INFORMATION DISSEMINATION IN A NETWORK

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ABSTRACT

This paper addresses the process of information dissemination in a network whereby a message, originated at a node, is transmitted to all other nodes of the network. We restrict our attention to a special type of dissemination process, called 'local broadcasting', where a vertex can either transmit or receive a message and an informed vertex can transmit it to only one of its neighbors at a time. Based on the recently published results for a tree by Koh and Tcha, this paper proposes an efficient heuristic which determines the call sequence at each vertex node under both minimax and minisum criteria. Computational experiments with this heuristic are conducted on a variety of networks of medium size.

1. Introduction

Information dissemination refers to any process whereby a set of messages, generated by a set of originators, is transmitted to a set of receivers within a communication network. Specific classes of information dissemination processes may be defined by placing constraints upon the sets of messages, originators, and receivers and upon the topology and transmission characteristics of the network. Transmission of a message from one originator to one receiver represents the fundamental communication process of message transfer. When both sets of originators and receivers contain all members, we have gossiping. Furthermore, if a message, originated by one member, is transmitted to all members of the network, the process is broadcasting, which is dealt with in this paper.

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Our concern is on the communication delays which occur in sending a message from one member (center) in a network to all other members, which is referred to as *broadcasting* [1]. We restrict ourselves to broadcasting in point-to-point communication networks where a vertex can communicate with its neighbors only one at a time. This type of communication occurs frequently in local networks [29]. This capability for broadcasting a message is required for the transfer of control message necessary for synchronization or for the support of remote file access [3].

Information is transmitted by placing a series of calls over the communication lines of the network. This is to be completed as quickly as possible subject to the constraints that:

i) each call involves only two members - a sender and a receiver;

ii) at any time, a member can participate in at most one of a set of concurrent calls (i.e., calls sharing the same time interval);

iii) for each call, the sender is either the center or has been the receiver of a previous call; and

iv) a member can only call a member to which it is adjacent.

This type of broadcasting is referred to as 'local broadcasting' [2]. Note that restriction (ii) above does not allow simultaneous receptions of several members from one sender, which is distinguishable from radio broadcasting. Restriction (iii) confirms that a sender has been informed of the message being broadcast. Restriction (iv) leads to the term 'local' broadcasting. Under the constraints, information is transferred from a member to its neighbors one after another.

A typical example is depicted in Figure 1. Each circle represents a member and the member 1 is a center which has the information to be broadcast. It is assumed that transmission on each line requires one unit of time. The number beside each member indicates the time at which it receives the information in one possible calling scheme. First, the member 1 sends the information to member 2 during one time unit. Next, members 1 and 2 send it to members 5 and 7 respectively. Then members 1, 2, 5 and 7 send it to members 4, 6, 13 and 16 respectively, and so on. It is easy to check that the time to complete the broadcast process is 6 and the total reception time over all members is 58. Note that reception times are related directly to the calling scheme.

