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REVIEW

Broadcast Expenses Controlling Techniques in Mobile Ad-hoc Networks: A Survey

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Abstract The blind flooding of query packets in route discovery more often characterizes the broadcast storm problem, exponentially increases energy consumption of intermediate nodes and congests the entire network. In such a congested network, the task of establishing the path between resources may become very complex and unwieldy. An extensive research work has been done in this area to improve the route discovery phase of routing protocols by reducing broadcast expenses. The purpose of this study is to provide a comparative analysis of existing broadcasting techniques for the route discovery phase, in order to bring about an efficient broadcasting technique for determining the route with minimum conveying nodes in ad-hoc networks. The study is designed to highlight the collective merits and demerits of such broadcasting techniques along with certain conclusions that would contribute to the choice of broadcasting techniques.

Contents

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1. Introduction

Cliques of freely moving mobile nodes create self-organizing structures. These temporary structures are called Mobile Ad-hoc networks (MANETs). Configurations of these networks do not need any pre-established infrastructure or centralized supervision thus making them inexpensive networks that can be deployed easily (Perkins et al., 1999; Kaaniche and Kamoun, 2010; Ahmad and Hussain, 2013). Each node of the network also behaves like a router and has a limited transmission range. As a result, each node is not capable of communicating with nodes that are out of range. Whenever any node needs to communicate with other nodes, it initiates route discovery by broadcasting the query packet. This blind flooding causes the broadcast storm problem (Tonguz et al., 2006) that congests the entire network. This congestion increases the energy consumption and average latency, thereby degrades the performance of the network. In order to make the network congestion free and to reduce the flooding expenses, various packet broadcast expenses controlling techniques have been proposed and adopted. In this paper, we survey such broadcasting techniques and classify them into two categories: *Unbounded* and *Bounded* broadcasting techniques. In unbounded broadcasting techniques, source node broadcasts the query packets with no terminating condition as in Qayyum et al. (2002). Here, each node explores the set of selected neighbor nodes according to some metric e.g. weighted rough set (WRS) (Aitha and Srinadas, 2009) model based selection of nodes. Neighbor nodes, which belong to this set, participate in the forwarding of the query packet while other neighbor nodes discard it (Lou and Wu, 2002, Ghaffari, 2014). These techniques are reliable and guarantee to find the optimal path in minimum time (Al-Rodhaan et al., 2008). Though such broadcasting techniques reduced the duplication of packets, they are not able to control unnecessary propagation or retransmission of query packets even after the route has been determined. Bounded broadcasting, on the other hand are controlled flooding techniques which broadcast the packets in a specified ring. These techniques provide less congested networks than unbounded broadcasting techniques, but are very slow to find the requested path (Sakthipriya, 2014).

This paper looks into broadcasting techniques that have been utilized in reducing flooding expenses of route discovery. The purpose of this review is to select the most suitable broadcasting techniques to carry out the route discovery with minimum flooding expenses.

The rest of the paper is organized as follows: Section 2 introduces the route discovery phase of routing protocols. Section 3 describes the flooding of query packets in ad-hoc networks along with objectives of broadcasting techniques. Section 4 presents the taxonomy of the broadcasting techniques and their methodologies. In Section 5, future direction of the work is discussed, and Section 6 concludes this paper.

2. Route discovery in ad-hoc networks

Route discovery is a mechanism whose target is to choose the optimal path for the data transmission. This is a necessary process in any routing protocol to start the data transmission. This process may be either reactive or proactive depending on the nature of routing protocols. In proactive route discovery, route is always available in the table through periodic messages (Haas et al., 2002; Abolhasan et al., 2004; Boukerche et al., 2011). As a result, data can be transmitted quickly. For example, OLSR (Clausen et al., 3626), DSDV (Perkins et al., 1994), CGSR (Chiang et al., 1997) etc. are proactive in nature. Some of the power aware routing protocols (Maleki et al., 2002; Singh et al., 1998) also belong to the proactive routing category. Though these protocols are loop free and provide route in minimum time, the regular exchange of periodic messages congests the entire network. These protocols also use large storage space and consume too much energy of nodes. So, reactive routing protocols come into existence as an alternate solution to reduce this congestion and storage issues. These protocols function on *on-demand* basis (also called source initiated routing protocols) and do not require any periodic transmission. Route is availed when a node needs to send some data. Apparently, a large amount of battery power and bandwidth is saved (Abolhasan et al., 2004; Boukerche et al., 2011).

In order to find the requested path, source node broadcasts/floods the query packet in the entire network. Each intermediate node processes this packet and checks its cache for a route. If no route is available, it re-broadcasts the packet. This practice is sustained until the route node or the destination node itself is found. AODV (Perkins et al., 1999), DSR (Johnson et al., 2001), TORA (Park et al., 1997), ABR (Toh, 1997) used reactive route discovery to find the requested path. Since no one type of routing protocol alone was substantial, hybrid routing protocols were proposed that have both properties of being proactive and reactive. ZRP (Haas et al., 2002), IZRP (Samar et al., 2004), TZRP (Wang and Olariu, 2004), AntHocNet (Di Caro et al., 2005), HOPNET (Wang et al., 2009) and cluster based routing protocols such as DWCA (Choi et al., 2006), DMAC (Basagni et al., 1999), LEACH (Heinzelman et al., 2002), and DTMNS (Jamuna, 2012), etc. are examples of hybrid routing protocols. These protocols use hierarchical approach to find the path in which proactive approach is used within the proximity of the node and reactive approach between the proximity of nodes.

In routing protocols, different techniques are used from the MAC layer to a higher level to reduce packet diffusion cost. Consequences of packet diffusion can be analyzed in AODV (Perkins et al., 1999), LCC (Least Clusterhead Change) (Chiang and Gerla, 1997) and ZRP (Haas et al., 2002) that are overcome in Kataria et al. (2010),Wu and Lou (2003) and Haas and Pearlman (2001) respectively. Some other similar broadcasting techniques were also proposed to lessen packet diffusion cost (Barjini et al., 2012). The objective of these techniques is to broadcast the query packet at minimum diffusion cost, so that the route discovery expenses can be curtailed. In the initial phase of route discovery, flooding is a common technique which increases the packet diffusion cost. It is described in detail in the next section.

3. Flooding of query packets

Flooding is a process to disseminate the query packet over the network so that each node of the network can process the query packet to find the optimal path. This is the simplest form of broadcasting used in the route discovery stage of routing protocols. Since flooding uses every path of the network, it guarantees to explore the shortest and optimal path for efficient and effective data transmission. Flooding was used in many routing protocols such as AODV (Perkins et al., 1999), OLSR (Clausen et al., 3626), DSR (Johnson et al., 2001), DSDV (Perkins et al., 1994). Since packets pass through every outgoing line (shown in Fig. 1), most of the nodes receive multiple copies of same packet and forward the query packet even after the route has been found. Hence, it consumes a large bandwidth of the channel and more battery power of nodes. This unnecessary circulation of query packets degrades the performance of any routing protocol. Two precautionary measures are taken to overcome this problem. First, selective flooding to prevent the redundancy of the packet at intermediate nodes and the second is the controlled flooding to stop the unnecessary propagation of query packets. Packet diffusion cost of flooding is calculated in Section 3.1. It shows that packet diffusion cost needs to minimize the congestion and energy consumption as well.

