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A Survey on Energy Efficient Multicasting in Ad Hoc Networks

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Abstract— Design of a suitable routing protocol is difficult for mobile ad hoc networks due to its inherent dynamism and frequent topology change. Multicasting is even more complex because it requires transmission of an information to various destinations at approximately same time, if possible. Active research work in this field has resulted in a variety of proposals based on tree or mesh structures. This paper presents a state-of-the-art overview of multicast routing protocols for ad hoc networks. We believe that this survey will be a great source of information for researchers in ad hoc networks.
Keywords— Ad hoc networks, Energy efficiency, Multicasting, Mesh, Tree.

I. INTRODUCTION

A mobile ad hoc network lacks a fixed infrastructure and has a dynamically changing topology. The nodes move freely and independently of one another. Ad hoc networks are heavily used in emergency situations where no infrastructure is available, for eg. battlefields, disaster mitigation etc. Design of multicast routing protocol is difficult due to the inherent uncertainty and unpredictable dynamism. Several multicast protocols have been proposed for mobile ad hoc networks. Based on the network structure along which multicast packets are delivered to multiple receivers, multicast protocols can be broadly categorized into two types, namely tree-based multicast and mesh based multicast. The tree structure is known for its efficiency in utilizing the network resource optimally, while tree based protocols are generally more efficient in terms of data transmission. Mesh based protocols are more robust against topology changes due to availability of many redundant paths between mobile nodes and result in high packet delivery ratio. On the other hand, multicast mesh does not perform well in terms of energy efficiency because mesh-based protocols depend on broadcast flooding within the mesh and therefore, involving many more forwarding nodes than multicast trees. In summary, the broadcast forwarding in mesh based protocols produces redundant links, which improves the packet delivery ratio but spends more energy than the tree-based multicast. The tree approach has some other drawbacks. The paths are non-optimal and traffic is concentrated on the tree, rather than being evenly distributed across the network. They are not robust to mobility as there is no back up path between a source and a destination, besides that, all tree based protocols need a group leader (or a core or a rendezvous point) to maintain group information and to create multicast trees [28].

A multicast packet is delivered to all the receivers belong to a group along a network structure such as tree or mesh, which is constructed once a multicast group is formed [6, 19]. However, due to node mobility the network structure is fragile and thus, the multicast packet may not be delivered to some members. To compensate this problem and to improve the packet delivery ratio, multicast protocols for ad hoc networks usually employ control packets to periodically refresh the network structure.

Ring-structured overlay networks are also used in some multicast protocols. Rings have certain qualities that make them suitable to use as overlays in dynamic networks. Rings are graphs with a connectivity of two, meaning that if one node goes down, the graph will still remain connected. This increases reliability of the communication [8, 10].

Energy efficiency is an alarming issue in ad hoc networks since nodes are equipped with limited battery power. As time progresses, the newly introduced node stars taking part in communication sessions to forward packets. Energy efficient multicast routing protocols are discussed in detail in section III where conventional multicast protocols appear in section II.

II. POPULAR CONVENTIONAL MULTICAST PROTOCOLS

A. *Ad Hoc Multicast Routing (AMRoute)*

AMRoute [1] is a tree-based multicast protocol that relies on the underlying unicast routing protocol. Among multicast members who are physically very close to one another, proactive bi-directional tunnels are continuously created. These tunnels may form a mesh for each such group. A multicast tree is created from multicast source to that core node in each multicast group. Responsibility of group member management is on shoulder of the core.

New group members select themselves as core and start broadcasting JOIN-REQ message using expanding ring search to find other group members. As soon as a node nj receives JOIN-REQ from n_i, then n_j will join the group of n_i provided j<i. A new bi-directional tunnel is established as n_j replies with JOIN-ACK. To build a shared tree, each core periodically transmits TREE-CREATE message, to mesh neighbours along unicast channels. The period depends on size of the mesh and node mobility. Group members detect core failure if no TREE-CREATE message is received from current core within a pre-specified interval.

