Multicasting in ad hoc networks: Energy efficient

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1. Introduction

Multicasting in ad hoc networks is more complex than in wired networks, because of host mobility, interference of wireless signals, and the broadcast nature of the communication. There are two ways we can classify the multicasting protocols: source-based and core-based.

In a source-based protocol, each source maintains a multicast tree to every member in the multicast group. Thus, multiple multicast trees exist in the network.

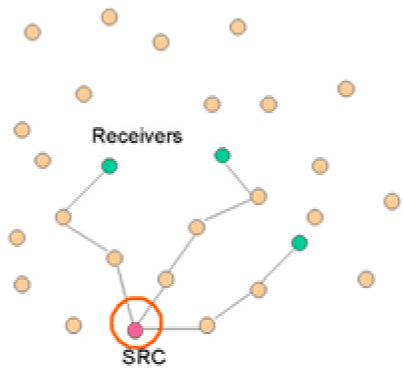


Figure 1: Principle of Source-based Tree in an Ad Hoc Wireless Network

The source constructs the tree by running a multicast tree algorithm. This kind of multicasting is not scalable: a tree is needed for every source-group pair.

In a core-based protocol, there are some special nodes, called cores, which are responsible for multicast data distribution. In these protocols, there is only one multicast tree that originates from the cores. This tree is spanned from the core host to the members of the multicast group.

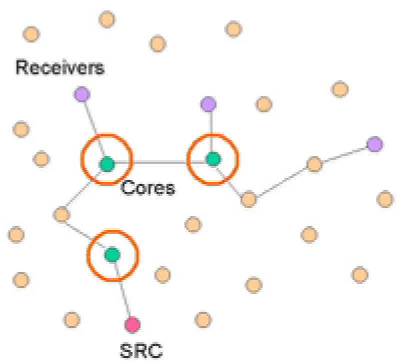


Figure 2: The Principle of Core-based Multicast for Ad Hoc Wireless Networks

Even though multicasting can be achieved with multiple unicast routing, the traffic could block the network, especially the resource-restricted ad hoc networks. Energy is a sensitive issue in these networks, since the nodes lack constant power supply. Packet transceiving consumes energy in ad hoc networks, since a packet can be routed through many intermediate nodes before reaching its destination. Because the nodes in an ad hoc network have limited power supply, it is vital to be able to find mechanisms and protocols that optimize the usage of battery power and thus increase the lifetime of the network.

2. Sources of power consumption

The power characteristics of the mobile radio used in wireless devices are instrumental in the design of energy-efficient communication protocols. A typical mobile radio may exist in three modes: transmit, receive, and standby, according to [2]. The transmit mode consumes power the most, whereas the standby mode the least. Therefore, the goal in such networks with limited power resources is to minimize the transceiver consumption. In this paper, the power consumption for packet processing has not been analyzed.

Communication-related consumption means the usage of the transceiver at the source, intermediate, and destination nodes. The transmitter is used for sending control, route request, and response messages, as well as data packets routed through this node. The receiver is used to receive data and control packets; some of them are destined for this node, the rest are forwarded further ahead.

3. Directional antennas

Since packet transmission consumes much energy, we might think of economizing on it by using directional antennas in order to narrow the beam width. Directional antennas, as mentioned in [4] have advantages over omni directional antennas in ad hoc networks. The energy focus in one direction increases spatial reuse, and provides farther transmission for same amounts of power. These mean that instead of several hops, we can have a node transmitting to a node far away, thus saving from the overall energy that would have been spent in all the nodes up to the destination. Some other advantages of directional antennas, out of the scope of energy would be:

- Higher ad hoc network capacity (more simultaneous transmissions and fewer hops);
- Improved connectivity (because of the longer range);
- Chances of eavesdropping are reduced.

