Energy Conservation for Broadcast and Multicast Routings in Wireless Ad Hoc Networks

Jang-Ping Sheu[1], Yuh-Shyan Chen[2], Chih-Yung Chang[3]

[1] Departmemt of Computer Science and Information Engineering
National Central University, Chung-li, Taiwan, R.O.C.
Email: sheujp@csie.ncu.edu.tw

[2] Department of Computer Science and Information Engineering
National Chung Cheng University, Chiayi, Taiwan, R.O.C.
Email: yschen@cs.ccu.edu.tw

[3] Departmemt of Computer Science and Information Engineering
Tamkang University, Taipei, Taiwan, R.O.C.
Email: cychang@mail.tku.edu.tw

Abstract

This Chapter introduces existing important energy conservation schemes developed for broadcast and multicast routings in mobile ad hoc networks (MANETs). Broadcast and multicast are essential and important operations for a node to construct routing paths to all other nodes or a group of nodes in MANET. To alleviate the phenomenon of transmission collision, message storm, and battery exhaustion, some high-performance energy conservation schemes for broadcast and multicast routings are developed in MANETs. Energy-efficient protocols reviewed in this Chapter are organized in two parts, the broadcast and multicast protocols. First, a number of existing energy-efficient broadcast protocols are introduced, which are classified according to the aspects of *tree-based* and *probability-based* approaches. Second, some existing energy-efficient multicast protocols are then introduced, which are classified according to the aspects of *tree-based* and *cluster-based* approaches. Finally, we make a conclusion and give some possible future works.

Keywords: Broadcast, energy conservation, MANET, multicast.

1. Introduction

Wireless ad hoc networks have received significant attention in recent years due to their potential applications in battlefield, disaster relief operations, festival field grounds, and historic sites. A wireless ad hoc network consists of mobile hosts dynamically forming a temporary network without the use of existing network infrastructure. In such a network, each mobile host serves as a router. One important issue in ad hoc network routing is the energy consumption. In MANETs, mobile hosts are powered by batteries and unable to recharge or replace batteries during a mission. Therefore, the limited battery lifetime imposes a constraint on the network performance. To maximize the network lifetime, the traffic should be routed in such a way that the energy consumption is minimized.

Broadcast and multicast are important operations for mobile hosts to construct a routing path in MANET. Broadcast is a communication function that a node, called the source, sends messages to all the other nodes in the networks. Broadcast is an important function in applications of ad hoc networks, such as in cooperative operations, group discussions, and route discovery. Broadcast routing is usually constructing a broadcast tree, which is rooted from the source and contains all the nodes in the network. In addition to broadcasting, multicasting is also an important function in applications including distributed game, replicated file systems, and teleconferencing. Multicast in MANET is defined by delivering multicast packets from single source node to all member nodes in a multi-hop communication manner. The energy cost of all the nodes that transmit the broadcast or multicast message in MANET should be minimized.

To overcome the problems of transmission collision, message storm, and battery exhaustion, several energy conservation schemes for broadcast and multicast routings are proposed in literature [1-23]. This Chapter consists of two parts. First part introduces novel energy conservation schemes for broadcast routing in MANETs, and the second part investigates existing energy conservation schemes for multicast routing in MANETs.

In the first part, existing energy-efficient broadcast protocols can be classified into tree-based and probability-based approaches. The tree-based broadcast protocol is to construct the *minimum-energy broadcast tree* [1-9], which is a broadcast tree with minimum-energy consumption. To establish the minimum-energy broadcast tree, centralized algorithms [1-3] and distributed algorithms [8-9] are investigated in wireless ad hoc networks. For centralized algorithms, we review centralized BIP protocol [1] and EWMA protocol [3]. For distributed algorithms, we describe DISP-BIP protocol [8] and RBOP protocol [9]. In addition, integer-programming technique can be used to establish the minimum-energy broadcast tree in [4]. Finally, the *approximation ratio* of existing minimum-energy broadcast protocols is calculated in [5-7]. By considering the probability-based approach, the energy conservation for broadcast routing can be achieved by alleviating the "broadcast storm problem" with high-performance probabilistic scheme [10-12]. A power-balance broadcast approach is then investigated in [13] to extend the network lifetime by using the probabilistic scheme to determine whether the host needs to rebroadcast or not.

In the second part, some existing power-efficient multicast protocols designed for MANET are investigated. According to the topology constructed in the protocols, existing power efficient multicast protocols can be classified into tree-based and cluster-based protocols. In the tree-based multicast protocols, an energy-efficient broadcast tree is firstly constructed. By considering power consumption of nodes in the tree, these protocols propose tree refining and/or pruning rules to construct a power-efficient multicast tree. According to the number of source nodes in the tree, the tree-based multicast protocols are further partitioned into two subsets, the single-source and multi-source multicast protocols. In the subset of single-source multicast protocols, power efficient multicast protocols MIP [2], S-REMiT [14], and RBIP [19] are reviewed. The MIP and S-REMiT protocols apply refining and pruning rules on existing broadcast tree to construct a power-efficient multicast tree. Some applications require the multicast to be reliable. The RBIP considers the reliable multicast and takes into consideration the retransmission cost in energy consumption. Another multicast protocol, G-REMiT [15] is also reviewed in tree-based multicast category. Different from the protocols mentioned above, G-REMiT [15] protocol is mainly designed for multi-source energy efficient multicast tree. In addition to the tree-based multicast protocols, subsection 3.2 reviews Cluster-Based Multicast Protocol (CBMP) [16] that applies the existing ODMRP [17] protocol on cluster topology to achieve the purpose of energy efficient multicast communication.

The rest of this Chapter is organized as follows. Section 2 reviews energy-efficient broadcast protocols in MANETs. Section 3 introduces energy-efficient multicast protocols in MANETs. Section 4 concludes this Chapter and gives some possible future works.

2. Energy-Efficient Broadcast Protocols in MANETs

This section describes existing valuable energy-efficient broadcasting protocols in MANETs. These energy-efficient broadcast protocols are categories according to the aspects of *tree-based* and *probability-based* approaches. The detail operations of these energy-efficient broadcast protocols are described as follows.

2.1 Tree-Based Approach

The *minimum-energy broadcast tree* is formally defined in [3] as follows. Given the source node *r*, a set consisting of pairs of relaying nodes and their respective transmission levels is constructed such that all nodes in the network receive a message sent by *r*, and the total energy expenditure for this task is minimized. The objective of energy-efficient broadcasting protocols herein is to construct the *minimum-energy broadcast tree*. In the following, sections 2.1.1 describes centralized algorithms to establish the minimum-energy broadcast tree. Section 2.1.2 expresses distributed algorithms of constructing the minimum-energy broadcast tree. Section 2.1.3 investigates the establishment of minimum-energy broadcast tree by using the integer programming technique. Finally, section 2.1.4 calculates the approximation ratio of existing minimum-energy broadcast protocols.

2.1.1 Centralized Algorithm

To build a spanning tree with the minimum energy consumption, one nature way is to construct a *Minimum Spanning Tree* (MST) [1, 2, 3]. A centralized algorithm, called as centralized BIP (*Broadcast Incremental Power*) algorithm, is developed in [1] to construct a *minimum-energy broadcast tree* in MANETs. An improved centralized algorithm, named EWMA (Embedded Wireless Multicast Advantage), is proposed in [3] to construct a minimum-energy broadcast tree with less power consumption.