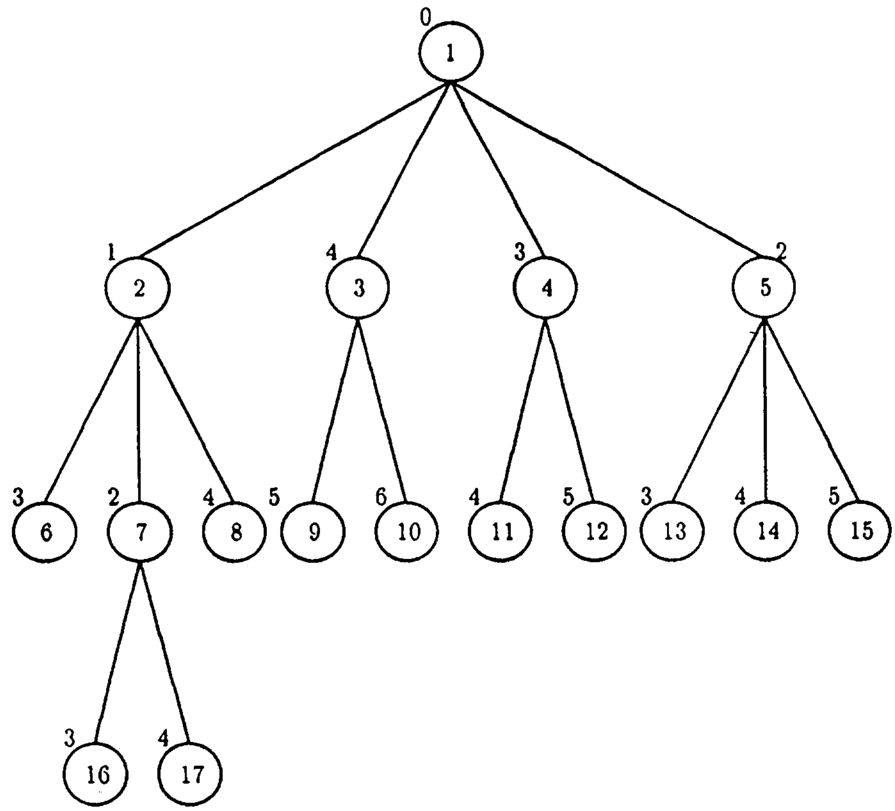

Figure 1. An example of local broadcasting in a tree.

This paper deals with the following problem. Given a network G and a center v in G, determine optimal call sequences at each vertex of the network.

For the case of uniform edge transmission times, it has been shown in [6] that the problem of determining the broadcast time $b(v; G)$ from an arbitrary vertex v in an arbitrary graph G is NP-complete. Scheuermann and Wu (1981) presented a dynamic programming formulation for determining $b(v)$ and a corresponding broadcasting scheme for a vertex v in an arbitrary graph. Scheuermann and Edelberg (1981) implemented a backtracking algorithm based on this formulation (cf. [5]). Since this exact algorithm is not efficient for large graphs, Scheuermann and Wu [5] also presented several heuristics for achieving efficient near-optimal schemes.

For the case of nonuniform edge transmission times, we note that until now no algorithms have been reported in literature. In this paper, some heuristics are presented for this case and their performances are evaluated.

2. Sequencing Strategies

In this section we describe some sequencing strategies which will be used to derive various heuristic algorithms. Some of them are based on the results of the tree-type network analysis and others take vertex degrees into consideration.

Assume that a vertex v has just completed transmission to its neighbor u, and the two vertices are to determine to whom they transmits the information respectively. Possible sequencing strategies are as follows.

Heuristic 1 (H1) : Minimax sequencing based on the shortest path tree
Once a shortest path spanning tree is determined from the center, sequencing for the tree under minimax criterion is adopted.

Heuristic 2 (H2) : Minisum sequencing based on the shortest path tree
Once a shortest path spanning tree is determined from the center, sequencing for the tree under minisum criterion is adopted.

Heuristic 3 (H3) : Eccentricity-based sequencing
The sequence is determined according to the eccentricity of the neighbors.

Heuristic 4 (H4) : Degree-based sequencing

The sequence is determined according to the degrees of the neighbors.

Heuristic 5 (H5) : Variation of degree-based sequencing
The sequence is determined according to the number of uninformed vertices adjacent to the neighbors.

Heuristic 6 (H6) : Random sequencing
An informed vertex randomly selects its neighbor.

The eccentricity $e(v)$ of a vertex v in G is defined as

$$e(v) = \max_{x \in V} \quad \mathrm{dist}(v, x),$$

where $\mathrm{dist}(v, x)$ is the length of the shortest path between v and x in the network G.

Heuristics 1 and 2 are considered expecting that the results for the tree-type network might hold good for the general case. Observe that Heuristic 3 attempts to select the neighbor with the highest degree of urgency and Heuristic 4 attempts to choose the neighbor that will be able to broadcast as many times as possible. Heuristic 5 takes account of the current state of the neighbors. Heuristic 6 seems to be the least effective, but is considered for comparisons.

3. Algorithms

With the strategies described in the preceding section, heuristic algorithms can be designed. But in order to evaluate the performance of each heuristic, a number of experiments are conducted for several networks. At each iteration, a network is generated, each heuristic is applied, and the result is analyzed. The general structure of the procedure is as follows.

Phase I — Network generation

Given the number of vertices, N, a random network is generated. First, for each vertex, degree is generated using a binomial distribution, $b(n,p)$, which is truncated by excluding the probability of zero. Then with the generated degrees, vertices are connected in random fashion. Once a network is constructed, edge transmission times are also generated. Exponential or uniform distribution is used.

