Journal of Information Processing Vol. 16 64–67 (July 2008)

Technical Note

Algorithms for Energy-Efficient Broad- and Multi-Casting in Wireless Networks

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This paper addresses the problem of broadcasting (and multicasting) focusing on the two points of energy efficient networking and of time efficient computing, where all base stations are fixed and each base station operates as an omni-directional antenna. We developed one broadcasting algorithm based on the Stingy method and based on the above performances. We evaluate this and the other two algorithms based on the Greedy and Dijkstra methods.

1. Introduction

In this paper, we study the problems of broadcasting and multicasting in wireless networks. In the network studied here, all base stations are fixed and each base station operates as an omni-directional antenna or transceiver. Therefore, a base station can broadcast to all the base stations that lie within its communication range. This means that there exists a trade-off between an immediate broadcast communication from an original source to all other base stations and the other type of broadcast communication, that is, broadcasting is realized by a set of "multiple hopped multicast communications". Since the propagation loss varies nonlinearly with distance (at somewhere between the second and fourth power), in unicast communications it is the best method (from the perspective of transmission energy consumption) of transmitting at the lowest possible power level, even though doing so requires multiple hops to reach the destination. However, in multicast communications such solutions are not always the best method, because the use of higher power may permit simultaneous communication to a sufficiently large number of base stations that lie within its communication range, so that the total energy required to reach all members of the broadcast or multicast group may actually be reduced [1]. Our problems are condensed into the two problems of energy-efficiency and calculation-time-efficiency.

There have been several papers which treat the problem of broadcasting based on the above two performance indices in the following networks; Voronoi cellular networks [2], wireless networks [3], and mobile Ad Hoc networks [4),5]. As it is known that finding a spanning tree of minimum routing cost in a general weighted undirected graph is NP-hard, and our energy-efficient broadcasting algorithm is also NP-hard, we must find an approximate solution. J.E. Wieselthier, et al. [3] evaluated three algorithms; the Greedy method, the Minimum-Cost Spanning Tree, and the Dijkstra method in wireless networks. They concluded that their presented algorithm based on the Greedy method provided better performance than the others that were developed originally in wired environments. However, in broadcast or multicast applications it is not prudent to draw such conclusions because the networks may not always have base stations randomly located within a region. Each algorithm may have an advantage in each particular circumstance. The purpose of this paper is to make clear the best performing domain of each algorithm, then their performances are evaluated in many types of networks.

2. The Broadcasting Algorithm

We will consider aspects of wireless networks, such that they consist of N nodes (base stations), which are distributed over a specified region. The transmitted power required to support a link between two nodes separated by range r is proportional to r^2.

In the Stingy method the first task is an immediate broadcast communication from an original source to the furthest node, and the next is to find the furthest intermediate station based on energy-efficiency and "one hopped multicast communications". In the following, we will present one Stingy algorithm we have built up. Let the power required to communicate from node A to node B, and the path consisting of hopping nodes to communicate, be E_{AB} and P_{AB} (or $P_{A12\ldots NB}$ when $12\ldots N$ are known as hopping chain nodes), respectively. (Let us see the above algorithm in an example shown in **Fig. 1**.)

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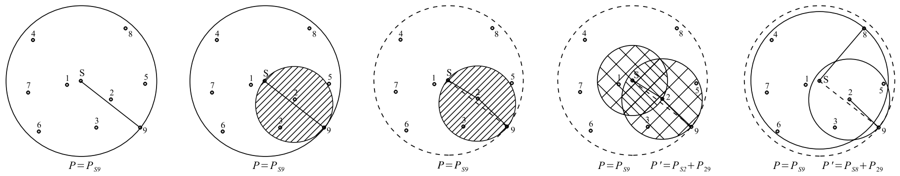


(a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4 (e) Step 5

Fig. 1 Algorithm for broadcasting.

[Broadcast Algorithm]

S1: Let the total power E be E_{SD} where D is the furthest node from the original source node S. ($E = E_{S9}$.)
$E_{det} = 0$ (detected casting nodes power of out rims). $\boldsymbol{R}$ = A set of nodes except S.

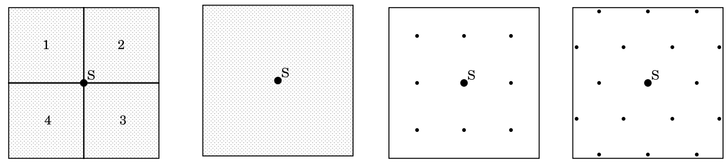
S2: Check whether there is at least one node in the circle with the diameter SD or not.
If there is at least one node, then go to S3, or else go to S6. (See Fig. 1 (b).)

