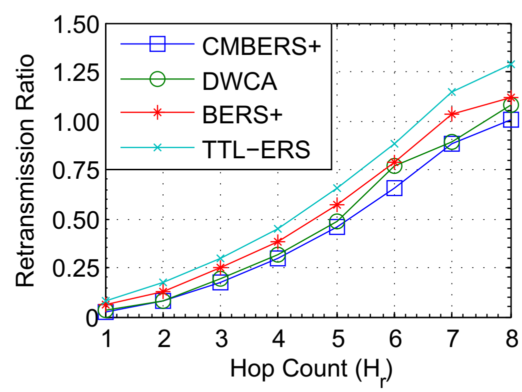

Figure 12 Retransmission ratio Vs hop count.

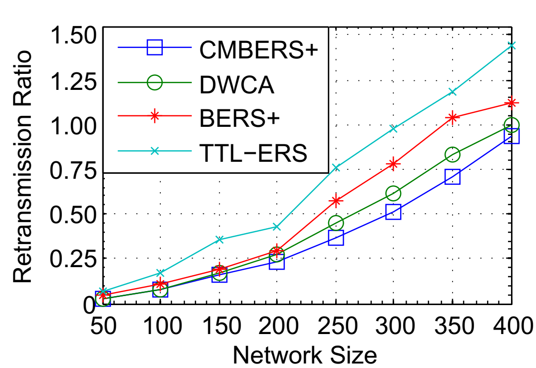

Figure 13 Retransmission ratio Vs network size.

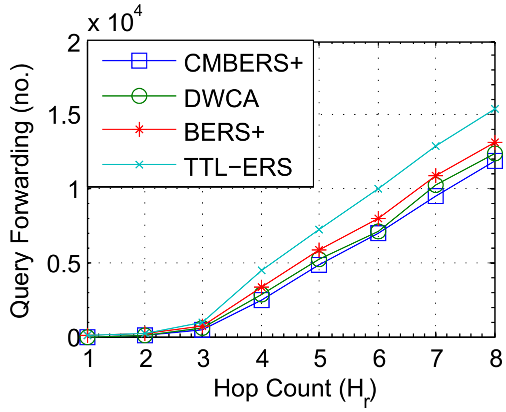

Figure 14 Query forwarding Vs hop count.

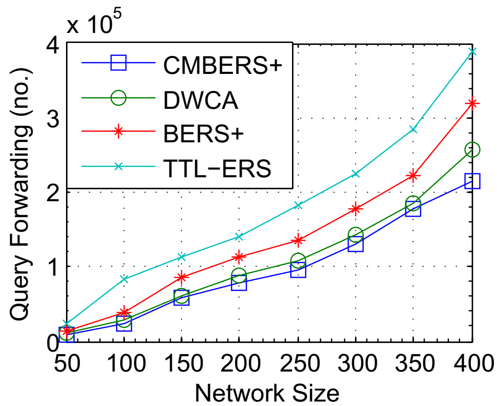

Figure 15 Query forwarding Vs network size.

varying hop-count and 4.4–12.4% with varying network size as compared with BERS+.

6.3. Experimental results of energy exhaustion ratio

Figs. 10 and 11 show the energy exhaustion ratio in the clustered and non-clustered network. It is the ratio of the exhausted energy to the initial energy. In the beginning, energy exhaustion ratio is nearly 0. As the query is carried by the intermediate nodes, energy exhaustion increases thus it reduces the network life. Proposed technique improves the performance of the existing protocol by applying controlled flooding in the sense that it minimizes the energy exhaustion. Moreover, the network scalability reduces routing overhead as network coverage increases that also minimizes the energy exhaustion. This effect can be seen in Figs. 10 and 11. CMBERS+ is more retransmission efficient than DWCA (Choi and Woo, 2006). CMBERS+ minimizes the energy exhaustion ratio 1.4–11.6% with varying hop-count and 3.1–12.4% with varying network coverage.