Phase II — Shortest-path-tree construction

In the network generated in Phase I, shortest paths from a vertex to all the other vertices are found using Dijkstra method. It has been shown that they form a tree. This tree will be used for call sequencing at each vertex with the results of the previous chapters.

Phase III — Priority determination for call sequencing

At each vertex, priorities of its neighbors are determined to be used for call sequencing at the vertex. For Heuristics 1 and 2, the results for a tree by Koh and Tcha [4] can be applied on the shortest-path-tree. For Heuristic 3, eccentricities of all vertices are computed and priorities are determined such that the top priority is given to the one with the largest eccentricity. For Heuristic 4, degrees have already been obtained in Phase I and thus priorities are easily determined. For Heuristic 5, priorities are determined during the broadcast process. For Heuristic 6, no priorities are needed.

Phase IV — Broadcasting

Broadcasting from the specified center is implemented for each of the sequencing strategies. During the process, an informed vertex determines call sequences according to the priorities obtained in Phase III. Suppose that transmission from a vertex u to a vertex v is completed at time t. Then each of the two vertices selects as the next receiver the one with the highest priority among its neighbors which are not informed. Transmissions from u and v to their respective partners are scheduled. For Heuristic 5, if a vertex receives the information, then the current degrees of its neighbors are decreased by 1. The modified degrees are used for determining the priorities.

The above structure is taken as the main framework in each heuristic except that Phase 2 is involved only in Heuristics 1 and 2.

4. Experimentations

A number of experiments have been conducted to compare the sequencing strategies in terms of maximum and average reception time. Using the algorithm as stated in the preceding section, six heuristics have been applied to the same network generated.

Network size, degree distribution, and distribution of edge transmission times are given as inputs for the algorithm. Let N be the number of vertices of the network and (n, p) be the parameter of a binomial distribution. We have conducted the experiments for the following sets of (N, n, p);

$N = 50, 100$;

$n = 5, 10, 15$;

$p = 0.3, 0.5, 0.7, 0.9$.

In addition, two probability distributions for edge transmission time were considered. One is the exponential distribution of which the mean is 10. In order to exclude extreme values, it was truncated such that generated times were all between 10 and 90 percentiles. The other is the uniform distribution $U(5, 15)$.

For each set of the above inputs, 50 networks were generated; thus a total of $2 \times 3 \times 4 \times 2 \times 50 = 2400$ networks were experimented with and $2400 \times 6 = 14400$ broadcasts were tried. The arithmetic means of maximum and average of reception times were obtained for each of the heuristics.

The results of these experiments appear in Tables 1 and 2. Table 1 shows the results for the uniform distribution of edge transmission time and Table 2 shows the results for the exponential distribution. Density indicates the sparsity of the generated network, i.e., the ratio of the total number of the edges of the network to the total number of edges of the complete network of the same size.

Table 1. Results for the uniform distribution
(a) $N = 50$

n	p	d	H1	H2	H3	H4	H5	H6
5	0.3	0.040	186.56*	186.56	186.56	186.56	159.00	186.56
			95.05**	95.05	95.05	95.05	82.40	95.05
5	0.5	0.050	136.52	136.50	136.50	136.50	120.00	136.58
			78.76	78.68	78.68	78.68	68.65	78.75
5	0.7	0.070	87.68	87.98	87.98	87.98	81.14	87.82
			57.47	57.43	57.43	57.43	52.36	57.46
5	0.9	0.089	75.06	75.10	75.10	75.10	71.78	75.08
			51.73	51.60	51.59	51.59	48.86	51.60
10	0.3	0.060	110.08	109.58	109.58	109.58	95.74	109.54
			66.40	66.29	66.29	66.29	57.01	66.34
10	0.5	0.098	78.52	78.10	78.26	78.26	72.14	78.40
			54.05	54.01	53.99	53.99	48.45	54.00
10	0.7	0.137	70.18	70.38	70.38	70.38	66.94	70.02
			50.44	50.26	50.27	50.27	47.54	50.21
10	0.9	0.176	70.42	69.32	69.32	69.32	67.28	69.68
			51.61	50.88	50.88	50.88	49.20	50.98
15	0.3	0.089	83.28	83.52	83.50	83.50	75.68	83.36
			56.42	56.26	56.26	56.26	50.18	56.31
15	0.5	0.145	71.72	70.88	70.80	70.80	65.90	70.86
			51.34	50.89	50.88	50.88	46.76	50.89
15	0.7	0.205	68.94	68.08	68.08	68.08	64.74	67.72
			50.36	49.69	49.70	49.70	46.62	49.72
15	0.9	0.263	69.54	68.48	68.38	68.38	66.20	68.60
			51.37	50.42	50.41	50.41	48.28	50.60