A. Centralized BIP (Broadcast Incremental Power Algorithm) [1]**:** A centralized algorithm, called BIP (*Broadcast Incremental Power*) algorithm, is developed to build an energy-efficient broadcast tree in a MANET. BIP algorithm exploits the broadcast nature of the wireless communication environment, and addresses the need for energy-efficient operation. The main objective of BIP is to construct a minimum-energy broadcast tree. The BIP algorithm is based on the Prim's algorithm [2], which is an algorithm to search for minimum spanning trees (MST). The wireless communication model is defined as follows. First, omni-directional antennas are used, such that every transmission by a node can be received by all nodes that lie within its communication range. Second, the connectivity of the network depends on the transmission power; each node can choose its power level, not to exceed some maximum value $P_{\max}$. BIP assumed that the received signal power varies as $r^{-\alpha}$, where r is the range and α is a parameter that typically takes on a value between 2 and 4. Without loss of generality, P_{ij} = power needed for link between nodes *i* and *j* = r^{α}, where *r* is the distance between nodes *i* and *j*.

BIP algorithm and following protocols adopts the use of omni-directional antennas; thus all nodes within communication range of a transmitting node can receive its transmission. Consider the example shown in Fig. 1, in which a subset of the multicast tree involves node *i*, which is transmitting to its neighbors, node *j* and node *k*. The power required to reach node *j* is P_{ij} and the power required to reach node *k* is P_{ik}. A single transmission at power $P_{i,(j,k)} = \max\{P_{ij}, P_{ik}\}$ is sufficient to reach both node j and node k, based on the assumption of omni-directional antennas. The ability to exploit this property of wireless communication, which is called as the "*wireless multicast advantage*", it makes multicasting an excellent setting in which to study the potential benefits of energy-efficient protocols.

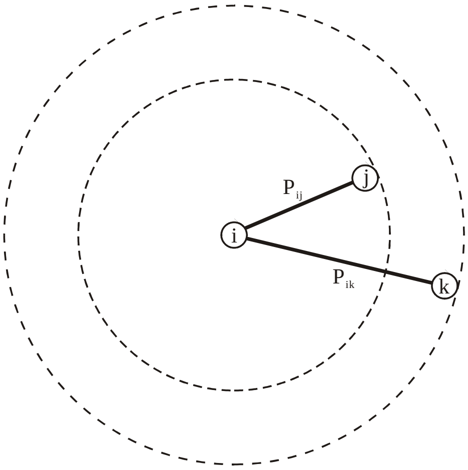

Fig. 1: The "wireless multicast advantage": $P_{i,(j,k)} = \max\{P_{ij}, P_{ik}\}$

The basic operation of BIP by offering a simple example of construction of the broadcast tree, rooted at a source node, is described as follows.

1) Fig. 2 shows a wireless network with ten nodes, in which node 10 is the source node. A propagation constant of α =2 is assumed. At the first, the tree only consists of the source node. Then BIP begins by determining which node should be selected so that source node can reach with minimum incremental power. The source node's nearest neighbor, which is node 9, should be added to the tree. The notation 10 $\rightarrow$ 9 means that adding the transmission from node 10 to node 9.

2) BIP then determines which "new" node can be added to the tree at *minimum additional* cost. There are two alternatives. Either node 10 can increase its power to reach a second node, or node 9 can transmit to its nearest neighbor that is not already in the tree. In this example, node 10 increases its power level to reach node 6. Note that the cost associated with the addition of node 6 to the tree is the incremental cost associated with increasing node 10's power level sufficient to reach node 6. The cost of a transmission between nodes 10 and 9 is $r_{10,9}^{\alpha}$, and the cost of a transmission between nodes 10 and 6 is $r_{10,6}^{\alpha}$. The incremental cost associated with adding node 6 to the tree is $r_{10,6}^{\alpha} - r_{10,9}^{\alpha}$. BIP exploits the broadcast advantage because when node 10 with sufficient power to reach node 6, the node 10 also can reach to node 9.

3) There are now three nodes in the tree, namely nodes 6, 9, and 10. For each of these nodes, BIP determines the incremental cost to reach a new node; that is 6 → 7, as shown in Fig. 2.

4) This procedure is repeatedly performed until all nodes are included in the tree. The order in which the nodes were added is: 6 → 8, 6 → 5, 9 → 1, 9 → 3, 9 → 4, 9 → 2.

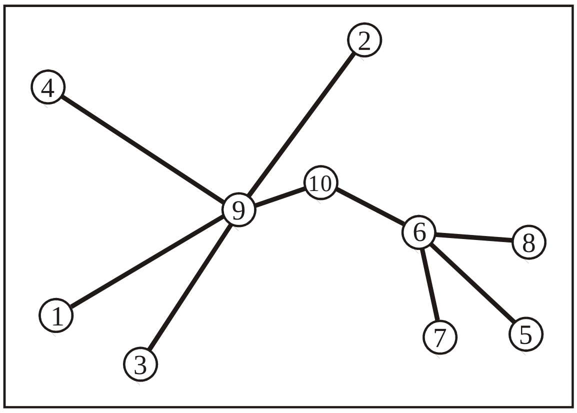

Fig. 2: Broadcast tree using BIP

B. EWMA (Embedded Wireless Multicast Advantage) [3]: The EWMA protocol includes two steps.

1) A minimum spanning tree (MST) for broadcasting tree is initially established as shown in Fig. 3, where node 10 is the *source* node and nodes 9, 1, 6, and 8 are *forwarding* nodes. The power consumptions of nodes 10, 9, 1, 6, and 8 are 2, 8, 4, 5, and 4, respectively. The total energy consumption of the MST is 23

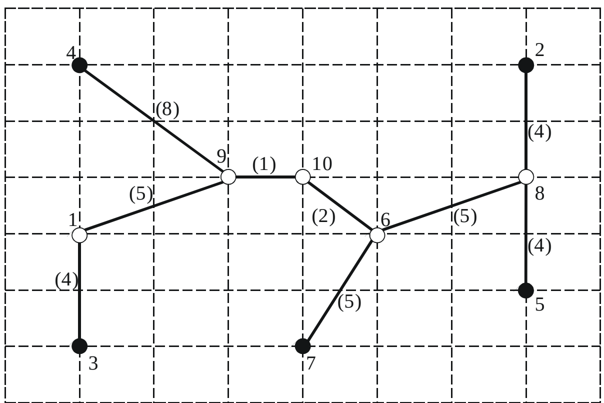

Fig. 3: A MST broadcasting tree

2) EWMA calculates the necessary power for every node from the constructed MST in step **1)**. A node is said to be an *exclude node* if the node is a transmitting node in MST but is not transmitting node in the final EWMA broadcasting tree. The key idea of EWMA is to search for exclude nodes by increasing less power consumption for the exclude node to cover more forwarding nodes. For example, the resultant broadcast tree produced by EWMA is shown in Fig. 4. After increasing power consumption of node 10 (from 2 to 13), then original forwarding nodes 9, 6, and 8 in MST, can be excluded in the EWMA broadcast tree. Therefore, only nodes 10 and 1 are used in the EWMA broadcast tree. The total energy consumption of EWMA broadcast tree is 13 + 4 = 17. This result is illustrated in Fig. 4.

