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Multicast Routing Based on the Ant System[1]

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Abstract

Based on the Ant System algorithm,we propose an efficient algorithm for generating a low-cost multicast routing subject to delay constraints(ASDLMA).The algorithm first construct a backup-paths-set from the source node to each destination nodes using Dijkstra Kth shortest path algorithm.Then transformed the formed procedure of the multicast tree to the Graph.When a ant on the Graph moves from a node to other node depend on the corresponding probabilities function, and update the pheromone on Graph when every iteration finished. Simulation results show our algorithm has features of well performance of cost, fast convergence and stable delay.

Mathematics Subject Classification: 68T20

Keywords: multicast routing, Ant System, delay constraint

1 Introduction

As computer networks become faster, new multimedia services such as videoconferencing are being offered.Networks of the future will be able to carry multimedia packets containing video and voice data in real time. Although networks are being faster and their capacity is increasing, reducing the cost of communications remains as an issue.As a typical multimedia application, videoconferencing requires two or more participants communicating simultaneously. In simple cases among the multicasting nodes, only one source node

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transmits data to destinations whereas in some cases all nodes in the multicasting set may become a source node individually. Before each multicasting session, a route that minimizes the network cost between communicating parties is to be chosen. This decision problem is closely related with the Steiner tree problem (STP) which is known to be NP-complete [1].

A good survey for multicast routing algorithms is provided by Salama[2]. Multicast routing algorithms can be classified into two categories.The first category is the shortest path algorithms,which minimize the cost of each path from the source node to a multicast group member node.The other category is the minimum Steiner tree algotithms.Their objective is to minimize the total cost of the multicast tree.The first heuristic for delay constrained minimum Steiner tree problem was given by Kompella[3] and is referred to KPP.The heuristic is dominated by the computation of a constrained closure gragh which takes time $O(u \mid v \mid^3)$.When the link delays and u takes nonintegers.Following this approach,KPP is guaranteed to construct a constrained tree if one exists.The bounded shortest multicast algorithm,BSMA is another delay constrained minimum Steiner tree algorithm that is constrained the best in terms of tree cost[4].BSMA iteratively replaces the edges in the tree until the tree cost cannot be further reduced.The time complexity for BSMA is $O(k \mid v \mid^3 \lg \mid v \mid)$,where k may be very large in case of large,densely connected network,and it may be difficult to achieve acceptable running times.

We used one of the well known Artificial Intelligence techniques, Ant System(AS) for solving this problem,which is successful on similar difficult combinatorial problems[5]. The meta-heuristic algorithm on the base of ants behavior was developed in early 1990s by Dorigo, Maniezzo, and Colorni (1991). They called it Ant System because it was motivated by ants social behavior. Ants are capable of finding the shortest path from food source to their nest or vice versa by smelling pheromones which are chemical substances they leave on the ground while walking. Each ant probabilistically prefers to follow a direction rich in pheromone. This behavior of real ants can be used to explain how they can find a shortest path.

In this paper,we propose an efficient algorithm based on AS for generating a low-cost multicast tree subject to delay constraints.We call this algorithm AS for delay-constrained low-cost multicast routing algorithm(ASDLMA).The algorithm starts with a backup-paths-set from the source node to each destination nodes using Dijkstra Kth shortest path algorithm.Then transform the formed procedure of the multicast tree to the Graph,and use AS to the QoSR problems: when a ant move from the node i to the node j depend on the corresponding probabilities function, and update the Pheromone on Graph when every iteration finished. Simulation results show our algorithm has features of well performance of cost, fast convergence and stable delay.

The rest of the paper is organized as follow.Section 2 defines the delay constrained multicast routing problem.Sections 3 describes our Ant-System-based QOS multicasting algorithm followed by time complexity of the algorithm.Simulation results and comparison with other reported heuistics are presented in Section4.Section 5 concludes the paper.