3.1. Packet diffusion cost model

Suppose that network is represented as a connected acyclic graph where vertices of the graph represent nodes and edges between two nodes represent connections. Network is consisted of N nodes and has diameter of D. Each node contains an average number of neighbor nodes d which is average degree of any graph ($d > 2$). Let PDC be the packet diffusion cost at a specified hop count and it can be defined as

$$PDC = \frac{TNN_k}{TNN_{k-1}} = \frac{\sum_{i=1}^{k} d(d-1)^{i-1}}{\sum_{i=1}^{k-1} d(d-1)^{i-1}} \quad (1)$$

where TNN_k is total number of nodes at k hop count. PDC of flooding (redundancy of packets at intermediate nodes is not considered) for the entire network is given by Eq. (2).

$$PDC_f = \frac{d(d-1)^R - 1}{d(d-1)^{R-1} - 1} \quad (2)$$

where R is the radius of the network which is equal to $D/2$. By solving Eq. (2) we have

$$PDC_f = 1 + \frac{d-2}{1 - \frac{1}{(d-1)^{R-1}}} \quad (3)$$

Let $a = d - 1$, then the value of packet diffusion cost at R hop count is given by Eq. (4)

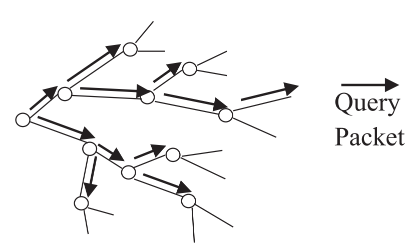


Figure 1 Flooding of query packets in the network.

$$PDC_f = \frac{a^R - 1}{a^{R-1} - 1} \quad (4)$$

Larger propagation of query packets increases the packet diffusion cost that leads to network congestion and energy consumption problem. Energy consumption (EC_n) of nodes affects the network life which is given by Eq. (5).

$$EC_n = n \times E_r \quad (5)$$

where n is the number of nodes and E_r denotes the energy drained per node. In route discovery, energy is consumed in two ways: query packet broadcast and reply packet unicast. Let H_i be the number of nodes at ith ring and R be the radius of network. The energy consumption for flooding can then be shown as

$$EC_n = \sum_{i=0}^{H_R} E_i \quad (6)$$

Total energy consumed in route discovery can be written as

$$EC_n = \sum_{i=0}^{H_R} E_i + E_{rrep} \quad (7)$$

where E_{rrep} is consumed energy in uncasting reply packet.

Following this analysis, PDC and EC_n for bounded broadcasting techniques are calculated as shown in Table 5.

In order to minimize consequences of flooding, broadcasting techniques are proposed with multiple purposes as discussed in Section 3.2.

3.2. Objective of broadcasting techniques

An optimized strategy of blind flooding is broadcasting in which only intended nodes receive the query packet. It is an essential technique to discover the desirable route for data transmission. This technique has multiple objectives in the route discovery phase which are common for every routing protocol. Some of these are listed below:

3.2.1. Reducing the flooding expenses

The main drawback of the blind flooding is the broadcast storm problem (Tonguz et al., 2006; Tseng et al., 2002) that congests the entire network. This congestion develops due to the unnecessary propagation of query packets. This undesirable circulation is reduced by using a suitable broadcast repealing technique.

3.2.2. Limiting the packet dropping

In ad-hoc networks, multiple classes of congestion (Karenos et al., 2008) exist that cause the packet dropping. To increase the reliability of the packet transmission, a traffic control technique is used which works during the packet broadcast to estimate the traffic in the network (Kataria et al., 2010).

3.2.3. Optimizing the path length

End to end delay is the average time taken by the source node to transfer the packet successfully (Al-Rodhaan et al., 2008). This depends on the length of requested path and traffic on that path. Therefore, such a broadcasting technique is used that optimizes the desired path.

3.2.4. Increasing reliability of the path

Reliability of any path depends on the stability of the path. Independent movement of the mobile nodes changes the topology of the network that causes link breakage. Frequent link breakage decreases the reliability of the path (Perkins et al., 1999; Perkins et al., 1994). Therefore, Broadcasting of the query packet is done in such a way that the packet can cover the smallest enough area of the network and choose the set of nodes with maximum battery life. Length of the path is also taken into account so that the data transmission can be done through a stable route with shortest length.

3.2.5. Utilizing unicast and multicast modes

Although several routing protocols exist that work for unicast and multicast communication in MANETs (Singh et al., 2014; Yin et al., 2014; Jia et al., 2014), no routing protocol fits in all scenarios due to their varying routing properties. These properties solely depend on the broadcasting techniques. For example, there are five clients and each of them is sending 50 kbps data in unicast mode. So the group bandwidth is 250 kbps, while in multicast mode, same load is experienced by one client to 250 clients. The use of multicasting in bounded broadcasting techniques can decrease the cost of packet diffusion by utilizing packet diffusion for group communication where the source node needs to find multiple routes at once for a particular group of nodes. In the unicast mode, unbounded broadcasting techniques are useful because of selective flooding.

4. Taxonomy of broadcasting techniques

From Section 3, it is clear that the overall performance of routing protocols depends on the broadcasting technique. To improve the performance of routing protocols, many broadcasting techniques have been proposed. These techniques are broadly classified into *Unbounded* and *Bounded* broadcasting techniques which is depicted in Fig. 2.

4.1. Unbounded broadcasting techniques

A broad variety of selective flooding based broadcasting techniques have been proposed in this field to lessen the broadcast expenses of route discovery phase. These techniques deter the redundancy of query packets at intermediate nodes and allow packets to travel without any terminating state. Some of the broadcasting techniques (Qayyum et al., 2002; Peng and Lu, 2001; Sucec and Marsic, 2000; Lim and Kim, 2000; Wei and Xicheng, 2001) were surveyed by Williams and Camp (2002). In their comparative study, the broadcasting techniques were classified into four categories: simple flooding, probabilistic, location based and neighbor knowledge based techniques. We categorize these techniques (Qayyum et al., 2002; Peng and Lu, 2001; Sucec and Marsic, 2000; Lim and Kim, 2000; Wei and Xicheng, 2001) as unbounded broadcasting to the proposed taxonomy. Apart from these, some other techniques surveyed in this work include FRESH (Dubois-Ferriere et al., 2003), DREAM (Basagni et al., 1998), WRS (Aitha and Srinadas, 2009), probabilistic technique (Preetha et al., 2012), Query Localization (Castaneda et al., 2002), Location Aided Routing (Ko and Vaidya, 2000), HoWL (Minematsu et al., 2005).