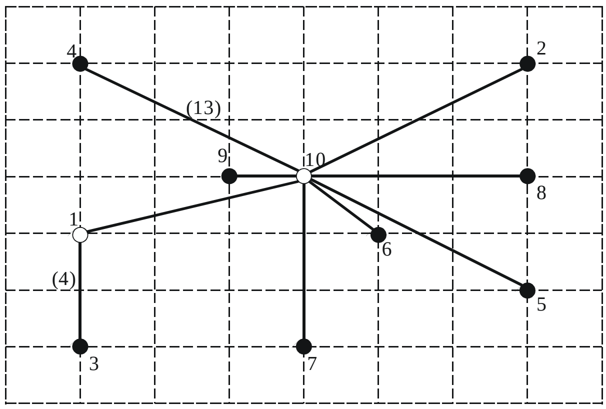

Fig. 4: The EWMA broadcast tree

C. Integer Programming Technique [4]:

It is interested that three different integer programming models which are used for an optimal solution of the minimum power broadcast problem [4]. The main idea is to use the *power matrix* P, where the (i, j)-th element of the power matrix P defines the power required for node i to transmit to node j. For instance as shown in Fig. 5, the power matrix P is $\begin{bmatrix} 0 & 8.4645 & 12.5538 & 13.6351 \\ 8.4645 & 0 & 0.5470 & 3.8732 \\ 12.5538 & 0.5470 & 0 & 5.7910 \\ 13.6351 & 3.8732 & 5.7910 & 0 \end{bmatrix}$. In addition, a *reward matrix* R is defined by $R_{mn}(p) = \begin{cases} 1, & \text{if } P_{mp} \le P_{mn} \\ 0, & \text{otherwise} \end{cases}$. An example shown in Fig. 5 explains the meaning of the reward matrix. A binary encodings is produced of all the nodes covered (or not covered) by all possible transmissions in the network. For instance, the transmission $2 \rightarrow 1$ results in nodes 1, 3, and 4 being covered, therefore $R_{21} = [1 \;\; 0 \;\; 1 \;\; 1]$ is encoded in the (2, 1) cell of the reward matrix. Therefore, reward matrix

$$R = \begin{bmatrix} [\ 0\ 0\ 0\ 0\ ] & [\ 0\ 1\ 0\ 0\ ] & [\ 0\ 1\ 1\ 0\ ] & [\ 0\ 1\ 1\ 1\ ] \\ [\ 1\ 0\ 1\ 1\ ] & [\ 0\ 0\ 0\ 0\ ] & [\ 0\ 0\ 1\ 0\ ] & [\ 0\ 0\ 1\ 1\ ] \\ [\ 1\ 1\ 0\ 1\ ] & [\ 0\ 1\ 0\ 0\ ] & [\ 0\ 0\ 0\ 0\ ] & [\ 0\ 1\ 0\ 1\ ] \\ [\ 1\ 1\ 1\ 0\ ] & [\ 0\ 1\ 0\ 0\ ] & [\ 0\ 1\ 1\ 0\ ] & [\ 0\ 0\ 0\ 0\ ] \end{bmatrix}.$$

To utilize the information of calculated *power matrix* P and *reward matrix* R, the minimum power broadcast tree is constructed by using integer programming formulations [4].

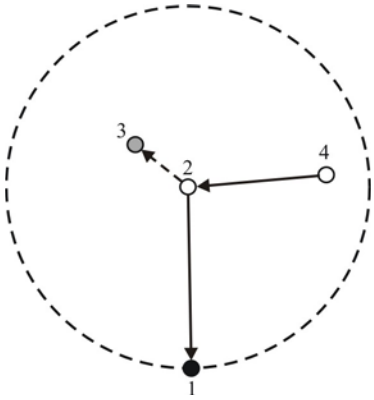

Fig. 5: Example of a MANET and node 4 is the source node.

D. Calculating Approximation Ratios on Static Ad Hoc Networks [5][6][7]:

A wireless ad hoc network is said as the *static* ad hoc wireless network [5][6][7] if the nodes in the ad hoc network are assumed to be a point set randomly distributed in a two-dimensional plane and there is no mobility. The minimum-energy broadcast routing in static ad hoc wireless networks are first considered in [5]. By exploring geometric structures of Euclidean MSTs, it is proven in [5] that the *approximation ratios* of MST and centralized BIP are between 6 and 12, and between $\frac{13}{3}$ and 12, respectively, where the approximation ratio means that the results obtained by their executions are how close to the optimal value. Furthermore, the approximation ratio of the MST-based heuristic for the energy-efficient broadcast problem in static ad-hoc networks is investigated in [6]. The main result in [6] shows that the approximation ratio is about 6.4. In addition, an energy-efficient broadcasting routing is developed in static ad hoc wireless networks [7]. This work proposed three heuristic algorithms, namely, shortest path tree heuristic, greedy heuristic, and node weighted Steiner tree-based heuristic, which are centralized algorithms. The approximation ratio of the node weighted Steiner tree-based heuristic is proven to be $(1+2\ln(n-1))$ [7].

2.1.2 Distributed Algorithm

A distributed version of BIP algorithm, named DIST-BIP, is then proposed in [8]. A localized minimum-energy broadcasting protocol is developed in [9] such that each node only requires the local information.

A. DIST-BIP (Distributed Broadcast Incremental Power) [8]: Two distributed BIP algorithms are proposed. One is Dist-BIP-A (Distributed-BIP-All), another one is Dist-BIP-G (Distributed-BIP-Gateway). In Dist-BIP-A algorithm, each node constructs its local BIP tree by using *centralized-BIP* algorithm [1] within one-hop transmission range. After constructing local BIP trees for every node, then each node hears and broadcasts messages from/to its neighbors to connect many local BIP trees to form a global BIP tree. For example, node *i* constructs a local BIP tree as shown in Fig. 6(a). A Dist-BIP-A tree is established as shown in Fig. 6(b) by connecting many local BIP trees, which are constructed by all neighboring nodes. The gateway nodes are jointed to hear and broadcast messages in the Dist-BIP-G protocol to form a Dist-BIP-G tree. An example for the Dist-BIP-G tree is illustrated in Fig. 6(c). Nodes *i*, *j*, and *k* are gateway nodes. The Dist-BIP-G tree is established by connecting local BIP trees, which are constructed by gateway nodes *i*, *j*, and *k*. In general, the message overhead of constructing a Dist-BIP-G tree is less than that of constructing a Dist-BIP-A tree. But the Dist-BIP-A tree is near to the centralized BIP tree.