2 Problem formulation

Mathematically, the delay-constrained low-cost multicast routing problem can be formulated as follows. Given a graph $G = (V, E)$. with node set V and edge set E, we define two objective functions, c(u,v) and d(u,v), on each edge $(u, v) \in E$. Let c(u,v) denotes the cost of edge (u,v) and d(u,v) be its delay. We assume that c(u,v)=c(v,u) and d(u,v)=d(v,u). Let P(u,v) denotes a constrained shortest path from u to v, where a constrained shortest path between nodes u and v is defined as the path with the least cost from u to v, subject to the constraint that the total delay along this path from u to v is less than the delay constraint $\triangle$. Let C(u,v) and D(u,v) denotes the cost and delay of this path, respectively. Let $\mid V \mid= n$,$\mid E \mid= m$. On this graph, we have a source node s, and a set of destination nodes M, called the multicast group. The set of vertices from the set V-M-s are called Steiner vertices. We try to construct a Delay Constrained Steiner tree T rooted at s, that spans the destination nodes in M such that for each node m in M, the delay on the path from s to m is bounded by a delay constraint $\triangle$.

Formally, for each $m \in M$; if $p(s, m)$ is the path in T from s to m,then

$$\sum_{e \in p(s,m)} d(e) < \triangle. \qquad (1)$$

where $\triangle$ is the delay bound value.

The minimum cost delay constrained multicast tree is a delay constrained steiner tree T such that

$$\sum_{e \in T} c(e) \qquad (2)$$

is minimised.

3 Ant-System-based QOS multicasting algorithm

3.1. Ant System

The nature has always been fascinating to human being and it has inspired many theories to be applied to various areas. The ant systems emulate the behaviour of real ants. Ants deposit a substance called pheromone on the path that they have traversed from the source to the destination nest and the ants coming at a later stage apply a probabilistic approach in selecting the node with the highest pheromone trail on the paths.Thus the ants move in an autocatalytic process (positive feedback), favouring the path along which more ants have travelled and by and by traverse all the nodes.

Ant system[5], was developed by Dorigo, Maniezzo and Colorni in 1991. AS is characterized by the fact that the pheromone update is triggered once all ants have completed their solutions and it is done as follows. First, all pheromone trails are reduced by a constant factor, implementing in this way the pheromone evaporation. Second, every ant of the colony deposits an amount of pheromone in its path which is a function of the quality of its solution. Initially, AS did not use any centralized daemon actions (actions not performed by the ants but by an external agent, which have not got any natural counterpart, but are just additional procedures to improve the meta-heuristic performance), but it is very straightforward to, for example, add a local search procedure to refine the solutions generated by the ants.

Solutions in AS are constructed as follows. At each construction step, an ant h in AS chooses to go to a next node with a probability that is computed as

$$f_{ij} = \begin{cases} \frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{u \in N_h(t)} [\tau_{iu}]^{\alpha}[\eta_{iu}]^{\beta}} & if \;\; j \in N_h(i), \\ 0 & otherwise \end{cases} \qquad (3)$$

where $N_h(t)$ is the feasible neighborhood of ant h when located at node i, and $\alpha, \beta \in R$ are two parameters that weight the relative importance of the pheromone trail and the heuristic information. Each ant h stores the sequence it has followed so far and this memory L_h is exploited to determine $N_h(i)$ in each construction step.

As said, the pheromone deposit is made once all ants have finished to construct their solutions. First,the pheromone trail associated to every edge is evaporated by reducing all pheromones by a constant factor:

$$\tau_{ij} \longleftarrow (1-\rho) \cdot \tau_{ij}, \qquad (4)$$

where $\rho \in (0, 1]$ is the evaporation rate.Next,each ant retracts the path it has followed (stored in its local memory L_h) and deposits an amount of pheromone $\triangle\tau_{ij}^h$ on each traversed connection (on-line a posteriori update or global update)

$$\tau_{ij} \longleftarrow \tau_{ij} + \triangle\tau_{ij}^h \qquad \forall\ \alpha_{ij} \in S_h \qquad (5)$$

The pheromone on a connective path (i, j) left by the mth ant is the inverse of the total length traveled by the ant in a particular cycle. The formula is as follows:

$$f_{ij} = \begin{cases} \frac{Q}{L_m} & if\, ant\, goes\, from\, connectione(i,j); \\ 0 & else \end{cases} \qquad (6)$$

In the above formula, Q is a constant, and L_m is the total path cost traveled by the mth ant during a cycle. Therefore, the longer an ant travels, the weaker the pheromone strength becomes on each connective path. In contrast, the shorter an ant travels on a path, the stronger the residual pheromone becomes. Therefore, the ants that travel more segments leave less pheromone.