This, of course, introduces the overhead of each node keeping and updating information about the position of other nodes. The benefit is when this overhead does not exceed the profit from the saved energy. Logically, this benefit is maximized when the nodes are not moving very much. Directional antennas help in profiting as much as possible from the wireless multicast advantage (it is explained later).

4. TCP

TCP relies on timeouts and duplicate ACKs as indications of congestion. But in ad hoc networks there are two features that make TCP perform badly: the wireless connections, and the mobility of the nodes. According to [4], their effects and possible improvements would be:

- *The wireless connections*. Due to the high error rate of the wireless connection, the packets are retransmitted at the data-link layer. This delays the TCP packets, and also their acknowledgements, which leads to a slow-down of the transmission rate and retransmission of the packets. The retransmission of packets consumes the energy of the sender itself, as well as the energy of the intermediary nodes. To counter this, Explicit Link Failure Notification (ELFN), and Explicit Congestion Notification (ECN) can be used, instead of the normal counters that TCP uses, such as round trip delay and acknowledgements.

- *The mobility of the nodes*. In ad hoc networks, the mobility of the nodes can cause packets of a connection to arrive at the destination along different routes. Thus, the packets are received out of order, and duplicate ACKs arrive at the sender. In response, the sender retransmits the out-of-sequence packet and reduces the congestion window. The decrease in the overall throughput of the connection has the effect of increasing the consumption of energy. To counter this in ad hoc networks, TCP might retransmit the packet, but not reduce the congestion window.

In ad hoc networks, TCP could rely on ECN and ELFN for congestion and link failure notification. Further more, TCP could be frozen (its counters be stopped), so that once the connection has been reestablished, fast recovery can take place, resulting in less energy consumption.

5. Energy-efficient broadcast and multicast tree construction

This section contains an explanation of the wireless multicast advantage, as well as several algorithms for tree construction in broadcast and multicast networks.

5.1. The wireless multicast advantage

The power that is required to transmit from a node i to a node j is $P_{ij} = r^{\alpha}$, where r is the distance between the nodes i and j, and α is a constant that depends on the communication medium. The power required by node i to communicate with nodes j and k is $P_{i,(j,k)} = \max(P_{ij}, P_{ik})$, instead of $P_{ij} + P_{ik}$. This means that the power required is the power required to transmit to the farthest node. This is referred to as the wireless multicast advantage; it is due to the broadcast nature of wireless medium.

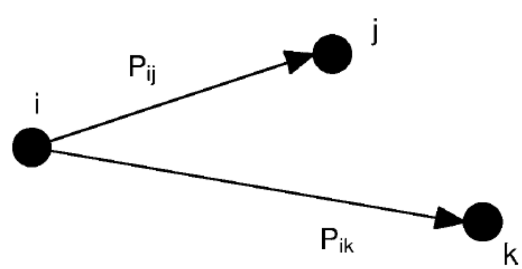


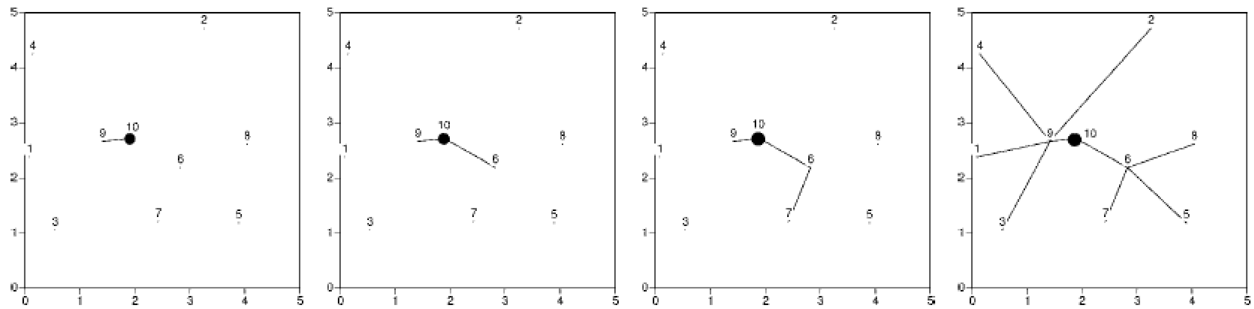
Figure 3: The wireless multicast advantage

The wireless multicast advantage saves energy and bandwidth in ad hoc networks. On the other side, this causes an increase in interference and collisions. The cause is the farther transmission, which causes more nodes to be in the range of the source node, and thus more nodes are likely to be competing at the same time for transmitting.