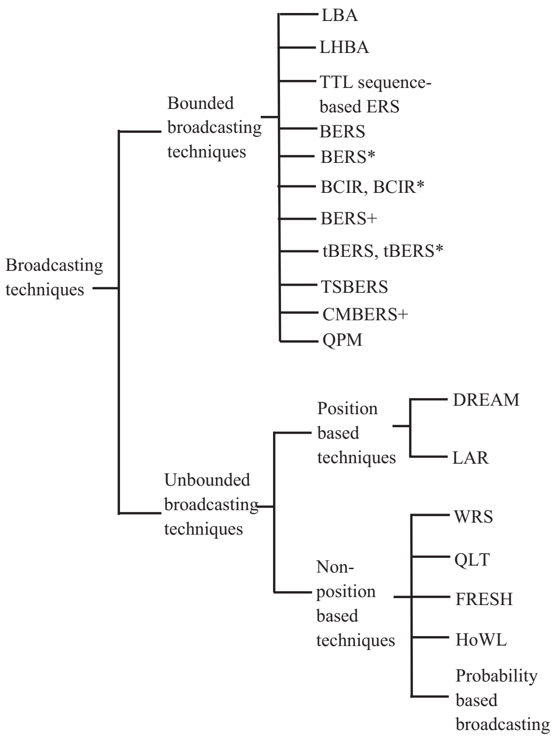


Figure 2 Taxonomy of the broadcasting techniques.

4.1.1. FResher Encounter SearcH (FRESH)

FRESH (Dubois-Ferriere et al., 2003) is an anchor based technique which is most useful for the first route discovery toward a destination. It makes use of an underlying primitive search in order to find the route. It is a simple route discovery for MANETs that works based on the anchor nodes.

Anchor nodes are those nodes that have found the desirable route most recently. Every node maintains an encountering history. This history consists of only the time of its last encounter with every other node. It can be detected by overhearing of any packet sent by neighbor nodes. The algorithm used relative times for encounter ages to be free from clock synchronization. Source node searches nearest anchor in its proximity using ERS (Al-Rodhaan et al., 2008). Each search is defined only in terms of node's local encounter table. This anchor node is decided by comparing the encounter ages of the intermediate node and source node. When the nearest anchor node receives route discovery packets, it informs the source node about itself and starts to search the next nearest anchor node. This practice is continued until the route node receives the query packet. These anchor nodes form the path from the source node to the destination node. The route node sends back a reply packet to the source node following the reverse series of anchor nodes. Since each anchor node searches the next anchor node using ERS in its proximity, various intermediate nodes are common in the proximity of two anchor nodes that can be seen in Fig. 3. These common nodes use their energy to process the query packet in search of two anchor nodes. This search increases total energy consumption of the route discovery. If anchor nodes are more in number on the path, it will lead to a longer path and take more time in route discovery phase. Thus FRESH is a time taken practice that wastes its time to search for anchor nodes.

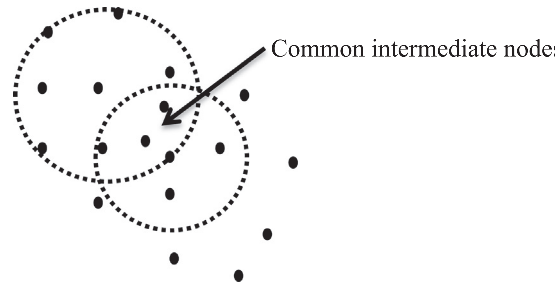


Figure 3 Searching area of two anchor nodes.

4.1.2. Weighted Rough Set based Broadcasting (WRSB)

WRSB (Aitha and Srinadas, 2009) is a weighted rough set model based broadcasting technique. Here, neighbor nodes are cataloged into two sets: lower (uncovered nodes) and upper (covered nodes) approximation sets. These sets are created based on the attributes of neighbor nodes. Like AODV (Perkins et al., 1999), WRSB uses the HELLO messaging technique to gather neighbor information up to 2-hop away. According to this information, each node prunes its neighbor nodes which have received the packet. Whenever any node i needs to send the data, it piggybacks the list $N(v_i)$ of forwarding nodes along the query packet.

Intermediate nodes receive this packet and starts pruning of the covered nodes. Lower set has more importance than the upper set. This neighbor nodes selection is done using mathematical formulation of WRS model which is given in Eq. (8).

$$w(x_i) = \sum_{j=1}^{n} T_j(x_i) \tag{8}$$

where $T_j(X_i)$ is the opinion measure of jth expert derived from assigned rules for ith domain to choose the set of maximum weighted neighbor nodes.

Assume that the network is configured in the form of a graph as shown in Fig. 4. Each intermediate node selects forwarding set $\{N(N(v_i)) - N(v_i)\}$ of neighbor nodes to retransmit the packet. In the case of Fig. 4, node J has neighbors $E, F,$ and H of 1-hop away and neighbors $D, C, G, I,$ and K of 2-hop away.

$N(J) = \{E, F, H, J\}$ and

$N(N(J)) = \{C, D, E, F, G, H, I, J, K\}$

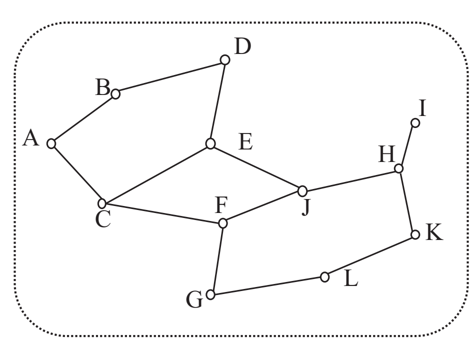


Figure 4 Ad-hoc network.

If node H receives a packet from J, H, it will forward the packet to only those nodes which belong to its forwarding set $N(H) = \{N(N(J)) - N(J)\}$. So, H forwards the packet to I and K. Unlike flooding, WRS reduced the redundancy of query packets, but sped up the diffusion of the query packet.

4.1.3. Query Localization Technique (QLT)

QLT (Castaneda et al., 2002) is one kind of bypass strategy which is based on the notion of the spatial locality. Most probably a mobile node does not move too far too soon; thus a new route contains mostly those intermediate nodes that the last valid route contained. Based on this assumption, QLT (Castaneda et al., 2002) considers two heuristics to exploit locality: exploiting path locality (protocol 1) and exploiting node locality (protocol 2). Protocol 1 predicts that the new route cannot be different from the last one while the protocol 2 considers that the destination node can be found within a small number of hops from the node where the link is broken. This node broadcasts the query packet with counter k (initialized to 1) to search any of the remaining nodes of route. Counter increases each time if a node is not present in last valid route. This process is continued until the destination node is found. This technique is not suitable where topology is changing frequently or communicated nodes are highly movable, and previous communication does not exist.