6.4. Experimental results of retransmission ratio

The ratio of the network covered by the route-query to the whole network is called retransmission ratio. The aim of any routing protocol is to establish the route with minimum conveying nodes so that broadcast storm problem as well as energy exhaustion can be curtailed. Figs. 12 and 13 show the retransmission ratio against hop count and network size. By imposing controlled flooding in clustered network, it is observed that CBERS+ reduced the retransmission ratio 2.1–15.2% in case of hop-count and 2–18% in case of network size corresponds to DWCA (Choi and Woo, 2006).

6.5. Experimental results of query forwarding

Figs. 14 and 15 highlight the results of query forwarding with respect to hop-count and network coverage. In networks, search cost is measured in number of route-query forwarded by the relaying-nodes to find the resources. Average cost of finding the resource increases as the distance between resources increases and also because of network size. In our experiment, we compared all these techniques in both the cases. Fig. 14 shows the effect of the hop-count on the performance of the techniques. Packet forwarding increases hop by hop. CMBERS+ gives the better result than all other mentioned techniques. Fig. 14 also demonstrate the better result in the favor of CMBERS+. CMBERS+ performs better than DWCA (Choi and Woo, 2006), and reduces the packet forwarding 2–38% in case of hop-count and 4.6–21.11% in case of network size.

Table 4 Performance improvement with variation of hop count.

Technique	AL (%)	EER (%)	RR (%)	QPF (%)	Throughput (%)
DWCA	0.29–4.4	1.4–11.6	2.1–15.2	2–38	2.29–5.79
BERS+	38–57	13.7–61.7	10.56–50	9.58–72	12.04–25
TTL-ERS	57.2–66.9	39.7–78.6	21.9–65.3	23.1–76.8	25–48.97

Table 5 Performance improvement with variation of network coverage.

Technique	AL (%)	EER (%)	RR (%)	QPF (%)	Throughput (%)
DWCA	0.8–9.3	3.1–12.4	2.1–15.2	4.6–21.1	0–4.47
BERS+	32–46	12.4–56.2	18.4–49.5	20.1–36.5	4.49–12.28
TTL-ERS	58.2–71	38.7–75.2	34.8–63.4	37.7–69.8	6.89–18.88

Furthermore, we summarize comparative performance of the proposed technique with other existing technique in detail in Tables 4 and 5.

7. Conclusion

Cluster based routing protocols provide an efficient way of routing in any ad-hoc network environment. This routing mechanism combines the two different routing methods into one routing protocol. The nodes within the cluster make routing proactively that requires up-to-date topological information. Whenever communicating nodes belong to two different clusters, they make routing reactively. This inter-cluster routing does not need current topological information. However, it requires a query control technique that notifies the relay-nodes cease the query broadcast from further propagation when route is found successfully. The query broadcast in a controlled manner helps improve the quality of the routing techniques in the ad-hoc network.

In ad-hoc networks, congestion problem due to unnecessary propagation of query has become a major issue. This motivates us to propose a query control technique for cluster based routing protocol. In this research work, a query control technique for cluster based routing protocol is proposed that reduces the query retransmission and its consequences in ad-hoc networks. Here, clustering is used to achieve the scalability and broadcast repealing technique to control the unnecessary circulation of the query which is an improve version of BERS+. Reply-packet is used for dual purpose instead of using separate reply, and chase packets. It makes the controlling of the query destination initiated so that the controlling of packets can be faster than BERS+. From analytical study, it is observed that clustering based implementation of modified-BERS+ uses lesser number of intermediate nodes than simple BERS+. It also helps non-participating intermediate nodes to save their energy.

