Chapter 8: Energy Conservation for Broadcast Routing in MANETs

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Outline

- Introduction
- Energy-Efficient Broadcast Protocols in MANETs
  - Tree-Based Approach
  - Probability-based Approach
- Conclusions

Introduction

- 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 is a communication function that a node, called the source, sends messages to all the other nodes in the networks.
- Broadcast routing is usually constructing a broadcast tree, which is rooted from the source and contains all the nodes in the network.

Introduction

- 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*, which is a broadcast tree with minimum-energy consumption.
- To establish the minimum-energy broadcast tree, centralized algorithms and distributed algorithms are investigated in wireless ad hoc networks.
- In addition, integer-programming technique can be used to establish the minimum-energy broadcast tree.

- 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.

Energy-Efficient Broadcast Protocols in MANETs

- Tree-Based Approach
  - Centralized Algorithm
  - Distributed Algorithm
- Probability-based Approach
  - Power-Balance Broadcast Protocol

Tree-Based Approach

- The *minimum-energy broadcast tree* is formally defined 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.

Tree-Based Approach

Centralized Algorithm

Centralized Algorithm

- A centralized algorithm, called as centralized BIP (*Broadcast Incremental Power*) algorithm, is developed to construct a *minimum-energy broadcast tree* in MANETs.
- An improved centralized algorithm, named EWMA (Embedded Wireless Multicast Advantage), is proposed to construct a minimum-energy broadcast tree with less power consumption.

Centralized Algorithm

Centralized BIP

(Broadcast Incremental Power Algorithm)

Centralized BIP (Broadcast Incremental Power Algorithm)

- The BIP algorithm is based on the Prim's algorithm, 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 max P .

- 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 $j = r^{\alpha}$, where r is the distance between nodes i and j.

Centralized BIP (Broadcast Incremental Power Algorithm)

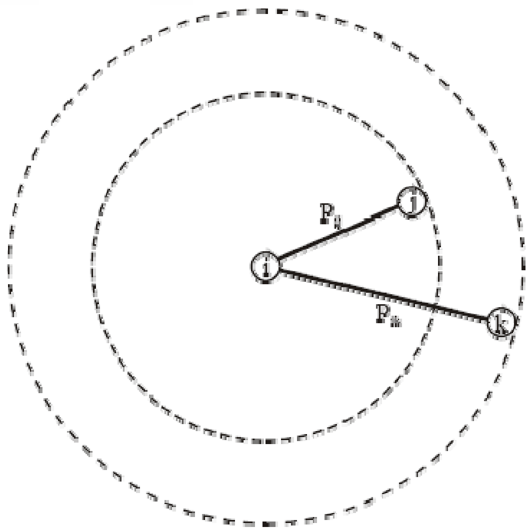


Fig. 1: The "wireless multicast advantage": $P_{i,(j,k)} = \max\{P_{ij}, P_{ik}\}$

- 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.

Centralized BIP (Broadcast Incremental Power Algorithm)

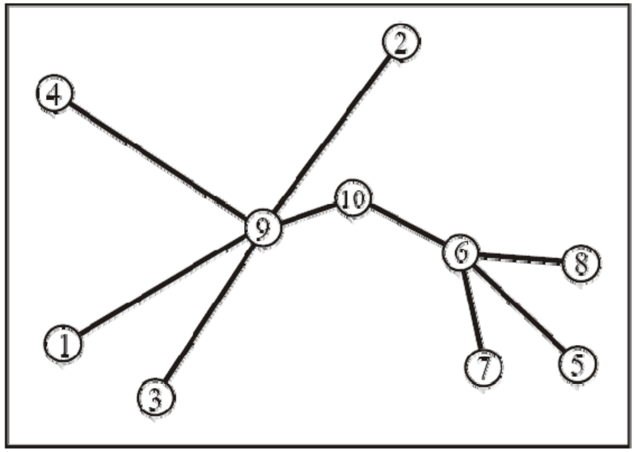


Fig. 2: Broadcast tree using BIP

- 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) 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 → 9 means that adding the transmission from node 10 to node 9.

Centralized BIP (Broadcast Incremental Power Algorithm)

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.

Centralized BIP (Broadcast Incremental Power Algorithm)

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.

Centralized Algorithm

EWMA
(Embedded Wireless Multicast Advantage)

EWMA (Embedded Wireless Multicast Advantage)

- 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

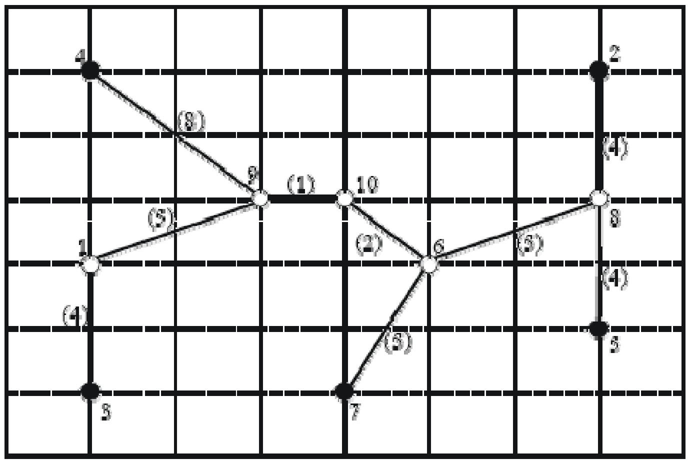


Fig. 3: A MST broadcasting tree

EWMA (Embedded Wireless Multicast Advantage)

2) 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.