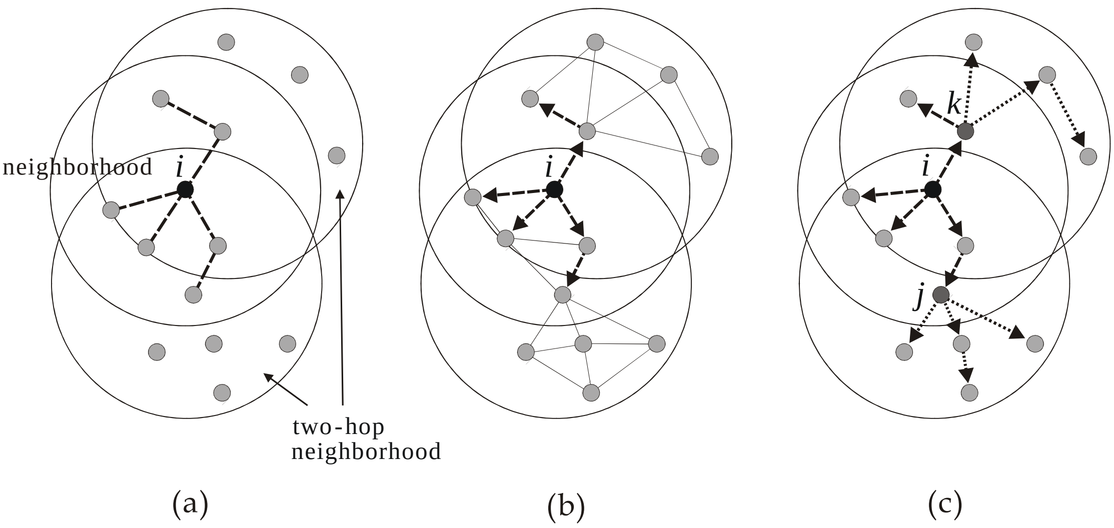

Fig. 6: (a) local BIP tree for node *i*, (b) Dist-BIP-A tree, and (c) Dist-BIP-G tree

B. RBOP (RNG Broadcast Oriented Protocol) [9]: A localized minimum-energy broadcasting protocol, named RNG Broadcast Oriented Protocol (RBOP), that utilizes the relative neighborhood graph (RNG), is developed in [9]. The protocol only requires the local information to design the minimum-energy broadcasting protocol. Unlike most existing minimum-energy broadcasting protocols that use the global network information, RBOP only maintains the local information, thus saves the communication overhead for obtaining global information.

To substitute minimum spanning tree (MST) in the protocol by utilizing the *relative neighborhood graph* (RNG), the wireless network is represented by a graph $G=(V,E)$, where V is the set of nodes and $E \subseteq V^2$ denotes the edge set which represents the available communications. Note that, (u,v) belongs to E means that u can send message to v, and *RNG* is a subgraph of *G*. An edge (u,v) belongs to the RNG if no node w exists in the intersection area for nodes *u* and *v*, as illustrated in Fig. 7. This topology control scheme is called the RNG Topology Control Protocol (RTCP), which is used to build the relative neighborhood graph (RNG).

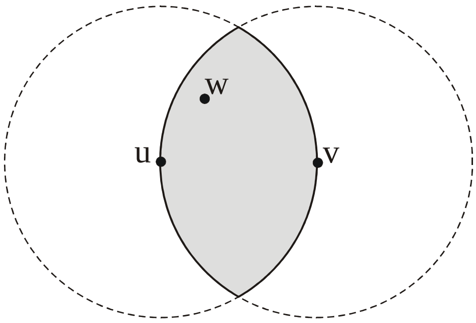

Fig. 7: The edge (u,v) does not belong to RNG since the existence of node *w*

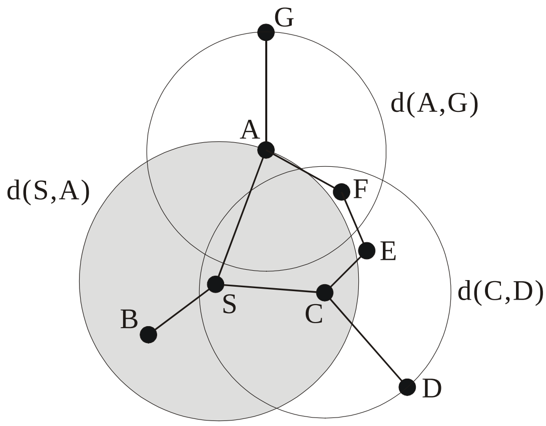

Fig. 8: Example of RNG Broadcast Oriented Protocol (RBOP)

The main idea of RBOP is when a node *u* receives a message from neighbor nodes, the node selects an edge (u,v) in RNG as far as possible to broadcast the message within radius *d*(*u*, *v*). For example as shown in Fig. 8, node *S* broadcasts message to *A*, *B and C* with radius *d*(*S*, *A*), since *d*(*S*, *A*) > *d*(*S*, *C*) > *d*(*S*, *B*), where (*S*, *A*), (*S*, *C*), and (*S*, *B*) are edges belonging to RNG. Then node *C* broadcasts with radius *d*(*C*, *D*). Finally, node *A* broadcasts with radius *d*(*A*, *G*). This method can reduce the total number of broadcast messages and efficiently transmit the broadcast messages. In the simulation results reported in [9], the centralized BIP protocol can save about 50% energy compared to RBOP protocol. But the communication overhead of centralized BIP is higher than the RBOP protocol.

2.2 Probability-based Approach

Probability-based approach also can be applied to determine whether or not a node should transmit the received packet during broadcasting. Some protocols [10-12] apply probability-based approach to resolve the broadcast storm problem, hence saving the power consumption for redundant transmission. A power-balance protocol proposed in [13] also adopts probability-based approach to balance the power consumption on each node, thus improving the network lifetime. This subsection introduces some probability-based protocols that help to improve the network lifetime.

In MANET, flooding is a basic requirement and is frequently used to broadcast a message over the MANET. However, blind flooding will cause the broadcast storm problem [10], resulting redundant message rebroadcasts, contentions, and collision. Alleviating the retransmission, contention, and collision situations will not only improve the success rate for receiving packet but also reduce the power consumption. To resolve the broadcast storm problem and achieve the goal of energy conservation, the *probabilistic*, *counter-based*, *location-based, polygon-based*, *cluster-based* schemes are investigated in [10].

2.2.1 Power-Balance Broadcast Protocol [10]: In [13], a power-balance broadcast algorithm was proposed to extend the network lifetime. The power-balance broadcast algorithm uses the residual battery energy to determine whether the host needs to rebroadcast or not. Thus, the host with more residual energy will have high probability to rebroadcast. On the other hand, the host with less residual energy will reduce the rebroadcast probability and reserve more energy for extending the network lifetime. The proposed algorithm consists of two steps. First , each node has an initial rebroadcast probability P_i bases on its remaining energy. Second, the algorithm uses the average remaining energy of the neighbors of host *i*, the number of neighbors of host *i*, and the number of broadcast message received by host *i* to refine the rebroadcast probability.

3. Energy-Efficient Multicast Protocol in MANETs

Energy-efficient multicasting has also been intensively discussed in wireless ad hoc networks. Multicasting is another important routing operations to transmit the message from one mobile host to a number of mobile hosts. A lot of applications require disseminating information to a group of mobile hosts in a MANET. These applications include distributed game, replicated file systems, teleconferencing, and so on. A single-source multicasting in MANET is defined by delivering multicast packets from single source node to all member nodes in a multi-hop communication manner. A multi-source multicasting is the one that each member can be the source of message sender of the other members. Although multicasting can be achieved by the multiple point-to-point routes; however, constructing a multicast topology for delivering the multicast packets always provides a better performance. A number of articles [20-21] recently investigate the multicast protocols in a MANET, by only considering how to reduce the tree level or the number of forwarding nodes. It is very important to take into consideration the factors of energy reservation and network lifetime to investigate the energy-efficient multicast protocol, because that wireless device in MANET is mainly limited and constrained by life of battery. According to the topology constructed in the previous protocols, existing energy efficient multicast protocols can be classified into *tree*-based and *cluster*-based protocols. This section reviews the existing power efficient multicast protocols for MANET.