4.1.4. Distance Routing Effect Algorithm for Mobility (DREAM)

DREAM (Basagni et al., 1998) is a location based technique that uses GPS to obtain the geographic location of the destination node at a particular time (t_0). This location information is used to improve the performance of the route discovery phase in MANETs by reducing the dissemination area of the query packet. This information is stored in the location table and consistency is maintained while exchanging the co-ordinates of nodes periodically. Since slower moving nodes require less periodic exchange, DREAM also optimizes the periodic exchange by observing relative mobility. Location of a node is calculated using directional angle (α), speed (v), and the co-ordinates (x, y) between two consecutive times. Angle α depends on speed v, and changes as speed of the node changes.

In this algorithm, a circular area of radius $v(t_1 - t_0)$ is calculated at time (t_1), also called expected zone. Destination node can relocate itself only within this expected zone. Direction of destination is calculated by

$$\alpha = arcsin\frac{(v(t_1 - t_0))}{r} \tag{9}$$

where r is the distance between source and destination nodes. Following location information, query packets are sent to the direction of the destination node using a request zone. Only intermediate nodes of request zone forward query packets toward the direction of the destination node. The main disadvantage of this scheme is that the request zone is not adaptive with increased mobility of the intermediate nodes. Fig. 5(b) shows that the path is not inside the request zone. In this case, it requires re-initiation of the route discovery that follows partial and blind flooding.

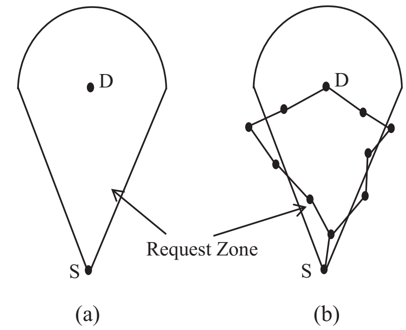


Figure 5 Path between Source S and Destination D exists outside the request zone, redrawn from Ko and Vaidya (2000).

4.1.5. Location Aided Routing (LAR) technique

LAR (Ko and Vaidya, 2000) is also a location based progressive routing technique. Basically, this is an improvement over DREAM that follows a rectangular approach for the request zone which is shown in Fig. 6(a). In DREAM, expected zone is not adaptive with increased speed of intermediate nodes. This shortcoming is addressed in LAR; the expected zone of nodes is flexible with mobility of intermediate nodes. It can increase or decrease the range of the searching area as the speed of destination node increases or the source node enters into the expected zone of the destination node.

NAVSTAR Global Positioning System (Hofmann-Wellenhof et al., 2012) (which gives more accurate result than GPS) is used in LAR to detect the speed (v) and location (x, y) of the destination in the form of coordinates at a particular time (t_0). Whenever the source node initiates route discovery, it selects 1-hop away neighbor nodes, which lie within the rectangular region and broadcasts the query packet to them. Neighbor and intermediate nodes also forward query packets within the requested zone to confine the query broadcast. Expected zone is a circular region (shown in Fig. 6) at time (t_1) of radius $v(t_1 - t_0)$ within which the destination node moves. Fig. 6(b) depicts that the source node can come within the expected zone of the destination node while moving toward each other. In that case, the source node decreases the request zone at the next attempt.

Although LAR increases the probability of determining the desirable path, it covers a larger area in route discovery. Thus network life is more affected in LAR than DREAM.

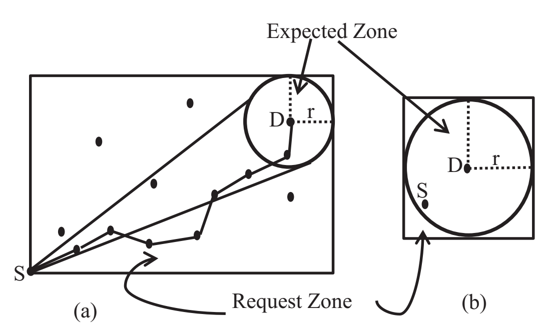


Figure 6 Path between Source S and Destination D exists inside the request zone, redrawn from Ko and Vaidya (2000).

4.1.6. Probabilistic Approach to Reduce the Route establishment Expenses (PARRE)

PARRE (Preetha et al., 2012) is a probabilistic approach, proposed to reduce the issues related to the route discovery process in AODV (Perkins et al., 1999). It works based on the probability that depends on the previous records of the routing table. This approach has maximum chance to find the path with limited transmitting nodes. But it requires a large storage space at each node of the network. It reduces the unwanted searches during the route establishment process by considering the previous behavior of the network. Whenever the node has something to send, it initiates a route discovery process. Node sends the query packet to only those intermediate nodes that have probability to find the route to the destination. This probability is calculated using the previous record of requested path from the routing table. Every node maintains a connectivity index table as shown below. This table contains a probability for each node. Whenever the node sends a query packet, it first checks a connectivity index table for probability of its neighbors. Only neighbors with non-zero probability receive the query packet to forward. Unlike flooding, it does not require any freshet of the packet for route discovery. Methods for calculating the connectivity index table are given in Eqs. (10) and (11).

$$u_k = \frac{\text{Number of success obtained}}{\text{Number of attempts made}} = \frac{S_{1..k}}{A_{1..k}} \tag{10}$$

For each attempt, each node updates u_k for each outgoing link using

$$u_k \leftarrow u_k\alpha + (1 - \alpha)u_k \tag{11}$$

where α is a constant, and $0 < \alpha < 1$. However, when no previous communication exists, connectivity index of each node is considered as 1 for each outgoing link in the first attempt of route discovery, hence it leads to flooding of the packet. (see Table 1)

4.1.7. Hop-Wise Limited broadcasting (HoWL)

HoWL (Minematsu et al., 2005) is an efficient route discovery approach for MANETs. It discovers the route by predicting the current location of the destination using hop count of a previously used route. It works on the theory of data mining where the source node uses cache as the operational database and history table as data warehouse. It is designed to reduce the packet retransmission of routing protocols, which use flooding as a way to propagate query packets. Whenever the source node wants to send some data, it searches for the route to destination in its cache. If a route is found, the source node sends data through this route. Otherwise, it searches its history table. If no route is found in its history table also it means no attempt has been made to find the destination node. In such a case, source node floods query to discover the route following revisiting-TTL the ERS method (Chang and Liu, 2004). It uses a predefined TTL value to limit the search area which is initialized by hop count. This hop count is of a previous route that is taken from the history table. TTL value varies as time passes. If the destination is found, the discovered route is followed to send the data. Otherwise, it follows the repeated packet broadcast to carry out the route discovery. Consequently, repeated packet broadcast increases the energy consumption, latency, and congestion.

Table 1 Connectivity index table.