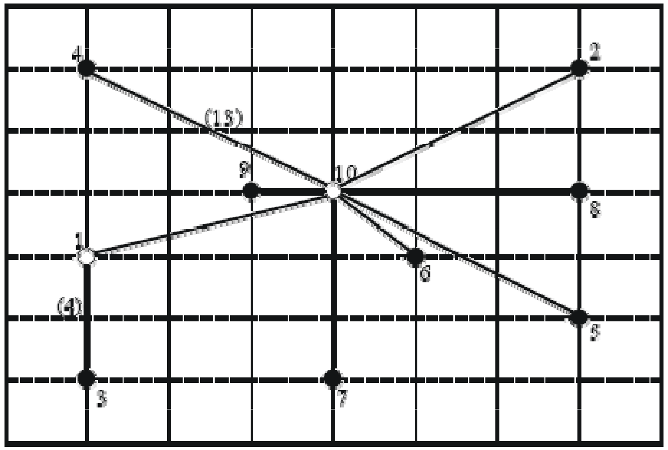


Fig. 4: The EWMA broadcast tree

Tree-Based Approach

Integer Programming Technique

Integer Programming Technique

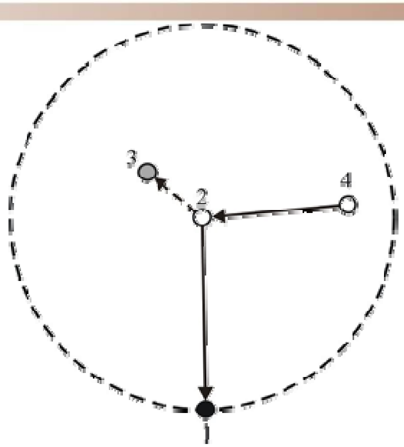


Fig. 5: Example of a MANET and node 4 is the source node.

- 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
$$\begin{bmatrix} 0 & 8.4645 & 12.5538 & 13.6351 \\ 8.4645 & 0 & 0.5470 & 3.8732 \\ 12.5538 & 0.5470 & 0 & 5.7910 \\ 13.6351 & 3.8732 & 5.7910 & 0 \end{bmatrix}.$$

Integer Programming Technique

- In addition, a *reward matrix* R is defined by

$$R_{mn}(p) = \begin{cases} 1, & \text{if } P_{mp} \le P_{mn} \\ 0, & \text{otherwise} \end{cases}.$$

- For instance, the transmission 2→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

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

Tree-Based Approach

Distributed Algorithm

Distributed Algorithm

- DIST-BIP (Distributed Broadcast Incremental Power)
- RBOP (RNG Broadcast Oriented Protocol)

Distributed Algorithm

DIST-BIP (Distributed Broadcast Incremental Power)

DIST-BIP (Distributed Broadcast Incremental Power)

- Two distributed BIP algorithms are proposed.
- One is Dist-BIP-A (Distributed-BIP-All),
  another one is Dist-BIP-G (Distributed-BIP-Gateway).

DIST-BIP (Distributed Broadcast Incremental Power)

- In Dist-BIP-A algorithm, each node constructs its local BIP tree by using centralized-BIP algorithm 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.