* maximum reception time
** average reception time

(b) $N = 100$

n	p	d	H1	H2	H3	H4	H5	H6
5	0.3	0.020	264.82* 136.52**	264.82 136.51	264.82 136.51	264.82 136.51	220.18 114.24	264.82 136.51
5	0.5	0.025	172.76 102.35	172.12 102.11	172.12 102.11	172.12 102.11	147.40 86.90	172.66 102.13
5	0.7	0.035	105.46 70.44	104.40 70.22	104.40 70.22	104.40 70.22	95.46 63.07	104.82 70.25
5	0.9	0.044	89.40 63.82	89.06 63.65	89.06 63.65	89.06 63.65	85.02 60.22	89.34 63.68
10	0.3	0.030	128.82 80.44	128.04 80.30	127.88 80.30	127.88 80.30	111.50 68.75	128.50 80.39
10	0.5	0.049	90.20 64.28	91.02 64.08	91.02 64.07	91.02 64.07	83.94 58.56	91.18 64.22
10	0.7	0.068	85.00 62.84	83.72 62.26	83.70 62.28	83.70 62.28	78.82 57.60	84.26 62.37
10	0.9	0.087	82.20 61.33	80.68 60.67	80.68 60.67	80.68 60.67	77.80 58.25	80.72 60.62
15	0.3	0.044	98.54 67.64	97.74 67.26	97.74 67.25	97.74 67.25	88.28 59.52	97.56 67.35
15	0.5	0.073	83.26 61.93	82.38 61.38	82.50 61.39	82.50 61.39	77.66 56.37	82.60 61.48
15	0.7	0.101	80.86 61.01	79.52 60.02	79.50 60.01	79.50 60.01	75.94 57.05	79.64 60.05
15	0.9	0.130	78.90 60.23	77.60 59.22	77.62 59.22	77.62 59.22	75.74 57.42	77.68 59.19

* maximum reception time
** average reception time

Table 2. Results for the exponential distribution

(a) $N = 50$

n	p	d	H1	H2	H3	H4	H5	H6
5	0.3	0.040	168.18*	168.18	168.18	168.18	139.42	168.18
			89.62**	89.62	89.62	89.62	72.03	89.62
5	0.5	0.050	134.02	133.68	133.50	133.50	113.74	133.42
			76.86	76.47	76.47	76.47	62.64	76.53
5	0.7	0.070	77.66	76.30	76.44	76.44	71.84	76.62
			47.47	46.50	46.49	46.49	43.42	46.58
5	0.9	0.089	63.38	61.96	62.04	62.04	60.44	61.92
			39.56	38.45	38.44	38.44	36.92	38.55
10	0.3	0.061	94.62	93.22	93.22	93.22	84.32	93.62
			55.23	54.81	54.76	54.76	46.43	54.95
10	0.5	0.099	63.28	61.46	61.80	61.80	61.76	62.22
			39.05	37.52	37.48	37.48	37.41	37.76
10	0.7	0.137	53.88	53.08	53.22	53.22	53.88	53.54
			32.69	31.87	31.86	31.86	33.28	32.09
10	0.9	0.175	49.76	48.50	48.34	48.34	51.44	48.30
			30.46	29.00	28.97	28.97	31.26	29.14
15	0.3	0.089	68.48	67.82	67.82	67.82	66.02	67.84
			42.51	41.76	41.76	41.76	38.57	42.01
15	0.5	0.147	55.70	54.14	54.10	54.10	56.86	54.34
			34.65	33.45	33.44	33.44	34.81	33.54
15	0.7	0.205	48.94	47.12	47.14	47.14	54.68	47.22
			28.94	27.56	27.53	27.53	34.14	27.59
15	0.9	0.263	45.90	45.24	45.16	45.16	50.28	45.36
			26.99	26.14	26.13	26.13	30.31	26.30