3.2. The algorithm details

ASDLMA belongs to source-based routing algorithm, because it assumes that sufficient global information is available to the source.

Step1: Backup-paths-set

For each destination node $m_i \in M$, we compute least-cost paths from s to m by using Dijkstra Kth shortest path algorithm to construct a backup-paths-set[2,6,7]. Let P_i be paths set for destination node i:

$$p_i = \{p_i^1, ..., p_i^j, ..., p_i^k\}, \qquad (7)$$

where p_i^j is the jth path for destination node i.

It might happen the some of the trees violate delay constraint. In that case, we assign an extra penalty by increasing its cost, so that it is less likely to be accepted.If there are no k different path from the source to destination node i satisfied the dalay constraint,show the dalay constraint Δ is too small,then negotiate with destinations node above the dalay constraint[8].

Step2: Encoding and the solution

In ASDLMA, a multicast tree T is encoded as an array of $m = |M|$ elements, where each element is a path from source s to a destination node $m_i \in M$.i.e.,$T = \{p_1, p_2, ..., p_m\}$,where $p_i = p(s, m_i)$,$m_i \in M$,p_i is a path select from Backup-paths-set,which is introduced in the step1.

Step3: Transformation the formed procedure of multicast tree to the Graph

Consider the multicast tree $T = \{p_1, p_2, ..., p_m\}$,where $p_i = p(s, m_i), m_i \in M$,$1 \leq i \leq k$.

Suppose m=4,k=3,for example, the multicast tree $T' = \{1, 3, 2, 1\}$ is equal that the destination node m_1 select the first path in corresponding set p_1,which is p_1^1;The destination node m_2 select the third path in corresponding set p_2,which is p_2^3;The destination node m_3 select the second path in corresponding set p_3,which is p_3^2;The destination node m_4 select the first path in corresponding set p_4,which is p_4^1.Wo suppose that the multicast tree $T' = \{1, 3, 2, 1\}$ is formed by the procedure:$\{0, 0, 0, 0\} \longrightarrow \{1, 0, 0, 0\} \longrightarrow \{1, 3, 0, 0\} \longrightarrow \{1, 3, 2, 0\} \longrightarrow \{1, 3, 2, 1\}$.

So the formed procedure of all multicast tree $T = \{p_1, p_2, ..., p_m\}$(m=4,k=3) is consider as the Graph showed in Fig.1.

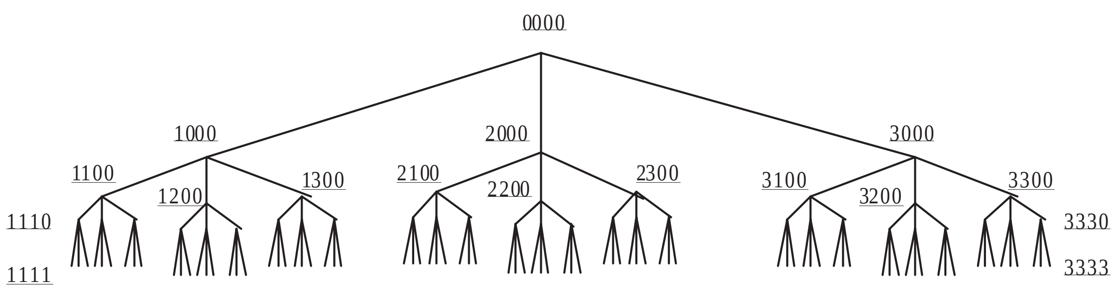


Fig.1. Graph of the formed procedure of all multicast tree(m=4,k=3)

For example,the multicast tree $T' = \{1, 2, 4, 2\}$ is formed by the procedure: $\{0, 0, 0, 0\} \longrightarrow \{1, 0, 0, 0\} \longrightarrow \{1, 2, 0, 0\} \longrightarrow \{1, 2, 4, 0\} \longrightarrow \{1, 2, 4, 2\}$.it is equal that in the first step,the destination node m_1 select path p_1^1;In the second step,the destination node m_2 select path p_2^2; In the third step,the destination node m_3 select path p_3^4;In the forth step,the destination node m_4 select path p_4^2.