Neighboring Node	u_k

4.2. Summary of unbounded broadcasting techniques

The task of making an efficient and effective packet broadcast for route discovery is pivotal in MANETs. This is because of the packet flooding incurred due to dynamic change in topology, poses the broadcast storm problem (Tonguz et al., 2006). The situation worsens, when the source and destination nodes do not have any previous communication. In order to prevent this, unbounded broadcasting techniques have been proposed. These techniques are based on the selective flooding and thus avoid blind flooding. This is just like a simulation where initially all nodes are colored white. Source node chooses a forward set of neighbor nodes which might be position based, neighbor knowledge based, or previous record based. The nodes of this forwarding set process the query packet and colors it black. This iterative selection and coloring is repeated until no white node remains. Resultant set of nodes is a set of participating nodes. For example, WRS uses weight metric to choose the forwarding set of nodes.

Position based broadcasting techniques like LAR, DREAM are scalable and reduce a large amount of the participating nodes by exchanging location information rather than whole network information as compared to non-position based techniques. Location based techniques are not suitable where GPS signal reception is poor or inaccurate.

On the contrary, knowledge and previous record based techniques do not require any special device. These techniques rely only on previous communication. As number of communicating iterations increases, satisfactory results are obtained as compared to location based techniques by reducing the consequences of broadcast storm problem (Tonguz et al., 2006). For example, techniques like HoWL, QLT, etc. require less effort to find the desirable route. Table 2 also depicts a comparative study of these techniques for other performance metrics. Though the goal of these techniques is to reduce the congestion by preventing redundancy of packets at intermediate nodes, they are not capable to prevent the query packets from further propagation. In order to prevent the unnecessary circulation of packets, bounded broadcasting techniques have been proposed which are discussed in Section 4.3.

4.3. Bounded broadcasting techniques

Unlike unbounded broadcasting techniques, the goal of bounded broadcasting techniques is to stop the unnecessary circulation of query packets. To achieve this goal, various controlled flooding techniques have been proposed that reduces the flooding expenses of the reactive route discovery. These techniques broadcast the query packets with limited hop count. Techniques like LBA (Gargano and Hammar, 2004), LHBA (Zhang and Jiang, 2005), Revisiting-TTL ERS (Chang and Liu, 2004), Blocking ERS (Park et al., 2006), Blocking ERS+ (Al-Rodhaan et al., 2008), BCIR (Lima et al., 2013), and tBERS (Pu et al., 2014) belong to this category.

Table 2 Comparative study of the unbounded broadcasting schemes.

Broadcasting schemes	Path strategy	Type	Complexity	NoT	HM
FRESH (Dubois-Ferriere et al., 2003)	ABF	Proactive	O(N)	1	Yes
HoWL (Minematsu et al., 2005)	RBF	Reactive	O(N)	1	No
WRS (Aitha and Srinadas, 2009)	NKBF	Reactive	O(N^2)	3	Yes
LAR (Ko and Vaidya, 2000)	LBF	Reactive	O(N)	1	No
DREAM (Basagni et al., 1998)	LBF	Proactive	O(N)	1	Yes
QLT (Castaneda et al., 2002)	RBF	Reactive	O($P+k$)	1	No
PBBS (Preetha et al., 2012)	PBF	Reactive	O(N)	2	Yes

ABF: Anchor Based Flooding, NKBF: Neighbor Knowledge based Flooding, RBF: Record Based Flooding, LBF: Location Based Flooding, PBF: Probability Based Flooding, P: Set of nodes lie in previous recorded route, k: Threshold Value, HM: Hello Message, NoT: No. of Table

4.3.1. Limited Broadcasting Algorithm (LBA)

LBA (Gargano and Hammar, 2004) is the first query packet controlling technique that is based on the slot sharing policy. It divides channel speed into two slots which are assigned periodically among the query, reply and chase packets. One-fourth of the channel speed is assigned to the query packet while the remaining is used by route reply and chase packet. Whenever any node starts route discovery, it broadcasts the query packet with one-fourth of the channel speed to find the requested path. As destination node receives the query packet, it sends back a reply packet on the second slot. Once the route has been discovered, source node immediately broadcasts the chase packet with a faster speed on the second slot. These chase packets terminate further propagation of the query packets. Although it reduces packet retransmission overhead; but higher priority of chasing over route discovery increases the end to end delay. Moreover, source node is responsible to initiate the chase packets which need to be destination initiated. Destination initiated chasing packets will speed up broadcast repealing to confine the disseminated area of the packet.

4.3.2. Limited Hop Broadcasting Algorithm (LHBA)

Limitations of LBA (Gargano and Hammar, 2004) were overcome in LHBA (Zhang and Jiang, 2005). Here, only one packet is used that works as a query packet, reply packet and also the chase packet. The nature of the packet depends on the reference bit. Packet with reference bit 0 works as a query packet and packet with reference bit 1 behaves like a reply packet. This reply packet is also used to control the query packets when the route is found.

In LHBA, whenever the source node wishes to send data, it sets the reference bit of the packet to 0 and broadcasts it to find the route. This packet is processed by intermediate nodes. As the key node (that has the requested route) receives this packet, it sets the reference bit to 1 and broadcasts it over the network with hop count k (hop count between source and destination nodes). Whenever the intermediate node receives this packet, it checks the packet header and forwards it as a reply packet if the node is in the header. If not, the node checks its cache whether the query packet has been received. Received packet is discarded if the query packet has been processed at the node, otherwise broadcasts it. Likewise, chase packet ceases the query packet at kth ring. In Fig. 7, reply packet ceased query packets at 3rd ring after destination because of limited journey of control packets. LHBA speeds up the controlling by initiating the chase packet at destination. But it still controls query packets of only one part of the network as shown in Fig. 7.

4.3.3. Revisiting-TTL ERS

Revisiting-TTL ERS (Chang and Liu, 2004) is an expanding ring search based technique which follows the controlled flooding. It broadcasts the query packet periodically with increased Time to Live (TTL) value as attempts fail rather than using the chase packet to limit disseminated area of query packets. Source node starts route discovery whenever required and broadcasts the query packet with predefined TTL value. Query packets propagate over the network until the TTL value reaches zero. When attempts fail, node again broadcasts this packet with increased TTL value. This periodic broadcast is done until the route node is found. In this technique, query packets flowed as the wave spreads around the water as shown in Fig. 8(a). The innermost circle is first broadcast, followed by the second innermost circle and so on. Suppose B_i denotes the set of nodes participated in ith broadcast. Since a broadcast occurs when the previous attempt fails and each broadcast contains the previous broadcast, we get

$$B_1 \subset B_2 \subset B_3 \subset \cdots B_i \quad (12)$$

Eq. (12) depicts that this technique consumes too much battery power of intermediate nodes due to periodic broadcast of the query packet and also increases the average latency.

