ONE-TO-ALL AND ALL-TO-ALL BROADCASTING ALGORITHMS IN CELLULAR NETWORKS

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Abstract: In this paper, a one-to-all broadcasting algorithm on a mobile cellular network is first discussed as a minimum diameter spanning tree problem in a graph where every arc has a constant weight. An all-to-all broadcasting algorithm is next discussed on a subject of avoiding heavy traffic conditions. Finally, a fault-tolerant broadcasting scheme is presented.

1 INTRODUCTION

In this paper, we study first the problems of one-to-all broadcasting in cellular networks. For communication primitives, Johnsson and Ho (S.Johnsson, C.T.Ho, 1989) introduced four different primitives:(1)one-to-all broadcasting (or single node broadcasting) in which a single node distributes common data to all other nodes,(2)one-to-all personalized communication in which a single node sends different data to all other nodes,(3)all-to-all broadcasting, and (4)all-to-all personalized communication.

Many researchers have proposed various communication algorithms for various kinds of networks such as multi-computer (hypercube, mesh, torus , or Chordal ring) networks (S.Park, B.Bose, 1997), MINs (multi-stage interconnection networks) (M.Yaku, H.Masuyama, 2001), wireless (J.E.Wieselthier et. al, 2000) or cellular networks (A.E.Baert, D. Seme, 2003). Most of their reports are concentrated on routing and one-to-all broadcasting in the presence of or in the absence of faulty components of the networks, because of the universality and importance of the primitives. This paper treats such one-to-all broadcasting schemes, that is, one node of the network, called “source” has to transmit a message to all other nodes (which are called base stations afterward). In addition, this paper treats all-to-all broadcasting schemes.

The importance of wireless or cellular communications is rapidly growing from the view points of their inherent convenient services. The cellular systems studied here are a little different from wired networks, that is, the emitters of calls are mobiles which are not connected by a physical link to the corresponding base station. All base stations are fixed in the cellular network, and neighboring base stations can communicate through a cable linked between them. Since the base stations operate as omni-directional antennas, then a broadcast from a base station can be received by all mobiles that lie within its communication range which is called “cell”. A mobile cellular network typically covers a large geographical services area which is partitioned into many cells. Central offices of a large telephone network form an irregular and random point pattern which is caused by spatial variations of population density, consumer demand, and a number of other geographical and technological factors (A.E.Baert, D. Seme, 2003). This network model corresponds to a PLMN (public land mobile network) counseled by CCITT.

Mobile environments pose some interesting problems in designing (1) energy efficient broadcasting scheme and (2) fault-tolerant broadcasting scheme. To clear problem (1) is to avoid transmitting the same information from redundant plural base stations to a base station. In other words, we do not consider such “flooding scheme” that copies of a received packet are sent to

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its neighbors except the node sending the packet. The later problem (2) can be cleared by preparing more than one transmission route to every base station (where we consider a link fault to be realistic faults here, and the appropriateness and node faults are discussed afterward). In these avoidance and clearance, there exist two approaches where one is to construct a peculiar broadcast routing tree for each source, and the other is to prepare a fixed common broadcast tree in the cellular network in advance. The former approach presents a drawback leading to the complexity problem of broadcasting algorithm. The latter presents a drawback leading to non-shortest path and the necessity of modification of routing tree when the topology of interconnection may change dynamically. B.A.Elisbeth and S.David (A.E.Baert, D. Seme, 2003) reported on the former approach where they presented a broadcasting algorithm whose order of complexity is the diameter of network. This algorithm is suitable for the fault-tolerance in the sense that it is available as far as the network is connected. We will consider the latter approach.

2 BASIC IDEAS

Mobile cellular network: The network consists of N nodes which are randomly distributed base stations over a specified region and, in order to transfer messages by the links, the neighboring nodes are connected as shown in Fig.1 as an example. Thus, we consider this cellular network is constructed as a mobile cellular network which can serve in the waves propagating area as shown in Fig.2. We note that each service area is not always connected with all its neighboring service areas.

Description of our approach: Fig.3 shows a broadcast tree which is obtained by applying our scheme to the network shown in Fig.1, where N=21. Any node can broadcast its message from its own position to all other nodes by taking a bold line route. This broadcast tree is just a spanning tree. Anywhere the source is, this broadcasting tree is energy-efficient, because any connected graph needs at least N-1=20 arcs, that is minimum. That is, every spanning tree is an energy-efficient tree. We note that the diameter of this broadcasting tree is 10 while the diameter of another spanning tree is 6. A spanning tree of minimum diameter is desirable as a broadcast tree. For the generalized graph, the minimum diameter spanning tree problem was discussed in (R.Hassin, A. Tamir 1995). Since our cellular networks are special in the sense in which arc lengths are all identical, we can obtain a simpler algorithm for an optimum broadcast tree, which is discussed below.