There are several algorithms for broadcast tree construction. Their multicast counterparts are quite analogous to them.

5.2. Broadcast Incremental Power (BIP)

The objective is to construct a minimum-power tree. According to [1], under the **BIP** algorithm, nodes are added to the tree one at a time until all nodes are included in the tree. The node that is added at each step is the one that requires the least amount of incremental power. BIP has the advantage that it takes into account the wireless multicast advantage to determine the incremental power for reaching a new node.



(a) Step 1: 10 → 9 (b) Step 2: 10 → 6 (c) Step 3: 6 → 7 (d) final tree ($P = 10.90$)

Figure 4: Example of a tree construction using BIP

From this tree, the Multicast Incremental Power tree can be obtained by pruning the unwanted branches of the tree.

5.3. Broadcast Least Unicast (BLU)

According to [1], the BLU tree construction consists of the superposition of the best unicast paths to each individual destination. Of course, we have the assumption of an underlying unicast algorithm providing minimum distance unicast paths from the source to destination. In contrast to BIP, BLU fails to profit from the wireless multicast advantage, which results in higher power consumption. The MLU is obtained by the superposition of only the unicast link to the desired destinations.

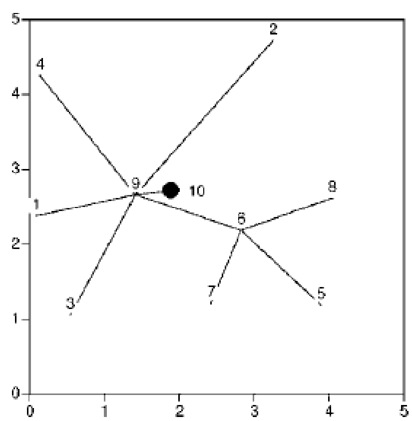


Figure 5: Tree produced by BLU

5.4. Broadcast Link-based Minimum-cost Spanning Tree (BLiMST)

According to [1], the BLiMST algorithm associates a link cost to each pair of nodes, for example, the power to sustain the link. As was the case with BLU, BLiMST too fails to exploit the wireless multicast advantage, thus it results in higher overall power consumption. The shortcomings of this approach come from the fact that this is basically designed for wired networks. The MLiMST is obtained by pruning all undesired nodes from the tree.

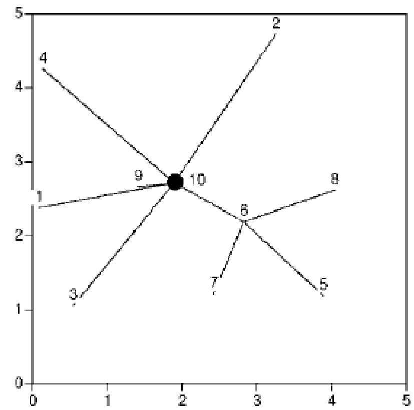


Figure 6: Tree produced by BLiMST

It has been proved that the determination of a minimum-cost multicast tree in wired networks is a difficult problem: NP-complete. The wireless multicast tree problem is at least as hard in wireless networks.

6. Energy-efficient multicasting for reliable data transfer

This section discusses energy-efficient multicasting protocols for reliable data transfer in ad hoc networks, based on [3].

