7th International Conference on DEVELOPMENT AND APPLICATION SYSTEMS
Suceava, Romania, May 27 – 29, 2004

INTELLIGENT TECHNIQUES FOR SAVING ENERGY IN WIRELESS AD HOC NETWORKS USED THE BROADCAST

Maria Rodica HOJBOTĂ
prof. informatică Grupul Şcolar "Alexandru cel Bun" Gura Humorului, Suceava
drnd. UPB Bucureşti
tel: 0230-235205, mobil: 0742185175
hojbota_r@yahoo.com"

Abstract. *In this paper we address the problem of energy - efficient broadcast in wireless ad hoc networks. The broadcast incremental power algorithm (BIP) is an efficient algorithm to construct broadcast trees –to support sectored antennas. We will simulate and extensively compare the original BIP algorithm with the extended and modified BIP. The simulation shows drastic reductions in the total and average power consumption*

Keywords: *wireless ad hoc networks, broadcast incremental power algorithm, simulation*

Introduction

Broadcasting is a communication paradigm that allows to send data packets from a source to multiple receivers. Broadcasting and multicasting in wireless ad hoc networks are critical mechanisms in various applications such as information diffusion, sensor networks, and also for maintaining consistent global network information. Broadcasting is more efficient that sending multiple copies the same packet through unicast. Wireless ad hoc networks are energy limited because the nodes are usually battery-powered. Therefore, it is highly important to use power-efficient broadcast algorithms for such networks. A method to construct broadcast trees is growing a tree algorithm by adding nodes that result in a minimal power increment. The last algorithm is called Broadcast Incremental Power (BIP). This algorithm is similar to Prim's algorithm to construct a minimum spanning tree (MST), starting from one set which initially contains only the source node, a new node with the minimum "incremental power"-the additional power necessary to reach the new code-is added to the set at each iteration. The algorithm stops when the set contains all the nodes. They also stimulate and compare the performance (in terms of power consumption) of these different algorithms.

We show that extending BIP to use sectored antennas can significantly reduce the energy consumption while keeping the algorithm very simple.

Intelligent techniques

1. BIP with sectored antennas

BIP assumes the use of an omnidirectional antenna. Using omnidirectional antennas results in energy waste for two main reasons. Firstly, in sparse or moderately crowded networks, not all sectors (directions) have receiving nodes. For example, in Figure (1), node A needs only one sector (upper-right) to broadcast to nodes Band C. Secondly, when a nod B receives a broadcast packet from node A and retransmits it to D, the energy spent retransmitting in the opposite direction of reception, i.e., the lower sector of B, is generally wasted because the nodes located in that direction such as C have probably already received that packet from A's transmission.

The implementation of our algorithm is similar to Prim's algorithm. Initially, the priority queue contains all nodes; queue is keyed on the minimal incremental power necessary to reach each node.

At the start of the algorithm, we set the source node's key to 0, and other nodes' keys to ∞.

At each step, we remove a node v with the minimum key from the queue (with the minimal incremental power).

If we denote the node responsible for v's removal as $\pi[v]$, witch extends one of its sectored antennas to cover v, we update the keys of the remaining nodes in the priority queue based on the transmission power levels of both *v* (with all sectored antennas transmitting at power level 0) and π[*v*] (one of π[*v*]'s antenna transmission power has been raised in order to cover *v*).

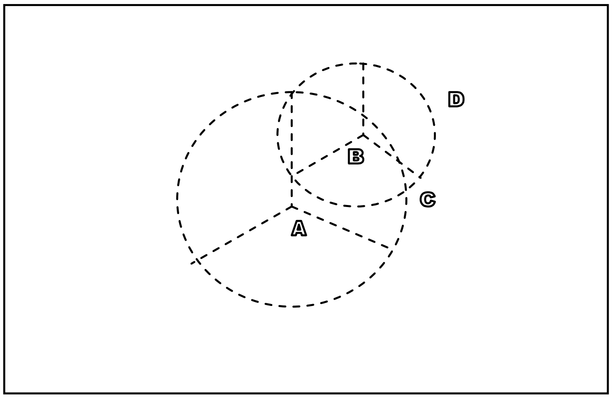


Figure 1: An example where sectored antenna is better than omni directional antenna

The Prim's algorithm:

The difference between our algorithm and the original BIP is that nodes have multiple sectors, each covering some non-overlapping region, so π[*v*] needs to pick one of its sectors, the one in *v*'s direction, raise its transmission power to cover *v*, while keeping the other sectors unchanged. BIP uses only one antenna sector (omnidirectional) for each node and the transmission power level in all directions is raised as a result of π[*v*]'s trying to cover *v*.

The complexity of our algorithm depends on the data structures used to implement the priority queue, as Prim's algorithm. If binary heap is used to implement the priority queue, the complexity will be O (NxN lg N), where N is the number of nodes. Note that we are assuming that every node can reach other nodes, thus the graph is fully connected, with O {NxN) edges.