Robustness in AMRoute comes from virtual mesh links and a core failure does not prevent data flow. Major disadvantage of the protocol is that it suffers from temporary loops and creates non-optimal tree under high mobility [9].

B. *On-demand Multicast Routing Protocol (ODMRP)*

Please consider fig 1, where n_s is the multicast source and n_{R1}, n_{R2}, n_{R3}, n_{R4} and n_{R5} are multicast receivers. Initially n_s floods JOIN-REQ in the entire network. This directly reaches n_a, receiving which it stores corresponding multicast session id, sender id and it's immediate predecessor in the path, in a table. Then n_a rebroadcasts it, which is received by both n_b and n_c. n_{R1} receives that from n_b. Since n_{R1} is a multicast receiver, it does not rebroadcast JOIN-REQ but instead sends a JOIN-REPLY to its immediate predecessor mentioning multicast session id, next node id and sender id.

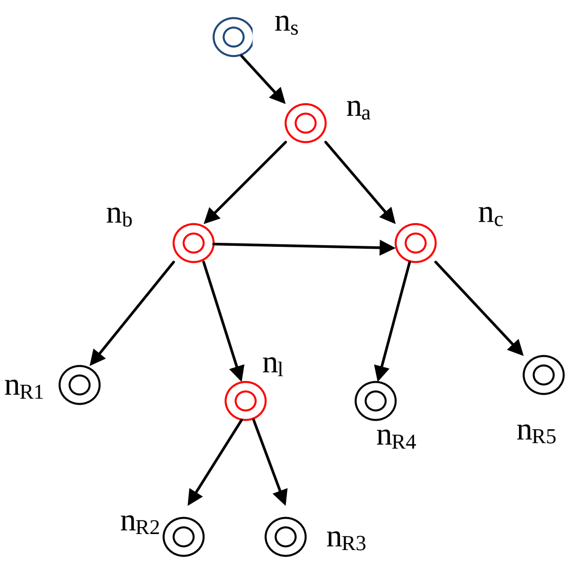

Fig 1: JOIN-REQ propagation in multicast routing

As soon as JOIN-REPLY of n_{R1} arrives at n_b, n_b checks whether next node id in the JOIN-REPLY matches with it's own id, along with match in sender-id and session-id. If these information match, then n_b forwards JOIN-REPLY of n_{R1} to n_a and from n_a it reaches n_s. Similarly, from n_{R2} and n_{R3}, JOIN-REPLY reaches n_s through n_b and n_a, and so on. In this way, forwarding groups are formed. In fig 2, members of the forwarding group are n_a, n_b, n_c and n_l. After establishing a forward group, n_s starts sending multicast packets to receivers through forwarding group members. Redundant routes may always exist in ODMRP [2]; so the protocol actually works on a mesh structure. This increases reliability at the cost of some extra control overhead. As far as route-refresh intervals are concerned, if it is small, then fresh route information and membership information are obtained at regular intervals and flow of a huge number of control packets will cause network congestion. On the other hand, if it is large, then definitely congestion won't be a real problem, but at the same time, up to date information about network nodes will not be known.

R-ODMRP is a ODMRP based wireless multicast protocol that offers more reliable forwarding paths in presence of both node and network failures. A subset of the nodes that are not on forwarding paths rebroadcasts received packets to nodes in their neighborhoods to overcome perceived node failures. This rebroadcasting creates redundant forwarding paths to circumvent failed areas in the network. Each node makes this forwarding decision probabilistically. It produces better delivery ratio than ODMRP with minimal overheads while retaining the original strengths of ODMRP.