3.1 Tree-based Energy-Efficient Multicast Protocol

According to the number of source nodes in networks, existing tree-based energy-efficient multicast protocols are classified into two categories, the single-source and multi-source multicast protocols. Some articles construct the power-efficient multicast tree by pruning the broadcast tree which is established by existing power-efficient broadcasting protocols such as MST [2][3], BIP [1][8] and BLiMST [2]. By taking into consideration of power consumption of nodes in the broadcast tree, these protocols propose tree refining and/or pruning rules to construct a power-efficient multicast tree. Section 3.1.1 firstly reviews existing single-source multicast protocols. Section 3.1.2 reviews multi-source multicast protocols.

3.1.1 Single-Source Multicast Protocol

A. MIP (Multicast Incremental Power Algorithm) [2]**:** Operations of MIP can be partitioned into three phases. In the first phase, a power-efficient broadcast tree is constructed by centralized BIP (*Broadcast Incremental Power*) algorithm, as described in Section 2.1.1.A. By considering the characteristic of wireless transmission, the second phase applies sweep operations to the constructed broadcast tree to eliminate the unnecessary transmission. Nodes in the broadcast tree are examined in ascending ID order and leaf nodes are ignored because they do not transmit. The non-leaf node with the lowest ID will be the first candidate for restructuring. If the candidate's transmission range can reach a neighbors node *k* and its downstream neighbor node *j*, then the link between node *j* and *k* can be eliminated. To obtain the multicast tree, the broadcast tree is pruned by eliminating all transmissions that are not needed to reach the members of the multicast group. More specifically, nodes with no downstream destinations will not transmit, and some nodes will be able to reduce their transmitted power. The similar technique can also be applied to broadcast trees produced by alternative algorithms, such as BLiMST (Broadcast Link-based MST), resulting in the algorithm of another energy-efficient multicast protocol MLiMST(Multicsat link-based MST) [2].

B. S-REMiT (Distributed Energy-Efficient Multicast Protocol) [14]**:** Different from the MIP protocol [2], S-REMiT tries to minimize the total energy cost for multicasting in a distributed manner. The S-REMiT algorithm is divided into two phases. In the first phase, S-REMiT uses minimum-weight spanning tree (MST) as the initial solution. In the second phase, S-REMiT tries to improve the energy efficiency of multicast tree by switching some tree nodes from their respective parent nodes to new corresponding parent nodes. In the first phase, the algorithm starts with each individual node as a fragment. Each fragment finds its adjacent edge with minimum weight and attempts to combine with the fragment at the end of the edge. Finally, an MST that combines all the fragments will be constructed in a distributed manner.

The second phase of S-REMiT is organized in rounds in order to reduce the energy consumption of the constructed MST. In each round, the Depth-First Search (DFS) algorithm is used to pass the S-REMiT token, which gives the permission to a node to refine the tree topology, improving the energy consumption of the tree. For each node i on the multicast tree T rooted by source s, S-REMiT uses $E_i(T, s)$ to evaluate energy metric cost of each node i, where

$$E_i(T,s)=\begin{cases} E^T + Kd_i^{\alpha} & \text{if } i \text{ is the source node;} \\ E^T + Kd_i^{\alpha} + E^R & \text{if } i \text{ neither the source nor a leaf node;} \\ E^R & \text{if } i \text{ is a leaf node in } T; \end{cases}$$

where E^T denotes a constant that accounts for real-world overheads of electronics and digital processing, E^R denotes the energy cost at the receiver side, K is a constant dependent upon the properties of the antenna, and α denotes a constant which is dependent on the propagation losses in the medium. Let $TEC(T, s)$ denote the total energy cost of nodes in multicast tree T. In a round, assume node i in MST obtains the S-REMiT token. The S-REMiT protocol is described in below.

S-REMiT multicast protocol:

Step 1: Node i selects a neighboring node x in MST that link $\overline{ix}$ has a highest energy cost tree. Node i then selects a new parent candidate j with the highest positive gain $g_i^{x,j} := \left(\left(E_x(T,s)+E_j(T,s)\right)-\left(E_x(T',s)+E_j(T',s)\right)\right)$, which does not result in tree disconnection if node i replaces link $\overline{ix}$ with link $\overline{ij}$. If there is no such node j available, then it sets token with *flag=false*.

Step 2: Node i replaces link $\overline{ix}$ with link $\overline{ij}$ and notifies nodes j, x, and its neighbors about the replacement.

Step 3: Node i passes the token to next hop node according to DFS algorithm.

Step 4: If node s gets back the token with *flag* = *false*, which means that no energy *gains* in this DFS round, s will request all of the tree node to prune the redundant transmissions that are not needed to reach the members of the multicast group from the tree.

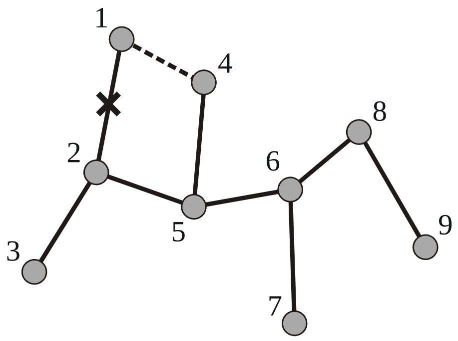

Figure 9: An example of executing S-REMiT protocol

Figure 9 gives an example of S-REMiT. The execution of Phase I will construct a MST T rooted by node 5 as shown in Fig. 9. Assume node 1 obtains the S-REMiT token, it selects node 2 from tree neighbors since link $\overline{12}$ is the highest energy cost tree link of node 1. Then, node 1 will try to replace link $\overline{12}$ with some other link to reduce the total energy consumption of the tree. To achieve this goal, node 1 considers those communicative neighbors as candidates to refine the multicast tree. Node 1 selects node 4 from candidates and then evaluates the gain $g_1^{2,4} := (E_1(T,5)+E_2(T,5)+E_4(T,5))-(E_1(T',5)+E_2(T',5)+E_4(T',5))$, where T' denotes the tree after replacing link $\overline{12}$ by link $\overline{14}$. In case that gain is positive, node 1 will replace link $\overline{12}$ by $\overline{14}$, and notifies its communicative neighbors about this change. Hereafter, node 1 passes the S-REMiT token to node 2 to refine the multicast tree.

C. Reliable Energy-Efficient Multicast Protocol (RBIP) [19]**:** The BIP, BLU, and BLiMST heuristic algorithms for computing energy-efficient trees for unreliable wireless broadcasting and multicasting were presented in [2]. In wireless environments, individual links often have high error rates. This results that reliable delivery potentially requires one or more retransmissions. Since the number of retransmissions needed clearly depends on the error rates of the associated links. Banerjee et al [19] present appropriate modifications to these algorithms, BIP, BLU and BLiMST, to compute energy efficient data delivery trees that take into account the costs for necessary retransmissions. Unlike most energy-efficient multicast protocols, this protocol selecting neighbors in the multicast tree is based not only on the link distance, but also on the error rates associated with the link.