6.1. Energy-Efficient Reliable Broadcast and Multicast Protocols

The reliability requirement introduced here means that a certain amount of energy will be spent for retransmitting the packet. These schemes take into consideration packet-error probability of a link in order to determine the required energy for the reliable transmission of the packet, [3]. The relationship between the energy required for reliable transmission and the energy required for normal transmission is: $E_{ij(reliable)} = E_{ij} / (1 - p_{ij})$, where p_{ij} is the packet-error probability and $1 / (1 - p_{ij})$ is the expected rate of retransmissions from node i to node j. All BIP, BLU, and BLiMST can be modified to take into consideration $E_{ij(reliable)}$ in their algorithms of tree formation.

6.2. A Distributed Power-Aware Multicast Routing Protocol

In this protocol, an underlying unicast protocol is implied that can give the least-cost path from a node to any other node. This unicast protocol provides the information for constructing the multicast tree. There are two similar metrics for this protocol; both of them consider the power factor, [3].

In the first one, to find the minimum cost of a path of nodes (1, 2, 3, …. , j - 1, j) the cost is given by: $C = (P_{1,2} + P_{2,3} + \ldots + P_{j-1,j}) / \min(K_1,K_2,\ldots,K_j)$. Here, K_i is the number of free transceivers available at node i, and P_{ij} is the power needed for transmitting a packet from node i to node j.

The other way of characterizing the energy cost would be first to define the distance between two nodes as: $D_{i,j} = Pi_{,j} / \min(K_i,K_j)$. Then, the end-to-end distance between two nodes would be: $D = \Sigma^{n-1}_{i=0} D_{i,i+1,}$ where 0 is the ID of the source node and n is the ID of the destination node. The lowest path from node 0 to node n would be the one having the smallest D.

6.3. Energy-Efficient Multicast Routing Protocol

This protocol is a mesh-based one, which means that each node has at least two links to other nodes. According to [3], it consists of two phases which use these two heuristics: Minimum Energy Consumed per Packet (MECP) and Minimum Maximum Node Cost (MMNC).
The first phase considers a path the minimum one for packet delivery if the total consumption of energy along all the nodes through to the destination is the minimum. The heuristic of the second phase is based on and quantifies the power that is available at nodes along the path.

The protocol switches between the two phases: the MECP phase and the MMNC phase. In each phase, the routes are chosen based on the corresponding heuristic and a mesh is formed. This mesh is valid for period of time, and then the other phase comes in. The system continuously toggles between these two phases.

6.4. Energy-Efficient Cluster Adaptation of Multicast Protocol

This is a proposal for power optimization in cluster-based schemes. As we know, there are several clusters in the network, each has a cluster head. The cluster heads are connected in a super-node network. In these schemes, there is a balance to be stricken concerning the number of cluster heads. On the one hand, the fewer cluster heads we have, the more nodes will belong to a cluster head, and the more energy it is likely to spend in order to reach distant nodes. On the other hand, having more cluster heads increases the overhead and energy consumption in the super node level. Therefore, we need to find a balance, as mentioned in [3].

In this protocol, each node starts out as a cluster head. It then exchanges recruiting messages with neighbors. These messages also contain power level information. Based on mutual information, single nodes can decide to join a cluster. The cluster head has the responsibility of making sure that all nodes within the cluster are reachable from all nodes within the cluster. This is why it keeps sending cluster-forming and finalization messages. In order not to deplete the energy in the cluster heads, the cluster nodes take the cluster head position in turns.

7. Conclusions

In this paper, I have analyzed the issues related with energy-efficient multicasting in ad hoc wireless networks. As inferred from above, better performance can be achieved when the features of the wireless medium are exploited, namely, the wireless multicast advantage. Overall, a joint effort should be made in order to optimize the energy consumption, and thus the network lifetime. These efforts can start from the physical layer with the consideration of the power levels of the nodes. Then, we can improve things at the TCP level, by using optimized protocols for these environments. The multicasting protocols measure, and optimize these feature by organizing the nodes in such a way as to save as much energy as possible.

References

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