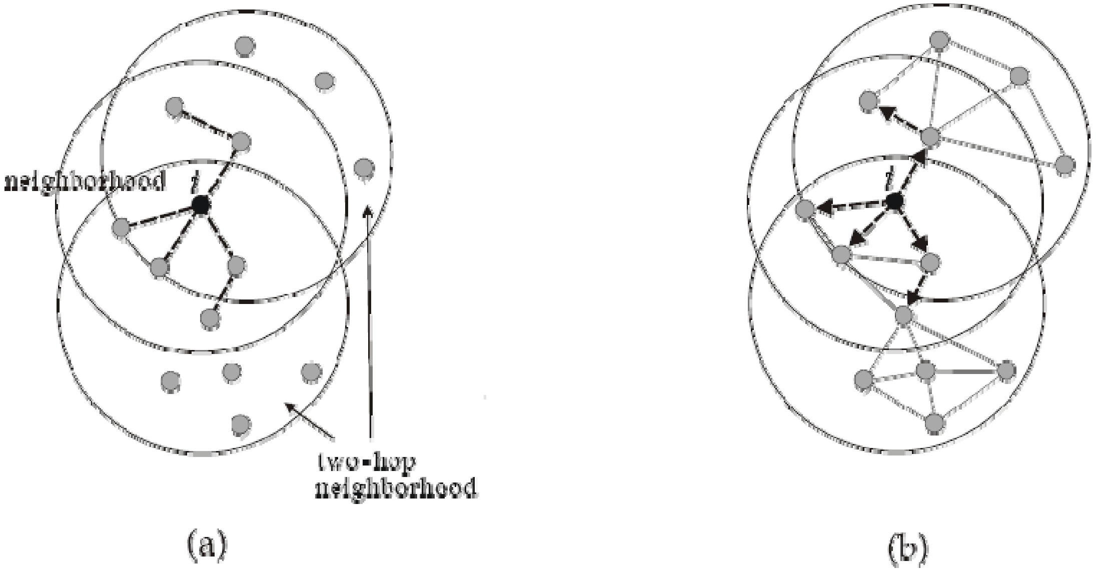
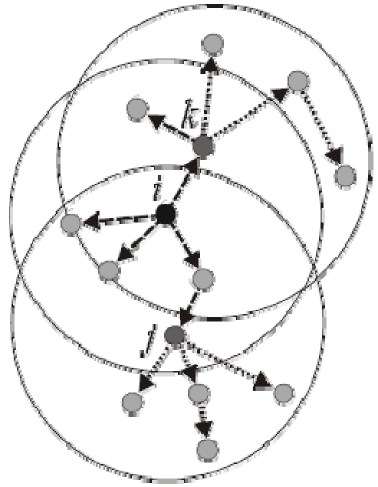


Fig. 6: (a) local BIP tree for node *i* Fig. 6: (b) Dist-BIP-A tree

DIST-BIP (Distributed Broadcast Incremental Power)

- 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.



(c)

Fig. 6: (c) Dist-BIP-G tree

DIST-BIP (Distributed Broadcast Incremental Power)

- 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.

Distributed Algorithm

RBOP (RNG Broadcast Oriented Protocol)

RBOP (RNG Broadcast Oriented Protocol)

- Relative Neighborhood Graph (RNG)
- 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.

RBOP (RNG Broadcast Oriented Protocol)

- 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).

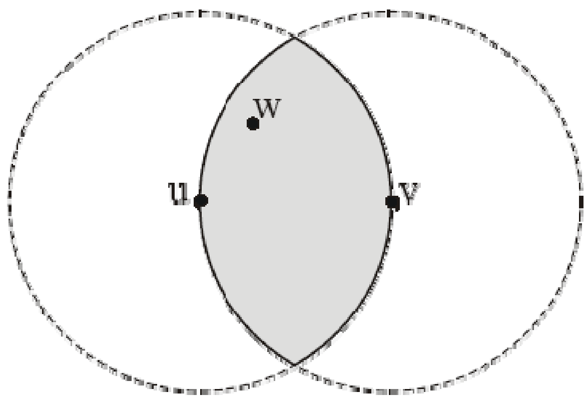


Fig. 7: The edge (u,v) does not belong to RNG since the existence of node w

RBOP (RNG Broadcast Oriented Protocol)

- 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*).

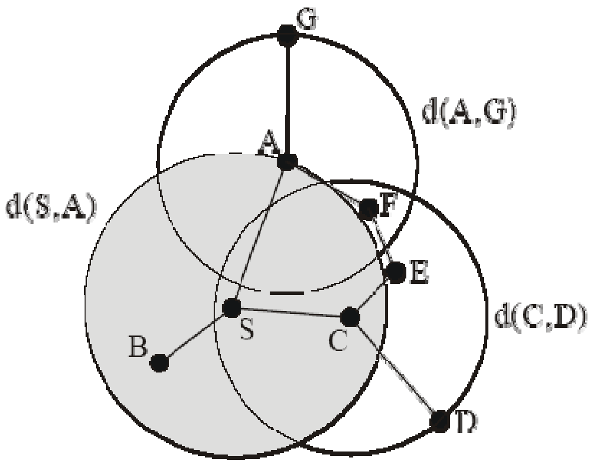


Fig. 8: Example of RNG Broadcast Oriented Protocol (RBOP)

RBOP (RNG Broadcast Oriented Protocol)

- This method can reduce the total number of broadcast messages and efficiently transmit the broadcast messages.
- In the simulation results, 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.

Probability-based Approach

Power-Balance Broadcast Protocol

Power-Balance Broadcast Protocol

- 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.

Conclusions

- The broadcast routing protocols are categorized into two families: tree-based and probability-based approaches.
- The tree-based broadcast routing protocols 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.
- The probability-based approach reduces the power consumption, alleviate the broadcast storm situation, or balance the power consumptions.

Homework #8:

- What is the minimum-energy broadcast tree ?
- What is the difference of centralized BIP and (Broadcast Incremental Power) EWMA (Embedded Wireless Multicast Advantage) algorithm in MANETs ?
- What is the Power-Balance Broadcast Protocol in MANETs ?