This broadcasting tree is not optimum in all-to-all broadcastings, because, since every source node uses this tree as a unique and common routing tree, the traffic problem occurs. In order to avoid this problem, we need to select the broadcast trees which have the smallest number of arcs in common. We will discuss, an algorithm of this type afterwards.

On the other hand, Fig.4 shows a fault-tolerant broadcasting route. The condition of constructing this original circle is that at least two component nodes are adjacent to each non-component node. In this fault-tolerant route, nodes on the original circle accept messages (from a link) and translate the messages (to all other links), and nodes not on the original circle operate only as receivers if they are not source nodes. Then, the route shown in Fig.4 guarantees that any node can accept a message started from every other node even if any one of links is cut off. The graphs like this can be embedded only in graphs where the degree of every node is over 1. Though the diameter of this fault-tolerant route is not the minimum among the graphs which satisfy the above constructing condition, it is hard to embed the optimum graph like this into a graph. Then, in Sec.3 we discuss an algorithm to obtain the fault-tolerant broadcasting route like the one shown in Fig.4.

Algorithm: The outline of this algorithm is as follows; Find the shortest path tree with each different node as its root. Since the number of nodes in a connected and non-directed graph is N, we obtain N shortest path trees. Next, find a shortest path tree with the minimum diameter among all the spanning trees. This algorithm is based on the theory that the spanning tree with the minimum diameter in a graph is also the shortest path tree. This theory is proved in Appendix1 which is omitted in this paper for space limitation. Along this outline, we can establish the following algorithm:

```
Algorithm A-----------------------------------------------
while i = 1 to N do
  begin
    find the minimum routes from node i to all
    other nodes, and make a shortest path tree T(i)
    with root i.
    find one (j) of the most faraway nodes from i,
    next find one (k) of the most faraway nodes
    from j, finally define the diameter D(i) of T(i)
    as the distance between j and k.
  end
find the minimum value among the diameters D(i)
for all i and output a shortest path tree with the
minimum value D(i).
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Since it takes O(m) time to find a shortest path tree, the time complexity of algorithm A is O(mN), where m is the number of arks in a graph.

All-to-all broadcasting algorithm: The outline of this all-to-all broadcasting algorithm is as follows: Each node i has a spanning tree as its own one-to-all broadcasting route from source node i. An all-to-all broadcasting route is a set of N one-to-all broadcasting routes. Then, in the all-to-all broadcasting, many one-to-all broadcasting routes hold the same arc in common. Data transmitting on a common arc is performed in order of source node number. Optimum solution of this type broadcasting is to find a set of spanning trees where the maximum number of duplications of an arc is the smallest. This problem is defined as follows:

[Let Ti denote a spanning tree rooted at node i and let S denote a set of p spanning trees of G, i.e., S={T1,...,Tp} where p<N, and let (T1,...,TN) be a permutation of N spanning trees in the set S, repetitions allowed. Our optimum solution is a permutation where the maximum number of duplications of any arc is the smallest.]

Since the time complexity to solve the above problem is over the polynomial order, let us consider another algorithm to obtain an approximate solution. The outline of this algorithm is as follows; Let a set of spanning trees of a graph G be S={T1, T2, T3, …, Tp} where S covers all arcs in G.. To each Ti (i=1, 2, 3,…, p), assign $\lfloor N/p \rfloor$ or $\lceil N/p \rceil$ different nodes in G. A set of nodes assigned to Ti is a group of source nodes which use Ti as the broadcast tree. The following algorithm is considered:

```
Algorithm B------------------------------------------------
   begin
      S1: find a set of spanning trees S={T1, T2,
          T3,…, Tp } by which all arcs in a
          connected graph G are covered.
      S2: for every Ti,
          assign Ti to a set of nodes where any two
          elements are congruent to each other
          modulo p.
   end
----------------------------------------------------------------
```

If a simple method to find a spanning tree Ti is adopted, the time complexity is O(mN), where Ti covers (N-1) arcs in G. Then, we must find at most (m-(N-1)) spanning trees where each one can cover at least one arc uncovered by other spanning trees. Since the time complexity to find S is O(mmN), we conclude the time complexity of Algorithm B is O(mmN).

In order to verify the validity of Algorithm B, let us compare Algorithm B and another ordinary algorithm finding a spanning tree for each root node, and evaluate the complications of broadcasting trees in both algorithms. Two algorithms are applied to the graph shown in Fig.5. Figs.6 shows the number of duplicated paths on an arc in each all-to-all broadcasting, and proved the superiority of Algorithm B to the other.

3 FAULT-TOLERANCE

Let us show the following algorithm to obtain the circle from which a fault-tolerant broadcasting route originates.