* maximum reception time
** average reception time

(b) $N = 100$

n	p	d	H1	H2	H3	H4	H5	H6
5	0.3	0.020	224.10*	223.64	223.64	223.64	180.94	223.64
			115.30**	115.27	115.27	115.27	91.22	115.27
5	0.5	0.025	144.46	142.82	142.40	142.40	120.74	142.86
			83.37	82.76	82.69	82.68	68.58	82.82
5	0.7	0.035	87.74	86.10	85.76	85.76	79.96	87.00
			54.92	53.95	53.87	53.87	48.50	54.09
5	0.9	0.044	76.14	74.80	74.78	74.78	71.18	74.66
			49.81	48.28	48.23	48.23	45.77	48.30
10	0.3	0.030	115.94	113.40	113.84	113.84	98.98	113.78
			68.64	67.65	67.64	67.64	58.24	67.86
10	0.5	0.049	74.52	71.36	71.48	71.48	68.28	72.52
			46.82	45.19	45.17	45.15	41.40	45.40
10	0.7	0.068	66.38	63.54	63.00	63.00	62.32	63.60
			42.63	40.44	40.27	40.26	39.86	40.64
10	0.9	0.087	61.66	58.96	58.68	58.68	60.92	59.12
			39.75	37.38	37.33	37.33	38.83	37.50
15	0.3	0.044	81.98	78.90	78.82	78.82	74.14	79.04
			52.44	50.26	50.18	50.18	44.91	50.53
15	0.5	0.073	64.52	62.70	62.58	62.58	62.78	63.02
			41.99	40.07	40.03	40.03	39.57	40.29
15	0.7	0.102	58.08	55.40	55.32	55.32	60.28	55.62
			36.70	34.31	34.26	34.27	38.18	34.65
15	0.9	0.131	54.00	51.08	51.16	51.20	58.24	51.26
			33.23	30.93	30.90	30.90	36.69	30.99

* maximum reception time
** average reception time

5. Result Analyses and Discussions

For the uniform distribution, Heuristic H5 outperforms other heuristics in all cases. It coincides with the result of [5], wherein some heuristics were experimented for the simplifying case that each call requires one unit of time. But contrary to expectations, Heuristics H1 and H2 do not give good results. Rather H1 has the worst performance in most cases.

For the exponential distribution, extreme behaviors are observed for Heuristic H5 depending upon the sparsity of the network. In a sparser network, it yields the best result. But as the density of the network becomes larger, its performance goes down. When the density is larger than 0.1, H1 is the worst strategy and H3 and H4 are relatively good ones.

From the observations, we deduce the following:

(i) for the uniform distribution, since variation in edge transmission times is relatively small, edge transmission time has little effect on call sequencing;

(ii) for the exponential distribution, the situation is reversed;

(iii) rather than degree distribution, the sparsity of the network has more effect on the performance of sequencing strategies;

(iv) in a sparse network, since the number of possible recipients is small, it seems a good strategy to transmit a message first to the member with the largest number of uninformed neighbors; and

(v) when the network is dense, the number of possible recipients is large for each vertex and thus not only the vertex degree but also the eccentricity is the important factor to be considered in determining the call sequence.

6. Conclusions

This paper is concerned with information dissemination in a communication network, whereby a message, originated by one member, is transmitted to all members of the network. It has been assumed that each call has two participants, a member may be a participant in at most one call during any time, and a member may only call another member to which it is directly connected by a line of the network. Almost all of the existing studies have made the assumption that each call requires one unit of time. The problem for the nonuniformly weighted edge transmission times has been left open. The main objective of this thesis is to investigate the extended case.

In this paper, broadcasting in a general-type network has been considered. Some heuristics have been presented and their performances have been evaluated through the computer simulation. It has been shown that for a sparse network or for a network with small variance of edge transmission times, it is good to send a message first to the member with the largest number of uninformed neighbors. But for a network with large variance, it has been shown that the eccentricity or vertex degree is the important factor which one must take into consideration in determining call sequences.

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