Simulation and Results

```
MST-PRIM (G, r)
Q: = V [G]
    for each u ∈ Q
  do key[u]: = ∞
  key [r]:= 0
  π[r]:= NIL
     while  Q
    do u: = EXTRACT-MIN (Q)
    for each v ∈ Q
  do if min{BIP(u,v), BIP(π[u],v)} < key [v]
    then π[v]:= BIP (u, v) < BIP (π [u], v)? u : π[u]
  key [v]:= min {BIP (u, v), BIP (π [u], v)}
```

In this section, we present the simulation of BIP with omnidirectional antennas, and BIP with multi-sector antennas. The nodes are randomly placed within a square of dimension 600x700. The nodes density is varied by taking N = {20, 40, 60, 100, 200, … , 1000}. The number of antenna sectors S is taken with {1, 3, 6}. The path loss attenuation factor ∝ is taken with {2, 3, 4}. For each combination of N, S, and ∝ we take the average of 100 different of N nodes.

For an antenna with S sectors, each sector's covering angle is 2π/S, evenly divided between 0 and 2π. For simplicity, we assume that the antennas are broadcasting in two dimensional space. The antennas orientation is static. Since the nodes are randomly picked, and the orientation is static, the initial orientation of the antennas should have no effect on our result.

Table 1: ∝ = 2, normalized power consumption

N	omni	3-sector	6-sector
20	1	0.394	0.208
40	1	0.382	0.203
60	1	0.387	0.206
100	1	0.381	0.203
200	1	0.384	0.204
300	1	0.384	0.204
400	1	0.384	0.204
500	1	0.384	0.204
600	1	0.384	0.204
700	1	0.385	0.204
800	1	0.384	0.204
900	1	0.385	0.204
1000	1	0.384	0.204

We compute the power consumption for transmission between nodes s and *d* with distance d(s, t) as specified in:

$$P(s, t) = 1/S*d(s, t)^{\propto} \qquad (1)$$

For multi-sector antenna (S> 1), the gain achieved by optimizing BIP, for example, using the “sweep” post - processing discussed by Wieselthier, is very small. And for omnidirectional antenna, the improvement is about 20 % (data not shown), much smaller compared to the gain with multiple antennas, foe example, 3-sector, with results in more than 60% in saving of power consumption.

We normalize average power consumption as:

$$P'(sector)=P(sector)/P(omnidirectional) \quad (2)$$

where *P(sector)* is average power consumption using BIP with sectored antenna and is the average power consumption for BIP using omnidirectional antennas. These two values are computed using the same node topology.

Figure 2 shows the total power consumption with various node densities for α = 2 and Table1 shows normalized power consumption.

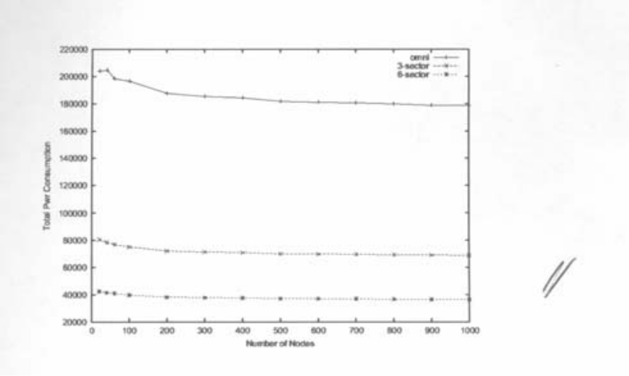
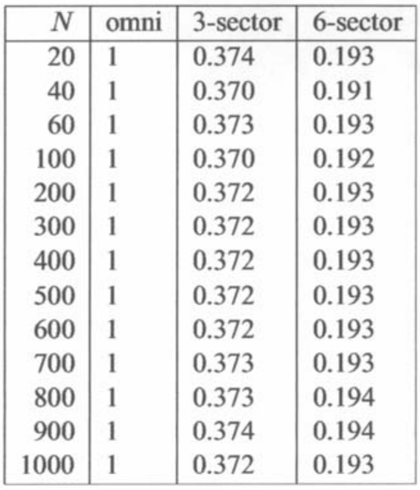


Figure 2: Total power consumption using different number of antenna sectirs with various node densities, α = 2



N	omni	3-sector	6-sector
20	1	0.374	0.193
40	1	0.370	0.191
60	1	0.373	0.193
100	1	0.370	0.192
200	1	0.372	0.193
300	1	0.372	0.193
400	1	0.372	0.193
500	1	0.372	0.193
600	1	0.372	0.193
700	1	0.373	0.193
800	1	0.373	0.194
900	1	0.374	0.194
1000	1	0.372	0.193

Table 1: ∝ = 3, normalized power consumption

Figure 3 shows the total power consumption with various node densities for α =3 and Table 2 shows the normalized power consumption.