```
Algorithm C------------------------------------------------
An elemental node is a node adjacent to a node of
degree 2.
A non-elemental node is a node of degree 2 which is
not elemental.
   begin
      S1: find all elemental nodes and non- elemental
          nodes in the mobile cellular network graph
          NW.
      S2: construct a connected graph G of NW
          which contains all the elemental nodes and
          as few non-elemental nodes as possible and
          in which every node is on at least one of
          circles.
      S3: remove non-elemental nodes and the arcs
          incident to them from NW if these non-
          elemental nodes are not in G.
          remove node i and the arcs incident to it
          from NW if two adjacent nodes of i are in G
          and (i has no other adjacent node except in
          G or every one of the remainder adjacent
          nodes of i has two nodes as adjacent nodes
          in G).
      S4: remove an arc connecting two adjacent
          nodes i and j in G from NW and G if i and j
          remain on a loop in G after the arc is
          removed from G.
      S5: remove an arc connecting two adjacent
          nodes i and j in G from NW and G if there
          exists at least one path between i and j in
          NW but at least a part of the path is not in
          G, and add the shortest path of them in G.
      S6: go to S2 if NW =G.
   end
----------------------------------------------------------------
```

4 CONCLUSION

In this paper, we showed that an optimum one-to-all broadcasting algorithm can be applied to the minimum diameter spanning tree problem on mobile cellular networks where every arc has a unity cost. An all-to-all broadcasting scheme is next discussed. A fault-tolerant broadcasting scheme was finally presented. We will discuss multicasting schemes across networks of this type in future.

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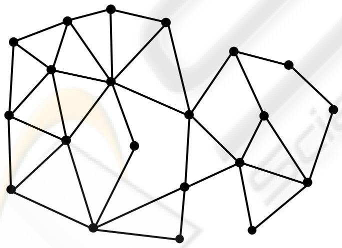

Figure 1: A network of base stations.

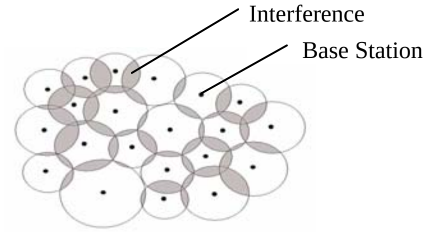

Figure 2: Service area of cellular network based on the network shown in Figure 1.

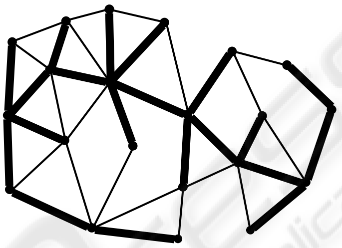

Figure 3: A broadcast tree.

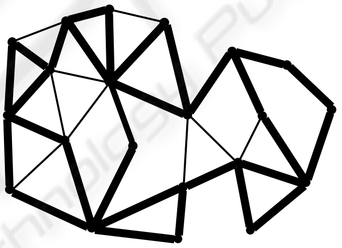

Figure 4: A fault-tolerant broadcasting route.

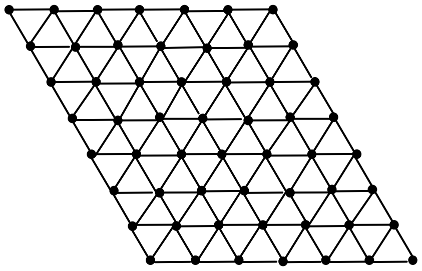

Figure 5: Network used as an example.

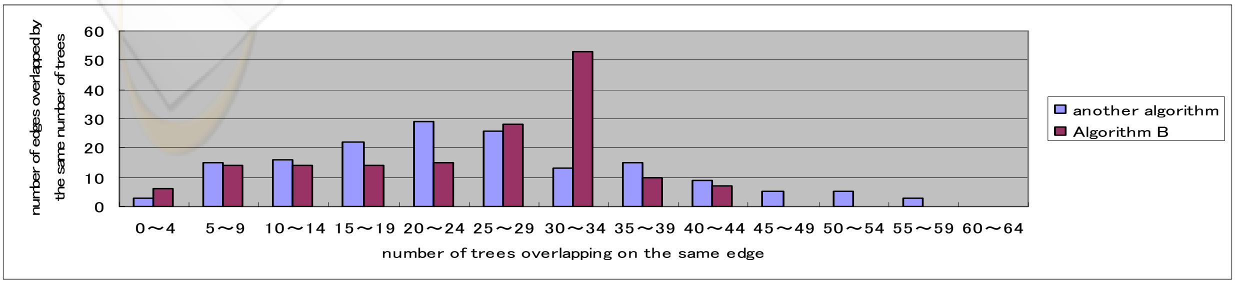

Figure 6: Comparison between two algorithms.