E-ODMRP, on the other hand, is an enhanced version of ODMRP with adaptive refresh. Adaptation is driven by receiver's reports on link breakages rather than mobility prediction. The adaptive refreshing mechanism is seamlessly integrated with a simple and unified local recovery and receiver joining scheme. As the time between refresh episodes can be quite long, a new node or a momentarily detached node might lose some data while waiting for the route to be refreshed and reconstructed. Upon joining or upon detection of a broken route, a node performs local route recovery procedure instead of flooding, to proactively attach itself to a forwarding mesh or to request a global route refresh from the source. Compared to ODMRP, a slightly lower packet delivery ratio is expected in E-ODMRP in light load since E-ODMRP uses packet loss as an indicator of the broken link. The major advantage is reduced overhead (up to 90%) which translates into a better delivery ratio at high loads [23].

C. Multicast Ad Hoc On-demand Distance Vector Routing(MAODV)

As in AODV, route-request (RREQ) packets are injected into the network by

- A node that wishes to join a multicast group as member
- A node that wishes to send packets to a group but doesn't have a route to it.

As soon as a RREQ packet arrives at a multicast member, it replies with a route-reply (RREP) packet back to the generator of RREQ. Identifier of immediate predecessor is stored in routing table of each node. This creates a forward path. Please note that whenever a source node tries to discover route to a multicast group, multiple RREPs are received. Among these routes, the RREP with highest sequence arriving from the nearest multicast member with minimum hop count is elected.

In MAODV [3], each multicast group has a group leader. A group leader periodically broadcasts "Group Hello" messages through the entire network. The "Group Hello" messages contain IP addresses and corresponding group sequence numbers of the multicast groups of which the sender is the group leader. Nodes update their request table after they received the "Group Hello" messages. Members update their distance to the group leader according to the "Group Hello" messages. MAODV uses a straightforward group leader election method: the first member of a multicast group becomes the leader. This node remains acting as the group leader until it decides to leave the group or a partitioned multicast group merges.

Links in the multicast tree are monitored to detect link breakages, and the downstream node of the break link takes the responsibility for tree maintenance. If the tree cannot be repaired, a new leader for the disconnected downstream nodes is chosen. If a group member initiates the route rebuilding, it becomes the new multicast group leader of the disconnected part. On the other hand, if the initiating node is not a group member and has only one next hop for the tree, it sends its next hop a prune message and leaves the tree. This operation continues until a group member is reached [21].

When a group member receives a "Group Hello" message for the multicast group and finds that the group leader information contained in the message is different from what it already has, it compares the group leader's IP addresses. If it is a member of the partition whose group leader has the lower IP address, it initiates reconnection of the multicast tree [7, 25].

D. Independent Tree Ad Hoc Multicast Routing (ITAMAR)

ITAMAR [4] aims at discovering multiple backup multicast trees with minimum number of overlapping nodes i.e. the trees should not have many nodes in common. In case of breakage of a link in a tree, another tree can be used to deliver multicast packets from source to multicast group members. This reduces number of route discovery cycles (i.e. mean time between two consecutive route discovery sessions, increase). Cost of communication is well-defined.and ITAMAR focuses on achieving a low transmission cost. Since a tree consists of multiple links, cost of a tree is summation of cost of its entire links. Similarly, cost of a set of trees is sum of cost of all its component trees. For a multicast group size, average cost is weighted average of cost of all its trees weighted by average number of time each tree is being used. Probability of usefulness of one particular tree is fraction of total number of trails for which failure time of the system is greater than failure time of a set of trees. A set of trees is selected for multimedia communication provided it is highly useful.

III.ENERGY EFFICIENCY IN MULTICAST ROUTING

A. Energy Efficient Clustering Technique (EECT)

EECT [5] is an energy efficient clustering technique where energy efficient clusters are formed based on transmission power, residual energy and relative velocity. A node joins a cluster provided it's line with the cluster head, be it single hop on multi-hop, is stable in terms of relative velocity, (i.e. consecutive nodes in the path do not have high relative mobility) and energy (i.e. all nodes in the path are equipped with sufficient residual battery power). Cluster head adjusts transmission power level depending upon its distance from the cluster member with which it wants to communicate. For example, let a cluster head n_i needs to send a data packet to a cluster member n_j at time t. Maximum transmission power of n_i is $P_{max}(i)$; R_i denotes the radio-range of n_i , whereas $distance_{ij}(t)$ is the distance between n_i and n_j at time t. Then, required transmission power $TP_i(j,t)$ of n_i to communicate with n_j at time t, is mathematically expressed below:-