Let $p_{i,j}$ denote the packet error probability of link (i, j). The expected number of transmissions to reliably transmit a single packet across this link is $1/(1- p_{i,j})$. The expected energy requirements to reliably transmit a packet across the link (i, j) is given by $E_{i,j}(\text{reliable}) = E_{i,j}/(1- p_{i,j})$. The computation of a minimum cost multicast tree will follow three steps as described in below.

Step 1: Similar to Prim's algorithm, RBIP greedily adds links to an existing tree such that the incremental cost is minimized. However since RBIP works on reliable transmission costs, these costs are a function of both the link distance and link error rates. The RBIP algorithm iteratively adds the minimum cost link from the set of eligible links to an existing tree. Hereafter, an energy-efficient broadcast tree has been formed.

Step 2: RBIP prunes those nodes from the tree that do not lead to any multicast group member. This processing is performed in a single post-order traversal.

Step 3: Finally, the sweep operations are performed on the remaining tree in post-order. A node, x is transferred from being a child of its parent, y to being a child of its grand-parent, z if doing so reduces overall energy requirements for reliable packet transmission costs.

The paper also proposes two other reliable multicast protocols RBLU and RBLiMST which are the extensions of protocols BLU and BLiMST by considering $E_{i,j}$(reliable) as the link cost in constructing the broadcast tree. Then step 3 of RBIP can be applied to RBLU and RBLiMST to construct a reliable energy-efficient multicast tree.

3.1.2 Multi-Source Energy-Efficient Multicast Protocol [2]

Multi-source multicasting problem is investigated in [2]. A multicast protocol G-REMiT is proposed [15] to reduce the energy cost for the constructed tree. The G-REMiT consists of two phases. Similar to S-REMiT protocol, G-REMiT constructs an MST in phase I then refines the MST in phase II to reduce the energy cost of the constructed multicast tree.

The G-REMiT employs an equation to evaluate the weight of each node. The energy consumption of each node in multicast tree highly depends on the highest energy cost link and the second highest energy cost link. Take a multicast tree shown in Fig. 10 as an example. Let the first and second highest energy cost links of node 2 are links $\overline{12}$ and $\overline{24}$, respectively. In case that node 1 is a source node, node 2 will receive the multicast packet from node 1 and then transmit to its neighboring nodes 3, 4, and 5. The power consumption thus depends on the link $\overline{24}$, which is the second highest energy cost link. However, in case that the source node is some other node rather than 1, node 2 will relay the message to neighboring nodes, including node 1. The power consumption of node 2 thus depends on the energy cost of link $\overline{12}$, which is the highest energy cost link. Thus, the energy cost of each node in MST thus could be evaluated by equation

$$E_i = w_i[1](d_i[2])^{\alpha} + (|G| - w_i[1])(d_i[1])^{\alpha} + |G| E_{elec},$$

where $w_i[1]$ is the number of group nodes which depend on node *i* using the second furthest transmitted power to forward the multicast packets and *G* is the set of multicast group nodes; $d_i[j]$ is the distance of the *j*-th furthest neighboring node of node *i*; E_{else} is a constant that accounts for real-world overheads of electronics and digital processing.

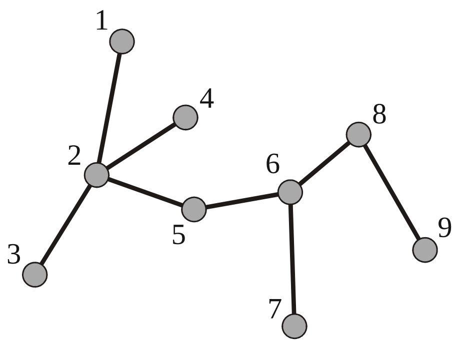

Figure 10: An example of evaluating the gain

In Phase I, a link-based minimum weight spanning tree is constructed as the initial tree. The Phase II of G-REMiT improves the initial tree by exchanging some existing branches in the initial tree for new branches so that the total energy cost of the tree is lower. The difference of total energy cost of the trees before and after the branch exchange is called *gain*.

The second phase of S-REMiT is organized in rounds. In a round, assume node *i* in MST obtains the G-REMiT token. One of the farthest connected neighbor in MST, say *x*, will be selected by node *i*. Another node *j* will be selected from candidate nodes that are communicative neighbors but not tree neighbors of *i* in the tree. Node *i* will replace link $\overline{ix}$ by link $\overline{ij}$ if this change improves the gain of power consumption of the tree.

Assuming that node i obtains the G-REMiT token. Each node evaluates its energy cost E_i according to parameters including its largest link distance and the power consumption of data transmitting and receiving. The following algorithm details the second phase of G-REMiT multicast protocol:

G-REMiT multicast protocol:

Step 1: Node i selects a farthest connected neighbor node x in tree. It there is no such node x available, go to step 6.

Step 2: Node i selects a new candidate node j that is located in its communicative range, to estimate the saving energy cost, called *gain*, after the link changes from $\overline{ix}$ to $\overline{ij}$. The gain $g_i^{x,j} := (E_i + E_x + E_j) - (E_i^{'} + E_x^{'} + E_j^{'})$, where E_i, E_x, E_j respectively denote the energy cost at node i, x, and j in original tree, and $E_i^{'}, E_x^{'}, E_j^{'}$ respectively denote the energy cost at node i, x, and j after link change.

Step 3: Node i sends *Path_Exploring(path_gain)* message along $path_{j,i}$. Every node on the $path_{j,i}$ may change *path_gain* value if its longest link is on $path_{j,i}$, and forwards hop-by-hop along $path_{j,i}$. When node i gets back *Path_Exploring*, it checks if *path_gain* is positive. Node i will go back to the first step to select another node x if *path_gain* is negative

Step 4: Node i changes link $\overline{ix}$ to link $\overline{ij}$.

Step 5: Node i sends path-updating information along $path_{x,i}$ to update local information of each node. Node i will locally broadcast to nodes located in its communicative range about the link change.

Step 6: Node i passes the token to next node according to the DFS algorithm.

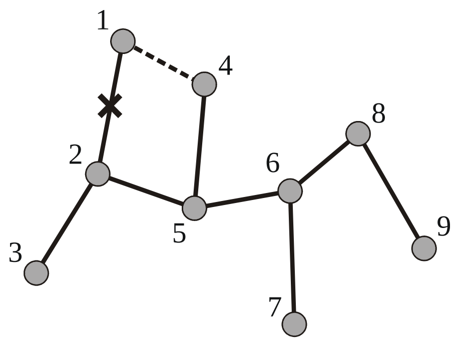

Figure 11: An example of executing G-REMiT protocol

Figure 11 gives an example of G-REMiT. The execution of Phase I will construct a

MST as shown in Fig. 11. Assume node 1 obtains the G-REMiT token, it selects node 2 from tree neighbors since node 2 has a largest energy cost. Then, the node 1 replaces link $\overline{12}$ with some other link to reduce the total energy consumption of the tree. Node 1 considers those communicative neighbors as candidates to refine the multicast tree. Node 1 selects node 4 from candidates and then evaluate the gain $g_1^{2,4} := (E_1 + E_2 + E_4) - (E_1^{'} + E_2^{'} + E_4^{'})$, and check if the path gain of *Path41* is positive. In case that both gains are positive, node 1 will replace link $\overline{12}$ by $\overline{14}$, and notifies its communicative neighbors about this change. Node 1 then passes the G-REMiT token to node 2 to refine the multicast tree.