Similar to for TSP problems,it is obviously found from the Graph that we could use AS algorithm to the QoSR problem.Suppose in the first step,the multicast tree select a path from p_1 for the destination node m_1;In the second step,select a path from p_2 for the destination node m_2;In the third step,select a path from p_3 for the destination node m_3;In the forth step,select a path from

p_4 for the destination node m_4.At last formed a complete multicast tree,which consist of source node and all the destination node.

Step4: Path selection procedure

When a ant move from the node i to the next node j,the probability function of the ant choosing node j as the next node as follows:

$$f_{ij} = \begin{cases} \frac{[\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{u \in N_h(t)}[\tau_{iu}]^{\alpha}[\eta_{iu}]^{\beta}} & if \;\; j \in N_h(i), \\ 0 & otherwise \end{cases} \quad (8)$$

α and β are the relative importance of pheromone strength and the distance between nodes that affect an ants judgment when choosing the next node to select.

Step5: Pheromone update method

The pheromone trail associated to every edge is evaporated by reducing all pheromones by a constant factor:

$$\tau_{ij} \longleftarrow (1-\rho)\cdot\tau_{ij} \quad (9)$$

where $\rho \in (0, 1]$ is the evaporation rate.Next,each ant retracts the path it has followed (stored in its local memory L_h) and deposits an amount of pheromone $\triangle\tau_{ij}^{h}$ on each traversed connection (on-line a posteriori update or global update)

$$\tau_{ij} \longleftarrow \tau_{ij} + \triangle\tau_{ij}^{h} \qquad \forall \;\; \alpha_{ij} \in S_h \quad (10)$$

The pheromone on a connective path (i, j) left by the mth ant is the inverse of the total length traveled by the ant in a particular cycle. The formula is as follows:

$$\tau_{ij}^{h} = \frac{Q}{L_m}$$

In the above formula, Q is a constant, and $L_m = (c_j - c_i)$,where c_i is cost of sub multicast tree node i and c_j is cost of sub multicast tree node j.To avoid the situation of $c_i = c_j$,we compute as $L_m = (c_j - c_i)^2 + 1$.

Step6: Stopping criterion

The stopping criterion of AS algorithm could be specified by a maximum number of iterations, a specified CPU time limit, or a given number of consecutive iterations within which no improvement on solutions is attained. Unless otherwise specified, in this paper, we set our criterion to the first one.

Procedure ASDLMA (G=(V,E),s,M,Δ)

1. Initialize,construct backup-paths-set using Dijkstra Kth shortest path algorithm;
2. While (termination criterion not satisfied) do
3. For (each ant in the colony)
4. Begin from the source node s;
5. While(for every destination node)
6. Compute the corresponding probabilities function $f_{i,j}$ in Graph;
7. Compute τ_{ij}^{h};
8. Local_pheromone_update();
9. Endwhile
10. Compute the multicast tree cost;
11. Endfor
12. Select the best solution in the iteration;
13. Global_pheromone_update();
14. Return the best solution in the procedure;
15. End while