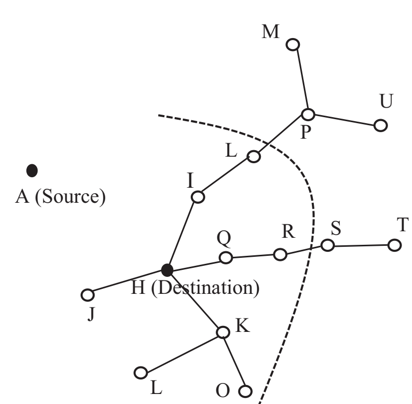
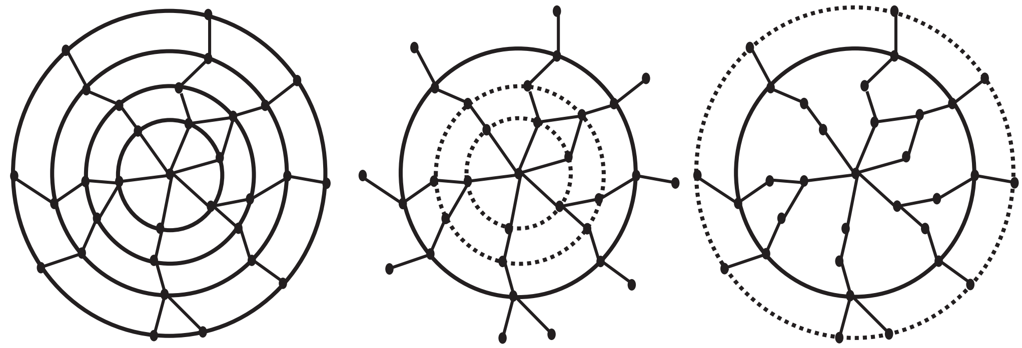


Figure 7 Area covered by the chase packet in LHBA.



(a) TTL sequenced-based ERS (b) Blocking ERS (c) Blocking ERS+

Figure 8 Processing of ERS based algorithms.

4.3.4. Blocking expanding ring search (BERS)

BERS (Park et al., 2006) is an extended version of revisiting-TTL ERS (Chang and Liu, 2004) which does not allow the source node to broadcast the packet periodically with increased TTL value. Source node broadcasts the query packet only once and provides full channel time to travel for the packet. The responsibility to transmit the packet beyond the first ring is shifted to relay nodes rather than the source node. When the route node is not found in the first ring, this relay nodes further broadcasts the query packet with increased TTL value which is shown in Fig. 8(b) by dotted circles. Following this practice, route node or destination node is found within the maximum predefined TTL value. It is called pure BERS where the source node does not require broadcasting again. When increased TTL value meets maximum limit of TTL value and attempt fails, this process is called partial BERS. Source node needs further broadcast following Revisiting-TTL ERS (Chang and Liu, 2004) which is shown in Fig. 8(b) by dark circles. Thus Eq. (12) can be rewritten as

$$\underbrace{\underbrace{\dot{B}_1 \cap \dot{B}_2 \cap \cdots \dot{B}_k}_{Pure\ BERS} \subset B_{k+1} \subset \cdots B_i}_{Partial\ BERS} \tag{13}$$

where $\dot{B}$ is the set of halt nodes that wait for control packets before forwarding.

Unlike revisiting-TTL ERS (Chang and Liu, 2004), two control signals work to prevent the query packets in BERS: first is the chase packet and the second is the reply packet. Each node processes the query packet and waits for the chase packet up to 2*hop-count*NTT (Node traversal time). When time elapses, it means the destination node is not in the search ring; relay nodes broadcast packets to their corresponding neighbors. This practice is continued until the route is found. Source node broadcasts the control packet immediately as it receives the reply packet, and control packets cease further propagation of query packets. Though this delay helps to chase the packets, it increases end to end delay. This technique is also not adaptive with mobility of the destination node because of the limited journey of query packets and leads to partial BERS.

4.3.5. Enhanced BERS (BERS)*

BERS* (Pu and Shen, 2009) is enhanced BERS that decreases the added delay at each intermediate node (halt node) following the same technique of BERS (Park et al., 2006). This technique speeds up the route discovery by giving priority over chasing packets. In BERS*, halt nodes wait for h*NTT unit of time before forwarding the query packet. When the source node has been discovered successfully, it initiates the terminating phase by issuing the chase packet. All intermediate nodes that have received the query packets immediately forward the chase packet; otherwise discard it. Again all intermediate nodes that have received chase packet discard incoming query packets. This improvement over BERS in terms of average latency can be seen in Table 3. Since BERS* increases the speed of the query packet, chasing becomes slower than BERS. Suppose source and destination nodes are h-hop apart from each other. In such case, BERS ceases the dissemination of packet at hth ring while BERS* at $(h+1)$th ring. BERS is more transmission efficient than BERS* although BERS* gives faster route discovery. Like BERS, BERS* is also not adaptive to the mobility of the destination node.

4.3.6. Improved BERS (BERS+)

Consequences of inefficient use of added delay in the processing of the query packet were analyzed in Sections 4.3.4 and 4.3.5 that increased the average latency of route discovery exponentially. An efficient use of added delay in BERS+ (Al-Rodhaan et al., 2008) offers better performance than BERS and BERS*.

BERS+ uses a two tier approach to eliminate deficiencies of the BERS. In tier one, all intermediate nodes forward query packets without delaying until k hop count reaches to the maximum limit of TTL value. This is the first attempt made by source node with predefined TTL value which is shown in Fig. 8(c) with dark circles. In tier two, all intermediate nodes after kth ring become halt nodes that wait for $2h$ unit time before forwarding query packets. Tier two occurs if the route node or destination node is not found in tier one. It is shown

Table 3 Added delay for BERS and BERS*.

ith ring	1	2	3	4	5	..	k[1]
$T_{BERS}(h)$	1	4	9	16	25	..	k^2
$T_{BERS*}(h)$	1	2	6	10	15	..	$\frac{k^2+k}{2}$
$T_{BERS+}(h)$	0	0	0	0	0	..	k^2

[1] Route node is found at kth ring.

in Fig. 8(c) by dotted circles. Eq. (13) for BERS+ can be rewritten as

$$\underbrace{B_1 \cap B_2 \cap \cdots B_k}_{Ist\ \ Tier} \cap \underbrace{\dot{B}_{k+1} \cap \dot{B}_{k+2} \cap \cdots \dot{B}_i}_{IInd\ \ Tier} \quad (14)$$

Eq. (14) shows that added delay is eliminated from tier one and places halting policy of query packets after kth ring. Apparently, eliminated delay speeds up the route discovery, and halting of query packets terminates the unnecessary query broadcast.

4.3.7. Destination Initiated Broadcast Termination (DIBT)

A major drawback of BERS, BERS* and BERS+ is slow convergence of broadcast termination. This is because of source initiated broadcast termination. Therefore, BCIR and BCIR* (Lima et al., 2013), and tBERS and tBERS* (Pu et al., 2014) make the broadcast termination destination node initiated that speeds up the broadcast termination and reduced the retransmission overhead. Both literatures (Lima et al., 2013 and Pu et al., 2014) follow the same approaches of BERS and BERS* except the termination mechanism. BCIR and tBERS are more retransmission efficient than BERS, while BCIR* and tBERS* are more retransmission efficient than BERS*.