In addition, simulation shows that obtained results favor proposed technique called CMBERS+. By imposing query control technique in clustered network, it is also observed that technique improves average latency of DWCA up to 4.4% with variation of hop-count and up to 9.3% with variation of network coverage. Lower route latency increases throughput which increased up to 5.79% in case of hop-count and 4.47% with varying network sizes. It also lessens the query forwarding up to 38% in case of hop-count and up to 21.11% in case of network coverage. Moreover, CMBERS+ reduced the retransmission ratio up to 15.2% in case of hop-count and up to 18% in case of network size corresponds to DWCA. Lesser the energy exhaustion ratio, longer will be the life of network. It means CMBERS+ also prolongs the life of network by saving energy of nodes in both the cases up to 11.6% and 12.4% respectively.

References

Abbasi, A.A., Younis, M., 2007. A survey on clustering algorithms for wireless sensor networks. Comput. Commun. 30 (14), 2826–2841.

Abolhasan, M., Wysocki, T., Dutkiewicz, E., 2004. A review of routing protocols for mobile ad hoc networks. Ad hoc Networks 2 (1), 1–22.

Ahmad, N., Hussain, S.Z., 2015. Broadcast expenses controlling techniques in mobile ad-hoc networks: a survey. J. King Saud Univ.-Comput. Inf. Sci. 28 (3), 248–261.

Aitha, N., Srinadas, R., 2009. A strategy to reduce the control packet load of AODV using weighted rough set model for MANET. Int. Arab J. Inf. Technol. 8 (1), 108–117.

Al-Rodhaan, M.A., Mackenzie, L., Ould-Khaoua, M., 2008. Improvement to blocking expanding ring search for MANETS. Dept of Computing Science, University of Glasgow, Glasgow, UK 286 (1), 1–13.

Al-Rodhaan, M., Mackenzie, L., Ould-Khaoua, M., 2008. On the performance of traffic locality oriented route discovery algorithm with chase packets. Bahria Univ. J. Inf. Commun. Technol. (BUJICT) 1, 9–16.

Basagni, S., Chlamtac, I., Syrotiuk, V.R., Woodward, B.A., 1998. A distance routing effect algorithm for mobility (dream). In: Proceedings of the 4th Annual ACM/IEEE International Conference on Mobile Computing and Networking, MobiCom '98. ACM, pp. 76–84.

Castaneda, R., Das, S.R., Marina, M.K., 2002. Query localization techniques for on-demand routing protocols in ad hoc networks. Wireless Netw. 8 (2–3), 137–151.

Chang, N., Liu, M., 2004. Revisiting the TTL-based controlled flooding search: optimality and randomization. In: Proceedings of the 10th Annual International Conference on Mobile Computing and Networking. ACM, pp. 85–99.

Chatterjee, M., Das, S.K., Turgut, D., 2002. WCA: A weighted clustering algorithm for mobile ad hoc networks. Cluster Comput. 5 (2), 193–204.

Choi, W., Woo, M., 2006. A distributed weighted clustering algorithm for mobile ad hoc networks. In: Proceeding of Advanced International Conference on Telecommunications/International Conference on Internet and Web Applications and Services, AICT-ICIW'06. IEEE, pp. 73–73.

Dubois-Ferriere, H., Grossglauser, M., Vetterli, M., 2003. Age matters: efficient route discovery in mobile ad hoc networks using encounter ages. In: Proceedings of the 4th ACM International Symposium on Mobile Ad hoc Networking & Computing. ACM, pp. 257–266.

Gargano, L., Hammar, M., 2004. Limiting flooding expenses in on-demand source-initiated protocols for mobile wireless networks. In: Proceedings of 18th International Conference on Parallel and Distributed Processing Symposium. IEEE, pp. 220–228.

Haas, Z.J., Pearlman, M.R., 2001. The performance of query control schemes for the zone routing protocol. IEEE/ACM Trans. Networking (TON) 9 (4), 427–438.

Haas, Z.J., Pearlman, M.R., Samar, P., 2002. The zone routing protocol (ZRP) for ad hoc networks.