$$TP_i(j,t) = \frac{P_{max}(i) \text{ x } distance_{ij}(t)}{R_i} \tag{1}$$

within each energy efficient cluster, for tree-based multicasting MAODV is implemented whereas for mesh-based strategy, ODMRP is implemented. EECT [5] claims that MAODV and ODMRP gives much better performance in terms of overall energy consumption, mean end-to-end delay, mean hop count, packet delivery ratio and percentage of alive nodes for various multicast group size and node mobility.

B. Scalable Energy Efficient Location Aware Multicast Protocol (SEELAMP)

SEELAMP [26] divides entire network into certain small-overlapped zones. One node (Pivot) within that zone keeps track of location of all other nodes in the zone. The Pivot maintains stable connectivity with energy other node in the zone. Instead of a mesh, shared bi-directional multicast trees are created. This helps to greatly reduce message cost in the network. Smaller message cost yields little signal collision, improving packet delivery ratio in the network. Although, mesh-based protocols provide more reliability, tree-based ones can overrun them provided its lines are stable. This effectively reduces overhead of route searching and shared tree maintenance.

C. An Optimized and Energy Efficient Multicast Routing based on genetic algorithm

The present algorithm [11] aims at finding nodes with minimum energy consumption and including them in multicast routes to inculcate energy efficiency in operations. But this may yield abrupt extra load on certain nodes that start to exhaust specially and eventually die creating partitions in the network. Partitions will reduce packet delivery ratio and generate link breakages. In order to repair those broken links, so many route-request packets will be injected into the network greatly increasing packet processing delay, and control packet overhead. This algorithm adopts a strategy for balancing energy consumption in the multicast tree. An energy efficient genetic algorithm is proposed that improves mating mechanism and introduces energy efficient mutation to repair broken links. In between a communication sessions the scheme always tries to replace low energy nodes with a higher one.

D. Stable Energy-efficient Position-Based Multicast Routing (SE^2PBM)

In SE^2PBM [12], a stable multicast tree is created for communication. Stability of links is measured as a function of transmission power and relative mobility of nodes. Transmission power control is applied for each router (and sender) in each communication session as per (1). This definitely improved energy efficiency in the network. Stability in terms of relative mobility is extremely important from the perspective of random movement characteristics of ad hoc networks. A mixed integer programming model is proposed that is sourced initiated and based on distributed position based heuristics.

E. Energy Efficient Delay Time Routing Algorithm (EEDTR)

EEDTR [13] is a modified version of Dynamic Source Routing (DSR) that selects fully distributed routes to different multicast destinations. This helps to manage energy consumption in links. EEDTR incorporates a delay in routers during forwarding of packets. This delay is inversely proportional to residual energy of nodes. Therefore, if a route has a large number low-energy nodes or exhausted nodes, packets travelling through the route will face high delay. By characteristic, DSR always selects the route with smallest delay. Hence, routes with low energy nodes will be eliminated.

F. Maximized Energy Efficient Routing (MEER)

In MEER [13], as the route-request packets injected by source, travel through various routers in the network, energy information in those routers gets embedded in the route-request. For example, consider the following figure.