In these techniques, concurrency plays the main role to reduce packet retransmission. In BERS, and BERS*, replying and controlling events are not concurrent that causes the more retransmission by the time the destination node replies to the source node. These events are concurrent in Lima et al. (2013) and Pu et al. (2014) that make tBERS (Pu et al., 2014), tBERS* (Pu et al., 2014), BCIR (Lima et al., 2013) and BCIR* (Lima et al., 2013) more energy and chasing efficient. Chasing latency can be analyzed in Table 4.

4.3.8. Cluster based modified BERS+ (CMBERS+)

Scalability is one of the necessary aspects for routing protocols which minimizes the retransmission overhead and energy consumption. In order to minimize these overheads, cluster based routing protocols are proposed that solve scalability issue. However, these routing protocols are prone to unnecessary propagation of query packets. CMBERS+(Hussain and Ahmad, 2014) one such clustering based technique that confine the propagation of query packets in clustered networks. As we have seen in Section 4.3.6, BERS+ has many benefits over BERS, BERS*, BCIR, BCIR*, tBERS and tBERS*. A modified-BERS+(destination initiated BERS+) is implemented in the clustered network which addresses the shortcomings of other broadcasting techniques in a significant manner like average latency, packet retransmission, energy consumption, etc.

Table 4 Chasing latency for ERS-based techniques (Pu et al., 2014).

Technique	Chasing latency
BERS (Park et al., 2006) and BERS+ (Al-Rodhaan et al., 2008)	$2H + H^2$
BCIR (Lima et al., 2013) and tBERS (Pu et al., 2014)	$H + H^2$
BERS* (Pu and Shen, 2009)	$1 + 2.5H + 0.5H^2$
BCIR* (Lima et al., 2013) and tBERS* (Pu et al., 2014)	$1 + 1.5H + 0.5H^2$

4.3.9. Two-Sided ERS (TSERS)

TSERS (Shamoun and Sarne, 2014) is two sided expanding ring search technique in which TTL sequence-based flooding is done from both source and destination nodes as shown in Fig. 9. Query packets travels from node to node. Any node that receives a query from both sides at the same time (we call it core-node), contains a set of sub-paths. As the core node receives a query from both nodes, it shares the path between both sided nodes to proceed with the communication. This technique uses TTL sequence based controlled flooding which increases the average latency as in one sided revisiting-TTL ERS (Chang and Liu, 2004), but TSERS cuts the cost by half.

Assume that A and B are two nodes, initiate to search for each other and broadcast the query following TTL-sequence with radius of R_1 and R_2 respectively. Difference of coverage area (C_{AB}) for two sided search and one sided search can be shown by Eq. (16).

$$C_A + C_B < C_{AB} \quad (15)$$

$$(R_1^2 + R_2^2) < (R_1 + R_2)^2 \quad (16)$$

where C_A and C_B are coverage area of the source node and destination node respectively. This technique is suitable for sensor networks where sensors nodes and base stations search each other regularly as link breaks. In TSERS, both sided nodes search each other with the expected cost of 0.5 which is half of the expected cost of full flooding or any one sided search.

4.3.10. Query packet minimize technique (QPM)

In QPM (Hong, 2014) is a timestamp information based technique which addresses the shortcoming of revisiting-TTL ERS (Chang and Liu, 2004) for non-uniform traversal time. In revisiting-TTL ERS (Chang and Liu, 2004), source node broadcasts query packet with predefined TTL value and wait for 2*h*NTT unit time. Whenever the query packet times out and the route node is not found, the source node rebroadcasts the query packet with increased TTL value. This rebroadcast can cause unnecessary rebroadcast when propagation delay is non-uniform. In order to handle this situation, QPM uses adjustable node traversal time which varies as average propagation delay of links vary.

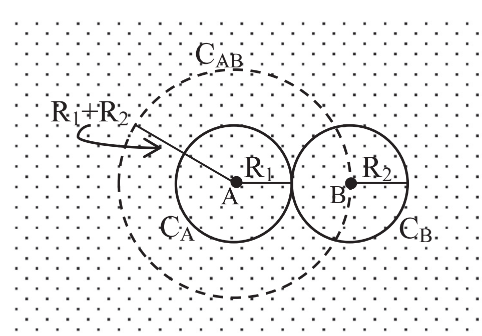


Figure 9 Overall comparison of broadcasting techniques.

Table 5 Comparative study of the Bounded broadcasting schemes.

Broadcasting schemes	Path strategy	Chasing strategy	Packet diffusion cost	Complexity	Waiting time	Energy drained
LBA	Flooding	SI	$\frac{a^{2R}-1}{a^2-1}$	O(N)	N/A	$\sum_{i=0}^{H_r} E_i + E_{rrep}$
LHBA	Flooding	SDI	$\frac{a^{2R}-1}{a^2-1}$	O(N)	N/A	$\sum_{i=0}^{H_r} E_i + \sum_{i=0}^{H_r} E_{rrep}$
TTL-ERS	TBLF	N/A	$\frac{a^2(a^{2l}-1)}{(a^2-1)^2} - \frac{l}{a^2-1}$	O(N^k)	N/A	$H_r * E_r + \sum_{i=1}^{H_r}\sum_{j=1}^{i} E_j + E_{rrep}$
BERS	TBLF	SI	$\frac{a^2(a^{2(k-l)}-1)}{(a^2-1)^2} - \frac{k-l}{a^2-1}$	O(N^{k-l})	2*H	$2\sum_{i=0}^{H_r} E_i + E_{rrep}$
BERS*	TBLF	SDI	$\frac{a^2(a^{2(k-l)}-1)}{(a^2-1)^2} - \frac{k-l}{a^2-1}$	O(N^{k-l})	H	$2\sum_{i=0}^{H_r} E_i + E_{rrep}$
tBERS and BCIR	TBLF	SI	$\frac{a^2(a^{2(k-l)}-1)}{(a^2-1)^2} - \frac{k-l}{a^2-1}$	O(N^{k-l})	2*H	$2\sum_{i=0}^{H_r} E_i + E_{rrep}$
tBERS* and BCIR*	TBLF	SI	$\frac{a^2(a^{2(k-l)}-1)}{(a^2-1)^2} - \frac{k-l}{a^2-1}$	O(N^{k-l})	2*H	$2\sum_{i=0}^{H_r} E_i + E_{rrep}$
BERS+	Flooding	SI	$\frac{a^{2k}-1}{a^2-1}$	O(N)	2*LP	$\sum_{i=0}^{H_r} E_i + E_{rrep}$
TSERS	TBLF	N/A	$\frac{1}{2}\left(\frac{a^2(a^{2l}-1)}{(a^2-1)^2} - \frac{l}{a^2-1}\right)$	O(N^k)	N/A	$\frac{1}{2}(H_r * E_r + \sum_{i=1}^{H_r}\sum_{j=1}^{i} E_j) + E_{rrep}$
QPM	TBLF	N/A	$\frac{a^2(a^{2l}-1)}{(a^2-1)^2} - \frac{l}{a^2-1}$	O(N^k)	N/A	$H_r * E_r + \sum_{i=1}^{H_r}\sum_{j=1}^{i} E_j + E_{rrep}$
CMBERS+	Flooding	SI	$\frac{a^{2k}-1}{a^2-1} - C_R$	O(N)	2*LP	$\sum_{i=0}^{H_r} E_i + E_{rrep}$

TLBF: TTL Based Limited Flooding, SI: Source Initiated, SDI: Source and Destination Initiated, H: Hop count, LP: Locality Parameter, R: Radius of the network, l and k: TTL values, where $l < k$, E_i: total energy consumed of n_i nodes at ith ring, C_R: no of ordinary nodes that are not participated.