Hussain, S.Z., Ahmad, N., 2014. Cluster based controlling of route exploring packets in ad-hoc networks. In: Advanced Computing, Networking and Informatics, vol. 2. Springer, pp. 103–112.

Karenos, K., Kalogeraki, V., Krishnamurthy, S.V., 2005. Cluster-based Congestion Control for Supporting Multiple Classes of Traffic in Sensor Networks (Ph.D. thesis). University of California, Riverside.

Ko, Y.-B., Vaidya, N.H., 2000. Location-aided routing (LAR) in mobile ad hoc networks. Wireless Netw. 6 (4), 307–321.

Lou, W., Wu, J., 2003. On reducing broadcast redundancy in ad hoc wireless networks. In: Proceedings of the 36th Annual Hawaii International Conference on System Sciences. IEEE, pp. 111–122.

Minematsu, M., Saito, M., Hiroto, A., Tokuda, H., 2005. Efficient route discovery scheme in ad hoc networks using routing history. IEICE Trans. Commun. 88 (3), 1017–1025.

Park, I., Kim, J., Pu, I., et al, 2006. Blocking expanding ring search algorithm for efficient energy consumption in mobile ad hoc networks. In: Proceeding of 3rd Annual International Conference

on Wireless On-demand Network Systems and Services, WONS'06, vol. 1, pp. 191–195.
Perkins, C.E., Bhagwat, P., 1994. Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. In: ACM SIGCOMM Computer Communication Review, vol. 24. ACM, pp. 234–244.
Perkins, C.E., Royer, E.M., 1999. Ad-hoc on-demand distance vector routing. In: Proceedings of 2nd IEEE Workshop on Mobile Computing Systems and Applications, WMCSA'99. IEEE, pp. 90–100.
Preetha, K., Unnikrishnan, A., Jacob, K.P., 1820. A probabilistic approach to reduce the route establishment overhead in AODV algorithm for MANET. CoRR 1204, 207–214.
Pu, I.M., Shen, Y., 2009. Enhanced blocking expanding ring search in mobile ad hoc networks. In: 3rd International Conference on New Technologies, Mobility and Security, NTMS'09. IEEE, pp. 1–5.
Pu, I.M., Shen, Y., 2010. Analytical studies of energy–time efficiency of blocking expanding ring search. Math. Comput. Sci. 3 (4), 443–456.
Qayyum, A., Viennot, L., Laouiti, A., 2002. Multipoint relaying for flooding broadcast messages in mobile wireless networks. In: Proceedings of the 35th Annual Hawaii International Conference on System Sciences, HICSS'02. IEEE, pp. 3866–3875.
Rezaee, M., Yaghmaee, M., 2009. Cluster based routing protocol for mobile ad hoc networks. INFOCOMP J. Comput. Sci. 8 (1), 30–36.
Stojmenovic, I., Seddigh, M., Zunic, J., 2002. Dominating sets and neighbor elimination-based broadcasting algorithms in wireless networks. IEEE Trans. Parallel Distrib. Syst. 13 (1), 14–25.
Tonguz, O.K., Wisitpongphan, N., Parikh, J.S., Bai, F., Mudalige, P., Sadekar, V.K., 2006. On the broadcast storm problem in ad hoc wireless networks. In: 3rd International Conference on Broadband Communications, Networks and Systems, BROADNETS'06. IEEE, pp. 1–11.
Wu, J., Li, H., 1999. On calculating connected dominating set for efficient routing in ad hoc wireless networks. In: Proceedings of the 3rd International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications. ACM, pp. 7–14.
Yousefi, S., Mousavi, M.S., Fathy, M., 2006. Vehicular ad hoc networks (vanets): challenges and perspectives. In: 6th International Conference on ITS Telecommunications Proceedings. IEEE, pp. 761–766.
Zhang, H., Jiang, Z.-P., 2005. On reducing broadcast expenses in ad hoc route discovery. In: 25th IEEE International Conference on Distributed Computing Systems Workshops. IEEE, pp. 946–952.