Initial Route – Request:

t_s	n_s	n_d	$l_s(x)$	$l_s(y)$	res_eng_s

t_s → current time stamp
n_s → source
n_d → destination
$l_s(x)$, $l_s(y)$ → location of the source in terms of latitude and longitude
res_eng_s → residual energy of source n_s

After the route-request arrives at a router n_i and gets forwarded by it, the new route-request becomes

t_s	n_s	n_d	n_i	$l_s(x)$	$l_s(y)$	res_eng_s	res_eng_i

fig 2: Residual energy embedded in route-request

After the route-request arrives at destination, residual energy of all nodes is embedded in it. Based on this information, destination node computes minimum of residual energies of all the nodes. The route with maximum of these minimum residual energies is elected. The algorithm increases lifetime of nodes at the extra control overhead of increased size of route-request packets. Maximum possible extra control overhead per route-request packet is Hf where H is maximum allowed number of hopes and f is number of bits required to express maximum initial battery power of any node in the network. Total number RR of route-request packets, is given by (2).

$$RR = \Psi + \Psi^2 + \Psi^3 + \text{-----------} + \Psi^H \quad (2)$$
$$= \frac{\Psi^{H+1} - 1}{\Psi - 1} \quad (3)$$

Hence, maximum possible extra control overhead per communication session in MEER, is denoted by MCO and defined in (4).

$$MCO = Hf \times RR \quad (4)$$

G. Distributed Algorithm for building energy-efficient Group-shared Multicast Tree

In mobile ad hoc networks, group based multicasting has wide applications due to low storage of status messages in nodes. Shared trees have become popular due to less control overhead. It mainly focuses on reducing energy consumption and extending network lifetime. In [14], an algorithm B-ReMit is proposed that introduces a metric named TEC or Total Energy Consumption. The tree with minimum TEC is used for multicast consumption.

H. Energy-efficient Real-Time Multicast Routing (MC - TRACE)

This algorithm MC-TRACE [15] particularly focuses on real time multicasting. It applies a cross-layer design where medium access control layer functionality and network layer functionality are performed by a single integrated layer. Multicast routing is performed by an active multicast tree surrounded by a passive mesh. Although in conventional multicast routing we implement either a tree-based on mesh-based approach. MC–TRACE integrates both of these in all energy efficient fashion. Re-engineering of both tree and mesh make the network robust, so that it becomes suitable for energy efficient multicasting. Nodes are allowed to sleep at suitable time when their uplink neighbors have an alternative path to their downlink neighbors avoiding the sleepy node. Also redundant data receptions are eliminated.

I. Signal and Energy Efficient Clustering (SEEC)

SEEC [16] applies two fold techniques for energy efficiency the first one is transmission energy adjustment as per (1) and the second one is energy efficient clustering. Whenever residual energy of a cluster head falls below the threshold level, a new cluster head with high residual energy and required connectivity is elected. Required connectivity implies connectivity with most of the cluster members, if not all.

J. Two Three Multicast (TTM)

TTM [17] uses two trees – primary and alternative back up tree. It consumes less energy than mesh because TTM applies multiple unicast communication paths to each of the destinations. When the primary tree is running short of energy or facing link breakages, the alternative tree is used for communication, instead of repairing link breakages. This greatly reduces cost of route-request packets that would have been injected otherwise in the network. Increased control packet overhead will impose additional forwarding workload on routers increasing their energy consumption, signal collision and collision in the network. Therefore, TTM produces better network life span and packet delivery ratio. As for as energy per delivered packet is concerned, TTM shows up to 80% and 40% performance improvement compared to mesh based multicast and conventional shared tree multicast, respectively.

K. S-ReMit: A distributed Algorithm for Source-based Energy Efficient Multicasting

Energy consumption model in S-ReMit [18] takes into consideration the following two things:-
i) Energy consumption due to radio-propagation
ii) Energy consumption at transceiver

This enables S-ReMit to adapt a given multicast tree irrespective of whether they use long-range or short-range radios.