End procedure

Fig.2. The pseudo code for ASDLMA

3.3.The complexity analysis

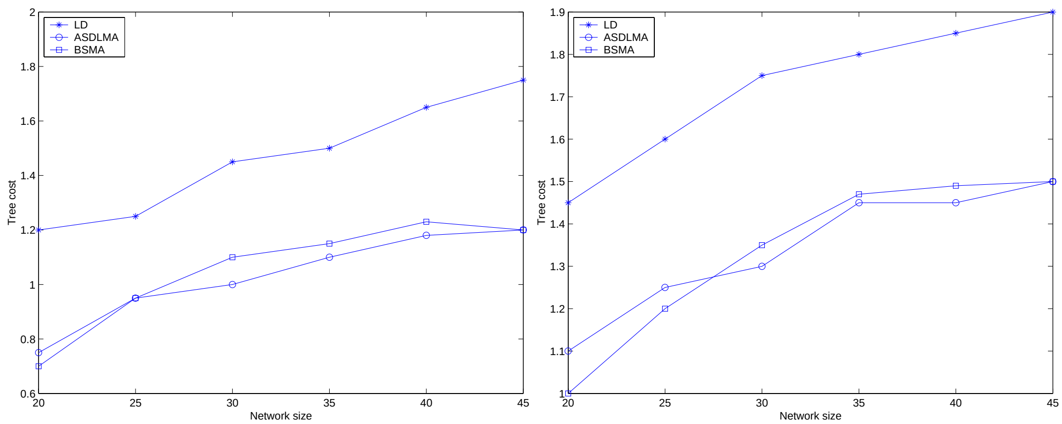
Theorem 1. The time complexity of ASDLMA is $O(kmn^3)$, where m is group size and n is network size, k is the parameter in $k-SPA$.

Proof: The complexity of constructing backup-paths-set by using $k-SPA$ is $O(kmn^3)$. In each iterations,our algorithm use m step(ith step to select a path to destination node i from the backup-paths-set p_i,where 1 ≤ i ≤ m) to construct a complete multicast tree;In each step(suppose the ith step)select a path to destination node i from the backup-paths-set p_i according to the path selection function,where1 ≤ i ≤ m and length of set p_i is k;So the complexity of each iteration is $O(mk)$ and the complexity of the iterations is $O(Imk)$,where I is the iteration times.The term $O(Imk)$ is usually much smaller than kmn^3, so the worst time complexity of SADLMA is $O(kmn^3)$.

4 Simulation results and discussion

The AS algorithm described in this paper has been tested on several randomly generated networks based on the Waxman's algorithm[1].In the algorithm, n nodes are randomly distruted over a rectangular coordinate grid.Each node is placed at a location with integer coordinates. The Euclidean metric is then used to determine the distance between each pair of nodes.On the other hand,edges are introduced between pairs of nodes u,v with a probability that depand on the distance between them. The edge probability is given by $P(u, v) = \beta exp(-d(u, v)/\alpha L)$,where $d(u, v)$ is the distance from node u to v,L is the maximum distance between two nodes,and α and β are parameters in the range (0,1).Larger values of β result in graghs with higher edge densities,while small values of α increase the density of short edges relative to longer ones.The cost of each edge was set to the Manhattan distance between its endpoints plus one. By adding one to the Manhattan distance, the unintersting case of zero edge cost is eliminated. The delay of an edge is set to a uniform random number in (0,l] time its cost plus one. This definition of delay is used to eliminate the unrealistic possibility of zero delay[1].If there are no k different path from the source to destination node i satisfied the dalay constraint,show the dalay constraint Δ is too small,then negotiate with destinations node above the dalay constraint[8].

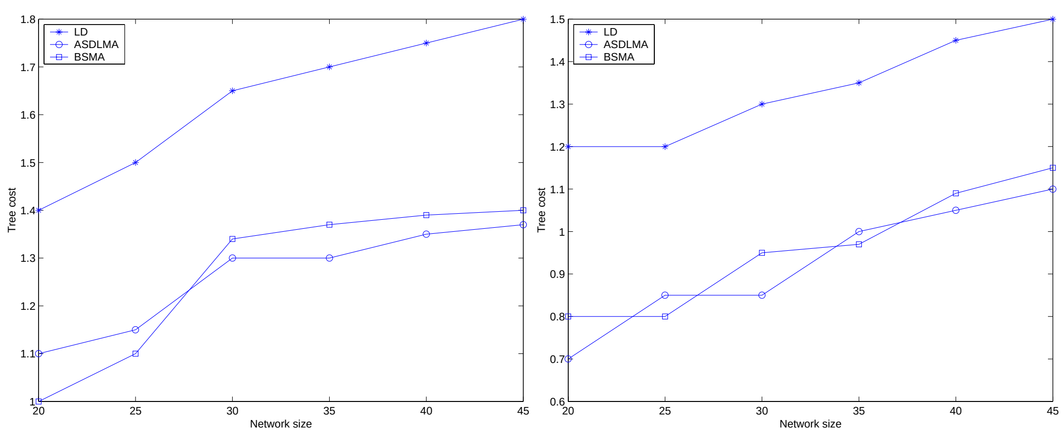
In the first set of experiments, ASDLMA is compared with BSMA and LD for cost performance,where LD is minmum delay Steiner tree no consider the tree cost[2,8] and BSMA is proved to be within 0.07 of the optimal for small networks[2].Fig.3 shows the tree cost for varying network size with the group size =4 and 6 respectively; average node degree of network =3; and $\triangle = 0.28$.It can be seen from Fig.3 that our algorithm has a better cost performance than LD algorithms,and is close to BSMA,and could construct low-cost trees which satisfy the given delay bound and manage the network resources efficiently.