The article proposes a distributed multicast protocol that dynamically refines the tree topology to reduce the energy consumption of tree node and extend the network lifetime. However, operations designed for preventing the constructed tree from disconnection also creates a lot of control overheads.

3.2 Cluster-based Power Efficient Multicast Protocol [16]

A large amount of mechanisms have been proposed for reducing the packet retransmission in previous research. Cluster management has been widely discussed to alleviate the packet flooding phenomenon. A network can be partitioned into several clusters each consists of a header, gateway (optional), and members. Information of two clusters can be directly exchanged by their headers if their distance is smaller than the communicative range, or relayed by gateway, which is a common member shared by more than one clusters. Cluster headers and gateways can be treated as the nodes of backbone of network, responsible for relaying broadcast (or multicast) packets to all nodes (or all multicast members), preventing large amount of packet retransmission and thus saving power consumption.

C. Tang *et al.* [16] applies the existing ODMRP [17] protocol on cluster topology to achieve the purpose of energy efficient multicast communication. Firstly, a clustering protocol is proposed for constructing cluster where all nodes are capable of communicating with each other within its cluster. After executing the clustering algorithm, the network has been partitioned into a set of disjoint clusters with a cluster head in each cluster. The cluster heads can be thought of as supernodes and they form a supernode network topology. The adaptation of ODMRP multicast protocol is proposed for the supernode topology. For balancing the energy consumption, nodes in cluster take turn to become cluster header using some round robin schedule. The work in [16] takes advantages of balancing energy consumption from cluster management and the good multicast features of existing multicast protocol to develop a power-efficient multicast protocol.

Based on the constructed supernode topology, the work in [16] proposes an adaptation scheme by using the existing ODMRP protocol to achieve the purpose of energy conservation multicasting. Packets flow from sender to its cluster header, then along the supernode topology, and finally get disseminated within clusters. The following gives an example to illustrate the adaptation scheme. In Figure 12, a multicast source node S intends to send multicast packet to receivers $\{M_1, M_2, M_3, M_4, M_5, M_6, M_7\}$. Node S firstly broadcast the message to all nodes within the same cluster. On receiving the multicast packets, header H_1 then forwards the packets to headers H_2 and H_4 along the supernode topology. The multicast packets thus can be received by all receivers from their header.

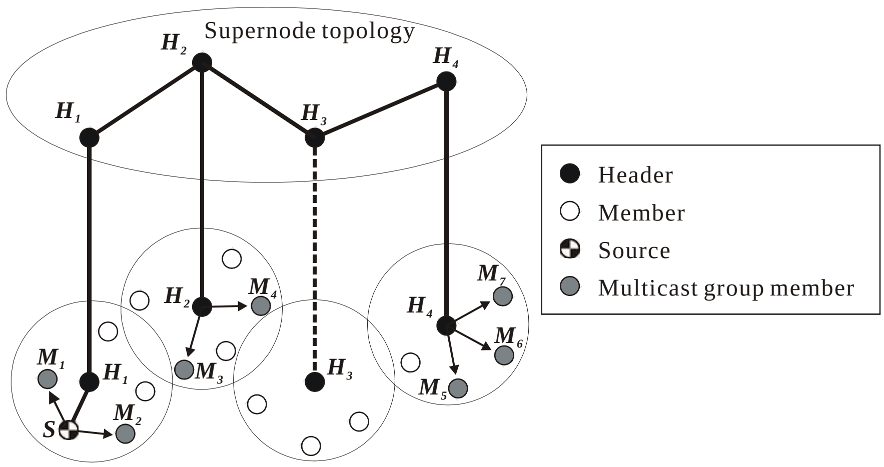

Figure 12: Adaptation of ODMRP protocol

The multicast data transmission highly relies on the supernode topology. Nodes in a cluster may take turn to play the header role, balancing the power consumption of nodes in the same cluster. However, supernode election in clustering process does not take into consideration the energy cost among headers. This may introduce large energy cost for transmitting multicast packets on supernode topology.

4. Conclusions and Future Works

Mobile ad hoc networks comprise mobile nodes that are power constrained as they operate with restricted battery power. Energy consumption is one of the most important issues in ad hoc networks. Selection of nodes to be active and control of the emitted transmission power are the most important issues in designing an energy efficient protocol in MANETs. Broadcast and multicast routings are important operations in network layer. Developing energy efficient broadcast and multicast routing protocols benefits to reduce the power consumptions of nodes and hence improve the network lifetime.

Table 1. A summary of energy-efficient broadcast protocols

Protocol \ Property	Tree-based Approach				Probabilistic Approach	
	Centralized algorithm	Distributed algorithm	Integer programming	Static network	Broadcast Storm	Power-Balance
Centralized BIP [1]	V					
EWMA [3]	V					
IP [4]	V		V			
Minimum-Energy Broadcast in Static MANET [5]	V			V		
MST-based Heuristic in Static MANET [6]	V			V		
Weighted Steiner tree-based [7]	V			V		
DIST-BIP[8]		V				
RBOP [9]		V				
Alleviating "Broadcast Storm Problem" [10-12]					V	
Power-Balance Broadcast Protocol [11]						V

Table 2: A summary of energy-efficient multicast protocols

Protocol \ Property	topology	Pruning or refining rules	Source in tree	Characteristics
MIP [2]	Tree	Yes	Single	Power-Efficient
S-REMiT [14]	Tree	Yes	Single	Power-Efficient
RBIP [19]	Tree	No	Single	Reliable and Power-Efficient
G-REMiT[15]	Tree	Yes	Multiple	Group Communication and Power-Efficient
CBMP [16]	Cluster/Tree	Yes	Multiple	Clustering and Power-Efficient

This Chapter reviews existing important energy-efficient broadcast and multicast protocols. Table 1 summarizes all reviewed energy-efficient broadcast protocols in this Chapter. According to their difference in mechanisms, the broadcast routing protocols are categorized into two families: tree-based and probability-based approaches. The tree-based broadcast routing protocols [1-9] construct a *minimum-energy* broadcast tree by greedily selecting some nodes from networks and control their power level to maintain a broadcast tree with minimal cost of energy consumption. By applying the probability-based approach, another family of protocols [10-13] is developed to reduce the power consumption, alleviate the broadcast storm situation, or balance the power consumptions. In addition to the study of broadcast routing protocols, this Chapter also investigates some important energy-efficient multicast protocols. Table 2 summarizes all reviewed energy-efficient multicast protocol. According to the constructed topology, existing power-efficient multicast protocols are classified into tree-based and cluster-based protocols. The tree-based multicast protocols [2][14][15][19] consider the power consumption issue and obtain an energy-efficient multicast tree by applying refining and pruning rules to the existing energy-efficient broadcast tree. Another approach that use cluster topology to achieve the goal of energy efficient multicasting is also investigated in this Chapter.