L. Node Selection Based on Energy Consumption (NEC)

Let, for a given communication session, n_s and n_d be the source and destination nodes. Their distance at current time stamp t, is given by, $distance_{sd}(t)$. Let rad-rng denote the average radio-range in the network. Hence, number of intermediate nodes $INT_{sd}(t)$ for communication from n_s to n_d at time t, is given by (5).

$$INT_{sd}(t) = \frac{distance_{sd}(t)}{rad\text{-}rng} - 1 \quad (5)$$

Let, average processing time per packet in each router in the region of source and destination, is given by w.
So, each router must remain alive (or operational) for the time T_{sd} defined in (6).

$$T_{sd} = w \times INT_{sd}(t) \times Pkts \quad (6)$$

where Pkts is the number of packets to be transferred from n_s. According to study of discharge curve of batteries heavily used in ad hoc networks, at least 40% of initial battery power is required for a node to remain in operable condition. So, for a router n_i, if E_i is assumed to be the initial battery power, after time duration T_{sd}, n_i must be equipped at least $(0.4 \times E_i)$ unit of battery power. Assuming com-eng(i) denote rate of energy consumption at n_i at that time, required condition for n_i to survive is expressed in (7), n_i started its journey in the network at time t1 (t1<t).

$$E_i - com\text{-}eng(i) \times (t - t1) - (com\text{-}eng(i) + 1/w)T_{sd} \geq 0.4 \times E_i \quad (7)$$

M. Power-aware Routing Protocol (PAR)

PAR [22] assigns high priority to routes that are less congested [i.e. produces less delay] and more stable. It considers particularly the following factors:-

- accumulated energy of a path
- status of battery lifetime
- kind of data to be transferred

with these factors in consideration, PAR can provide different routes for different type of data transfer and ultimately increase network lifetime [20, 24].

N. Power-aware Multicast Reactive Routing Protocol (PAMRRP)

PAMRRP [25] applies following techniques to ensure energy efficiency:-

i) Cautious distribution of forwarding load – Greater forwarding load is applied to links of a tree with high residual energy.
ii) Reduction in control overhead – Relieving low energy edges of a tree from high forwarding load enables construction of comparatively stable trees that won't fall much link breakages. Therefore, number of route-request packets injected into the network to repair broken links is also small. Moreover, low energy nodes are generally not included in the trees.
iii) Proactive tree maintenance – Even after steps (i) and (ii), if a node n_i finds that it's battery power will soon be exhausted, it sends a special alarm message to its predecessor in the tree, to start discovering alternative nodes to each of its successors, n_i may still be used for crucial data.

O. Fuzzy Controlled Power Aware Multicast Routing (FPMR)

In FPMR [27], two fuzzy controllers EINS (Eligible Intermediate Node Selector) and RPE (Route Performance Evaluator) are embedded in each node to incorporate intelligence in them. Inclusion of a router n_i in a multicast tree depends upon the following factors:-

- If n_i is equipped with sufficient residual battery power so that it can remain alive till the end of current multicast session, (taking care of additional forwarding load imposed by current multicast operation), then it has high chance to be included in the multicast tree, EINS examines this.
- n_i may be included in a multicast tree as child of a node n_j. Provided relative velocity of n_i, w.r.t n_j is small. This will enhance stability of the link $n_j \rightarrow n_i$
- If n_i has already established stable routes to one or more multicast member M_1, M_2, ….., M_V, then including n_i is a multicast tree will be beneficial, because routes from n_i to those multicast members M_1, M_2, ….., M_V won't need to be discovered, it is already available.

RPE evaluates performance of a multicast route depending upon its hop count number of eligible intermediate nodes and number of multicast group members present in it as routers. For energy efficiency purpose, routes with a short hop count, high percentage of eligible intermediate nodes and low group member cum routers, are preferred.

IV. CONCLUSIONS

The Present article focuses on presenting a number of energy efficient multicast protocols. It is very difficult to compare all these protocols directly with each other because they have their own goals and assumptions; own advantages and disadvantages. One particular multicast protocol can hardly satisfy all the requirements. Each protocol is designed to provide maximum possible requirements under different scenarios. Energy efficient communication is crucial in respect of ad hoc networks because each node is battery powered and has limited capacity. Increased lifetime of nodes provide support for almost interrupt-less service where reliable communication can go on through optimal paths.

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