(a)group size=4 *(b)group size=6*

Fig.3. Tree cost versus network size for Δ *= 0.28; node degree = 3.*

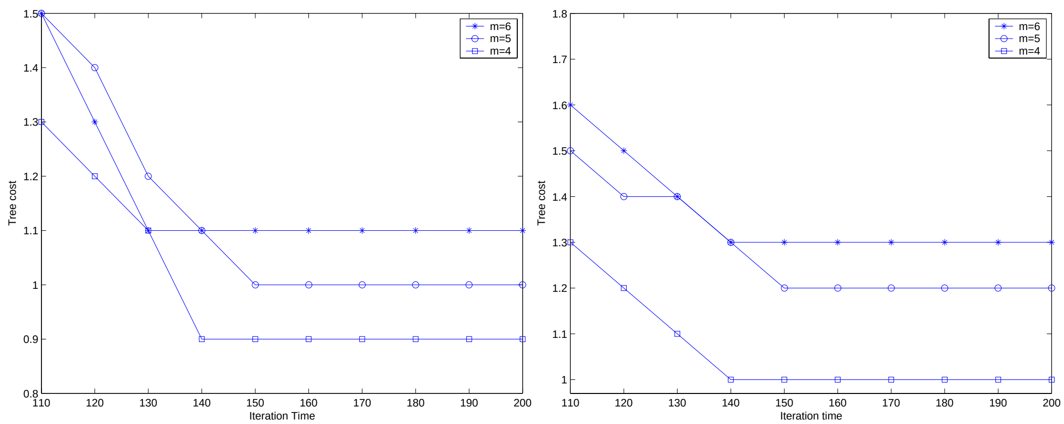
In the second set of experiments,Fig.4 shows the tree cost for varying network size with the group size =5; average node degree of network =3 and 3.5 respectively; and $\triangle = 0.28$.In general, ASDLMA has good cost performance and is feasible and effective.



(a)node degree=3 *(b)node degree=3.5*

Fig.4. Tree cost versus network size for Δ *= 0.28; group size = 5.*

Finally, we consider the iterations times of the algorithm. Fig.5 shows the tree cost for varying the iteration times with number of network nodes=30 and 40 respectively;group size =4,5 and 6. As is clear, the algorithm converges quickly,and has a desirable characteristics of approximation iterative heuristics, which satisfies the real-time requirement of multimedia network.



(a)Number of network nodes=30 *(b)Number of network nodes=40*

Fig.5.Tree cost versus iteration times for Δ = *0.30.*

5 Conclusion

A routing algorithm(ASDLMA), in which the AS algorithm is applied to support multimedia group communication, is discussed. The algorithm starts with a backup-paths-set from the source node to each destination nodes using Dijkstra Kth shortest path algorithm.Then transform the formed procedure of the multicast tree to Graph,and use AS to the QoSR problems: when a ant move from the node i to the node j depend on the corresponding probabilities function, and update the Pheromone on Graph when every iteration finished. Simulation results show our algorithm has features of well performance of cost, fast convergence and stable delay. The algorithm can guarantee the requirement of multimedia group communication for quality of service.

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