A lot of protocols address the broadcast and multicast problem with the goal of less power consumptions, but most of existing approaches are developed under the assumption of low mobility. Therefore, some possible future works are discussed as follows. (1) One possible future work is how to design energy-efficient broadcast and multicast tree maintenance mechanisms with the mobility-tolerant capability. Since ad hoc network is characterized by highly dynamic topology, the impact of mobility should be incorporated into the protocol design, especially for some applications of wireless sensor networks; for instance, the object-tracking problem. Improved performance can be obtained by jointly considering the node failure, node move, and node join situations. To design tree maintenance protocols by reconstructing and reconfiguring the tree or cluster topologies with minimal change of original topology. (2) One big challenge of protocol design in MANET is how to develop a reliable broadcast and multicast routing protocols to simultaneously concern the energy consumption cost and the number of packet retransmissions. (3) One interest topic in the future research is how to investigate the energy-efficient broadcast and multicast routing protocols by fully adopting the location information. Several algorithms have been known for providing node's location information in ad hoc and/or sensor networks. Location information is likely to be useful in calculating the node mobility and the power level required in maintaining the constructed energy-efficient topology. (4) In addition, the use of directional antenna may get benefit from the elimination of unnecessary interference and the less power consumption by focusing the transmitting power in a specific direction. Involving directional antenna and location information in the design of broadcast and multicast routing protocols expectably provides advantages of increasing the network life time. Consequently, how to utilize the location information with joint consideration of mobility, unreliable transmission, and the use of directional antenna will possibly be the next challenge to the design of energy efficient broadcast and multicast protocols.

5. References

[1] R. J. Wilson and J. J. Watkins, Graphs: an introductory approach: a first course in discrete mathematics. John Wiley and Sons. Inc. (1990)

[2] J. Wieselthier, G. Nguyen, and A. Ephremides, "On the Construction of Energy-Efficient Broadcast and Multicast Trees in Wireless Networks", in Proc. *IEEE Infocom'2000*, Tel Aviv, Israel, pp. 585–594, 2000.

[3] Mario Cagalj, Jean-Pierre Hubaux and Christian Enz, “Minimum-Energy Broadcast in All-Wireless Networks: NP-Completeness and Distribution Issues”, In Pro. *ACM MobiCom 2002*, Atlanta, Georgia, pp. 172 – 182, Sep. 2002.

[4] A.K. Das, R.J. Marks, M. El-Sharkawi, P. Arabshahi, and A Gray, “Minimum Power Broadcast Trees for Wireless Networks: Integer Programming Formulations”, in Proc. *IEEE Infocom'2003*, Vol. 2, pp. 1001 - 1010, 2003.

[5] P.-J. Wan, G. Calinescu, X.-Y. Li, and O. Frieder, “Minimum-energy broadcast routing in static ad hoc wireless networks”, in Proc. *IEEE Infocom'2001*, Vol. 2, pp. 1162 - 1171, April 2001.

[6] A.E.F. Clementi, G. Huiban, G. Rossi, Y.C. Verhoeven, and P. Penna, “On the Approximation Ratio of the MST-based Heuristic for the Energy-Efficient Broadcast Problem in Static Ad-Hoc Radio Networks”, in Proc. *PDPS'03: Parallel and Distributed Processing Symposium*, pp. 222 – 229, April 22-26, 2003.

[7] D. Li, X. Jia, and H. Liu, “Energy Efficient Broadcast Routing is Static Ad Hoc Wireless Networks,” *IEEE Trans. on Mobile Computing*, Vol. 3, No. 1, pp. 144-151, Apr.-June. 2004.

[8] J. Wieselthier, G. Nguyen, and A. Ephremides, “Distributed Algorithms for Energy-Efficient Broadcasting in Ad Hoc Networks”, in Proc. *MILCOM 2002*, Vol. 2 , pp. 7-10, Oct. 2002.

[9] J. Cartigny, , D. Simplot, and I. Stojmenovic, “Localized Minimum-Energy Broadcasting in Ad-Hoc Networks”, in Proc. *IEEE Infocom'2003*, Vol. 3, pp. 2210 - 2217, 2003.

[10] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network," *ACM Wireless Networks*, Vol. 8, No. 2, pp. 153-167, March 2002.

[11] Y. Sasson, D. Cavin, and A. Schiper, “Probabilistic Broadcast for Flooding in Wireless Mobile Ad Hoc Networks,” in Proc. *IEEE WCNC'2003*: *Wireless Communications and Networking*, Vol. 2, pp. 1124-1130, Mar. 2003.

[12] M.-T. Sun; W. Feng, and T.-H. Lai, “Location Aided Broadcast in Wireless Ad Hoc Networks,” in Proc. *IEEE GLOBECOM'2001*: *Global Telecommunications Conference*, Vol. 5, pp. 2842-2846, Nov. 2001.

[13] Jang-Ping Sheu, Yu-Chia Chang, and Hsiu-Ping Tsai, “Power-Balance Broadcast in Wireless Mobile Ad Hoc Networks”, in Proc. *EW2004: European Wireless Conference*, Spain, Feb. 2004.

[14] Bin Wang and Sandeep K. S. Gupta, "S-REMiT: A Distributed Algorithm for Source-based Energy Efficient of Multicasting in Wireless Ad Hoc Networks", *Proc. of IEEE 2003 Global Communications Conference (GLOBECOM),* San Francisco, CA, Vol. 6, pp. 3519 – 3524, Dec. 2003.

[15] Bin Wang and Sandeep K. S. Gupta, "G-REMiT: An Algorithm for Building Energy Efficient of Multicast Trees in Wireless Ad Hoc Networks", *Proc. of Second IEEE International Symposium on Network Computing and Applications*, Cambridge, MA, April 2003, pp. 265-272.

[16] Caimu Tang, Cauligi S. Raghavendra and Viktor Prasanna, "Energy Efficient Adaptation of Multicast Protocols in Power Controlled Wireless Ad Hoc Networks," in *2002 International Symposium on Parallel Architectures, Algorithms and Networks* , May 2002.

[17] S. Lee, W. Su, and M. Gerla, "On demand multicast routing protocol in multihop mobile wireless networks," *ACM/Baltzer Mobile Networks and Applications*, 2000.

[18] H. Lim and C. Kim, "Multicast tree construction and flooding in wireless ad hoc netowrks," in *Proceedings of the Third ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems* (MSWiM), Aug. 2000.

[19] S. Banerjee, A. Misra, J. Yeo, and A. Agrawala, "Energy-efficient broadcast and multicast trees for reliable wireless communication," in *IEEE Wireless Communications and Networking Conf. (WCNC)*, New Orleans, Louisiana, Mar. 2003.

[20] C.-C. Chiang, M. Gerla, and L. Zhang, "Adaptive shared tree multicast in mobile wireless networks," in *Proceedings of IEEE Globecom'98*, Sydney, Australia, , pp. 1817–1822, Nov. 1998.

[21] S. J. Lee, W. Su, J. Hsu, M. Gerla, and R. Bagrodia, "A performance comparison study of ad hoc wireless multicast protocols," in *Proceedings of the IEEE INFOCOM*, Tel Aviv, ISRAEL, pp. 565–574, Mar. 2000.

[22] J. E. Wieselthier, G. D. Nguyen, and A. Ephremides, "On the construction of energy-efficient broadcast and multicast tree in wireless networks," in *Proc. IEEE INFOCOM*, Tel Aviv, ISRAEL, pp. 585–594, Mar. 2000.

[23] R. Gallager, P. A. Humblet, and P. M. Spira, "A distributed algorithm for minimum weight spanning trees," in *ACM Trans. Programming Lang. & Systems*, vol. 5, no. 1, pp. 66–77, Jan. 1983.