S3: By using the Dijkstra algorithm, check in the circle whether there is at least one set of multiple hopped multicast communications brought on an energy-efficient or not, that is check whether E is greater than $E' = E_{S1} + E_{12} + \cdots + E_{ND}$ where $12\ldots N$ means the path $P_{S12\ldots ND}$ consisting of hopping chain nodes to communicate from S to D.
If there is at least one energy-efficient path, go to S4, otherwise go to S6. (See Fig. 1 (c). $E' = E_{S2} + E_{29}$.)

S4: Check in $\boldsymbol{R}$ whether there is at least one node which cannot communicate from S with the energy E' or not.
If there is at least one node, then let the furthest node from S among them be D' and go to S5 (in order to set a new E'), otherwise go to S6. (See Fig. 1 (d). Nodes 4, 6, 7, 8 are nodes which cannot communicate from S with $E' = E_{S2} + E_{29}$, and $D' = 8$.)

S5: Find the furthest node I from S on path $P_{S12\ldots ND}$ located in the circle with radius SD'.
Let the energy E' be $E_{SD'} + E_{ID} + E_{det}$.
If E is greater than E', then $E \leftarrow E'$, $E_{det} \leftarrow E_{det} + E_{ID}$, and remove all succeeding nodes to I on path $P_{S12\ldots ND}$ from $\boldsymbol{R}$. $D \leftarrow D'$, and go to S2. (See Fig. 1 (d). Since $E = E_{S9}$ is not greater than $E' = E_{S8} + E_{29}$, hold E.)

S6: End. (The final E is E_{S9}.)



(a) Pattern 1⋯5 (b) Pattern 6, 7 (c) Pattern 8 (d) Pattern 9

Fig. 2 9 basic patterns to generate many network examples.

3. Performance Results

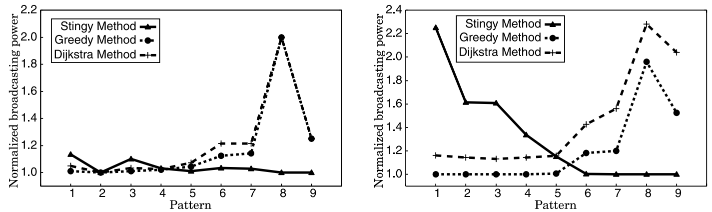
We have evaluated the performance of the three algorithms (Stingy, Greedy and Dijkstra [3])) for 9 different patterns of networks where each pattern has many network examples. Networks with a specified number of nodes (typically 10 or 100) are generated within a square region where the 5×5 region is characterized in the following 9 specified patterns, as shown in **Fig. 2**.

Pattern 1 ⋯ 5; nodes are distributed in normal distribution only in square region 1 / 1 and 2 / 1 and 3 / 1, 2, and 4 / 1, 2, 3, and 4.

Pattern 6, 7; nodes are distributed in normal distribution in the whole region / nodes are randomly distributed throughout the whole region.

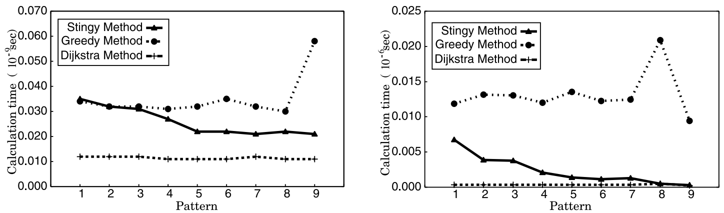
Pattern 8, 9; nodes are distributed in a lattice-patterned distribution in the whole region / in triangular-pattern distribution in the whole region.

A central node is chosen to be the Source. In all patterns, the results are based on the performance of 100 randomly generated networks which typically have 10 or 100 nodes (9 or 121 nodes in Pattern 8, and 13 or 93 nodes in Pattern 9). As mentioned above, one of our performance indices is the total power of the broadcast tree. To facilitate the comparison of our algorithms over a wide range of network examples, we used the notion of the normalized power for each network example, as the same as mentioned in Ref. 3). Let $Q_{best}(m)$ be the lowest power, in all algorithms in our comparison, required to broadcast in the network m. Based on the total power $Q_i(m)$ of the broadcast tree associated with algorithm i for network m, we then define the normalized power to be



(a) 10 node networks (b) 100 node networks

Fig. 3 Mean of normalized broadcasting power.