4.4. Summary of bounded broadcasting techniques

Generally, all bounded broadcasting techniques except revisiting-TTL ERS (Chang and Liu, 2004) follow the chase based broadcast termination. Chasing strategy guarantees the controlled flooding by canceling the packet broadcast at a specified hop in only one attempt. While revisiting-TTL ERS uses preiodic packet broadcast to carry out the route discovery. This is because the periodic broadcast increases the average latency, energy consumption and retransmission overhead although revisiting-TTL ERS is controlled flooding. While addressing the shortcomings of TTL-ERS, other techniques were proposed that eliminated the periodic broadcast by introducing an added delay at intermediate nodes. For example, broadcasting techniques BERS, BERS*, tBERS, tBERS*, BCIR, BCIR* have the same cost as conventional TTL-ERS in worst-case if predefined TTL value is short. In the case of increased distance between the source and destination, these techniques are not adaptive and follow TTL-ERS. In that case, these techniques lead to slow convergence of route discovery. BERS+ is adaptive to the mobility of the destination node and is best suitable for the worst-case scenario where no previous communication exists. The drawback with BERS+ is that broadcast termination is source initiated, which is the additional latency in the processing of control packets. This is not the case for BCIR, BCIR*, tBERS, tBERS* where destination initiated broadcast termination is used to control the unnecessary propagation of the query packet. Apparently, these techniques are more retransmission efficient than BERS, BERS*, and BERS+. Another method used to reduce the packet retransmission is cluster based broadcast. Only cluster heads and gateway nodes participate in packet retransmission and other ordinary nodes remain silent. It reduces the packet retransmission as compared to the traditional flooding techniques (Gu et al., 2014). CBERS+ is one such cluster based broadcasting technique. Here, destination initiated BERS+ is implemented over a distributed clustered network that achieves scalability and broadcast termination mechanism. In highly dynamic networks, maintaining clusters is quite a difficult task because it increases routing processing charges. Therefore, CMBERS+ is suitable for medium size networks with slow to moderate mobility. It also works better in networks where nodes move in groups and nodes are more likely to stay in groups.

5. Challenges ahead

The primary requirement for communication in ad-hoc networks is to explore the optimal path which is the central challenge in MANETs. A lot of effort was devoted to achieve an efficient and effective broadcasting technique for route discovery. In Section 4, we addressed some of the shortcomings of existing broadcasting techniques, and following points highlight some of the possible measures that may be taken to addressing those shortcomings.

1. Blocking ERS+ introduced added delay after threshold to capture the query packets that slows down the route discovery after kth failed attempt. It can also be improved by reducing the added delay.
2. A comparative analysis of broadcasting techniques can be done in the clustered network which is still lacking in the majority of works.
3. Destination unreachability problem in LHBA can be removed to prevent the dropping of the gratuitous reply packet.

Moreover, Internet of things (IoT) (Gubbi et al., 2013) is a new buzz word in the information communication technology which covers a variety of routing protocols and their applica-

Table 6 Overall comparison of broadcasting techniques.

Broadcasting technique class	Unbounded broadcasting technique	Bounded broadcasting technique
Method	Selective flooding	Controlled flooding
Packet disseminated area	Large enough area of the network to find the route; usually depends on the routing history and location as well. Eg. QLT, LAR and DREAM	Small enough area of the network which depends on the predefined time to live (TTL) count
Control packets	No, prone to unnecessary propagation of query packets eg. WRS, HoWL	Yes except (Chang and Liu, 2004), used to control the further propagation of query packets. Eg. BERS, BERS+, tBERS
Applicable in	Proactive routing protocols where source node has link information of whole network, which helps to prune the conveying intermediate nodes.	Reactive routing protocols where source node make first route discovery for any node.
Storage requirement	Yes, increases as number of nodes increases	No, however some type of cache is used to track the predefined TTL value.
Preferred for	Unicast mode	Multicast mode
Average latency	Very low, due to proactive nature	Higher due to added delay in processing of query packet at each intermediate nodes
Periodic updates	Yes, require to gain previous routing information.	Not required
Suitable	For small networks with high mobility	For large networks with slower to moderate mobility where no previous communication is available

tions. In such scenarios, broadcasting techniques can play an important role to monitor power theft, animals in the forest and automobiles with built-in sensors etc. In this growing field, a controlled flooding will be required for multicast or group commination.

6. Conclusion

In this paper, two categories of broadcasting techniques are reviewed. The unbounded broadcasting techniques, which are mainly derived from selective flooding, eliminate query packets redundancy at intermediate nodes in the route discovery, and bounded broadcasting techniques which reduce retransmission of query packets by following controlled flooding. Most of the flat routing protocols employ only one broadcasting property of the two categories. Hybrid routing protocols employ both unbounded and bounded broadcasting properties by maintaining selective flooding within the proximity of node and controlled flooding between the proximity of nodes. With analysis of performance metrics and categorical characteristics of broadcasting techniques, certain conclusions can be drawn in each category which is shown in Table 6. Unbounded broadcasting techniques are simple to implement where previous communications exist. For example WRS, QLT, Probabilistic approach, etc. work well in such a case. However, these techniques may not prevent the unnecessary propagation of query packets when flooding of query packets is required. In that case, one way is to use any special device like NOVSTAR GPS to carry out the route discovery with minimum conveying nodes. For instance DREAM and LAR, where query packets are broadcasted following request zone based on location information. However the problem with these techniques is weak signal and less signal accuracy of GPS devices due to atmospheric effects. In order to control the energy consumption due to unnecessary propagation of query packets, query packet broadcast must be bounded. This can be achieved by defining the TTL value of query packet to confine the region. In bounded broadcasting techniques, like TTL sequence based-ERS and its variance such as BERS, tBERS, route discovery converges slowly for short predefined TTL value. BERS+ sped up the route discovery by introducing added delay after maximum limit of TTL value, and sped up the route discovery. BERS+ was slow to cease the propagation of query packets. So, CMBERS+ sped up the broadcast termination by issuing control packets at route node. Moreover, scalability issue also has been resolved by dividing the network into distributed clusters. The advantage of these techniques over unbounded broadcasting techniques is that route discovery can be accomplished with controlled flooding when previous communication does not exist.

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