Table 3 shows the normalized power consumption.

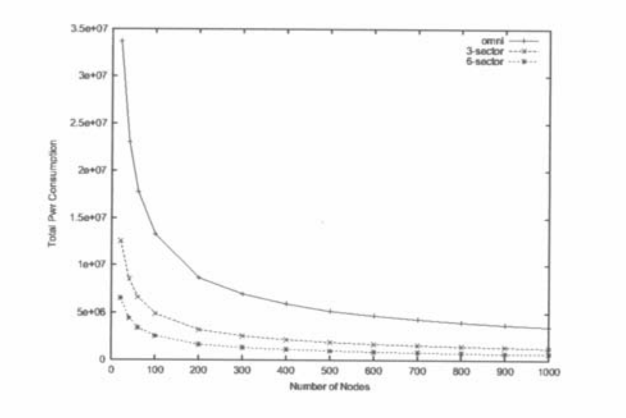
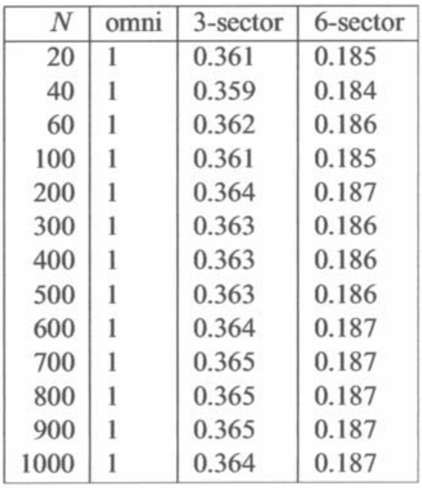


Figure 3: Total power consumption using different number of antenna sectors with various node densities, α = 3



N	omni	3-sector	6-sector
20	1	0.361	0.185
40	1	0.359	0.184
60	1	0.362	0.186
100	1	0.361	0.185
200	1	0.364	0.187
300	1	0.363	0.186
400	1	0.363	0.186
500	1	0.363	0.186
600	1	0.364	0.187
700	1	0.365	0.187
800	1	0.365	0.187
900	1	0.365	0.187
1000	1	0.364	0.187

Table 3: ∝ = 4, normalized power consumption

Analysis and Discussion

It is obvious from the simulation results shown above that the use of sectored antenna drastically reduces the average energy consumption by more than 60% for BIP with 3-sectors antennas, and 80% for BIP with 6-sector antennas. In the following we will attempt to provide an explanation for such energy saving.

The average number of sectors used per node is less than 1.

Assume that there are N nodes, and we color the node black and all the other nodes are colored white. From the algorithm, the node will stay black once is colored that way, but a white node can become black. At each step of our algorithm, at least one new code will be covered, thus the number of black nodes increases at least by one, but most one new sector is used. Thus, the algorithm will terminate within N -1 steps because by that time, all nodes will be black, and we are using at most n-1 sectors. So the average number of sectors per mode is at most N-1/n < 1.

So if the broadcast tree constructed by our modified BIP results in roughly the same broadcasting path as those by BIP, the saving in energy will be about 1-1/S, where S is the number of sectors each node has. For S= 3, the saving is about 67%, and for S=6, the saving would be 83%, witch agrees well with our simulation results.

Another observation is that when the nodes density is increased, the total power consumption (i.e., summation over all nodes) tend to decrease as shown in Figure 3 and 4. The node density is increased by keeping the same simulation area (600x700) and increasing the number of nodes from 20 to 1000. The effect of increasing the node density results is a shorter average distance between nodes. Whenever the average distance between two nodes is reduced by a factor of h, the average power increment is also reduced by a factor of h^{α} (where $\alpha >= 2$). Thus when the number of nodes increases, the average power decreases at faster rate.

Conclusions

In this paper we have extended the "Broadcast Incremental Power" algorithm to handle multi-sector antennas. We have show through extensive simulation that this results in drastic energy saving (e.g., more than 60% for a 3-sectored antenna). We also simulated the extended algorithm under various propagation constraints and node densities. We plan to extend this algorithm to handle multicast communication. In this case we plan to consider both power consumed due to transmitting packets but also due to receiving packets. This has not been addressed in the past. However, this is a major difference between multicast and broadcast since not all nodes are required to be awake to receive multicast packets. Another interesting question to be considered is the energy saving that can be obtained when considering smart antennae that can directional beams.

References

[1] J. E. Wieselthier, G. D. Nguyen, and A. Ephremides, (2000), *On the construction of energy-efficient broadcast and multicast trees in wireless networks,*

[2] P.Wan, G. Calinescu, X. Li, and O. Frieder, (2001), *Minimum-energy broadcast routing in static ad hoc wireless networks*

[3] B. Sklar, (1998), *Digital communications: Fundametals and applications*

[4] T. H. Corman, C. E. Leierson, and R. L. Riviest, (1990), *Introduction to algorithms*