(a) 10 node networks (b) 100 node networks

Fig. 4 Mean time to calculate the broadcast tree.

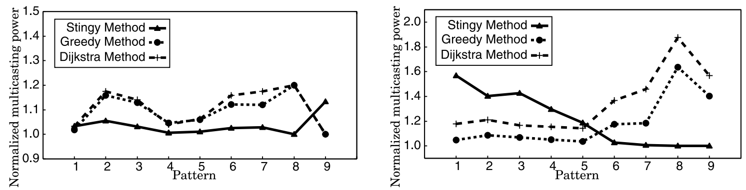
$N_i(m) = Q_i(m)/Q_{best}(m)$.

Figure 3 summarizes the performance results associated with the total power of the broadcast tree required for each algorithm in networks with 10 and 100 nodes, respectively. The Stingy and Greedy methods share the best performing regions, that is, the Stingy method provides the best average performance in patterns over 5 or 6, while the Greedy method provides the best performance except in the specialized region of the Stingy method.

Figure 4 summarizes the performance results associated with the other performance index. For the calculation time required to obtain the broadcast tree, the Dijkstra method provides the best average performance. The Stingy method gave the second best performance.

4. Performance Results for Multicasting Algorithm

In multicasting, we assume that we may use some non-multicast nodes (although they are not necessary to transmit messages) as intermediate nodes to transmit a message to multicast nodes. As was explained in Ref. 3), to obtain the multicast tree based on the Greedy method or Dijkstra method, 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 output [3].



(a) 10 node networks (b) 100 node networks

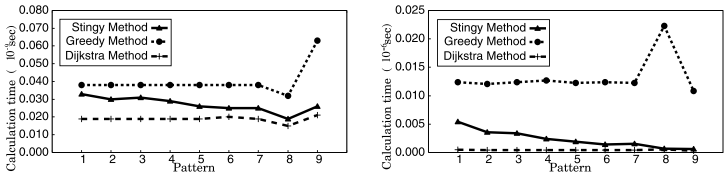
Fig. 5 Mean of normalized multicasting power (multicast node 50%).

As well as in the case of broadcasting, we have evaluated the performance of the three algorithms. Examined network scales are the same as in Section 3. The number of destination nodes is taken as ratios of the total number of nodes (that is, 30, 50, and 70% for 10-node network 5, 10, 25, 50, and 75% for 100-node network).

In the same way as in broadcasting, a central node is chosen to be the Source. In all patterns, the results are based on the performance of 100 randomly generated networks which typically have 10 or 100 nodes (9 or 121 nodes in Pattern 8, and 13 or 93 nodes in Pattern 9).

Figure 5 summarizes the performance results associated with the total power of the multicast tree required for each algorithm in networks with 10 and 100 nodes, respectively. In smaller size networks, the Stingy method provides the best average performance in most patterns, while, in larger size networks, both Stingy and Greedy methods share the best performing regions. The preformance results show a tendency for the best preforming region of the Greedy method to expand as the network size and the number of multicast nodes grow.

Figure 6 summarizes the performance results associated with the other performance index. For the calculation time required to obtain the multicast tree, the Dijkstra method provides the best average performance as well as in the case



(a) 10 node networks (b) 100 node networks

Fig. 6 Mean time to calculate the multicast tree (multicast node 50%).

of broadcasting. The Stingy method gave the second best performance.

5. Conclusion

We have presented one preliminary algorithm based on the Stingy method to address the energy-efficient and calculation-time-efficient broadcasting (and multicasting) problem, and made clear the best performance domain for the representative three traditional algorithms. The evaluation gave the result that, in small size networks, the Stingy method provides the best performance for energy efficient networking in almost all domains. When network sizes become large, it performs the best in the domain where base stations are distributed in the whole network, in detail, irrespective of distribution patterns as long as the base stations are distributed in the whole network. Both the Stingy and Greedy methods share the best performance domain in the larger networks. The Dijkstra method is superior to the others in calculation time. The Dijkstra and the other methods have a trade-off relationship within our performance indices.

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(Received September 19, 2007)
(Accepted January 8, 2008)
(Released July 9, 2008)

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