July 2010

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Recommended Citation

Patel, Manoj Kumar; KABAT, MANAS RANJAN; and Tripathy, Chita Ranjan (2010) "An Efficient Algorithm for Delay and Delay- Variation Bounded Core Based Tree Generation," *International Journal of Computer and Communication Technology*. Vol. 1 : Iss. 3 , Article 9.

DOI: 10.47893/IJCCT.2010.1045

Available at: <https://www.interscience.in/ijcct/vol1/iss3/9>

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An Efficient Algorithm for Delay and Delay-Variation Bounded Core Based Tree Generation

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Abstract—Many multimedia group applications require the construction of multicast tree satisfying the quality of service (QoS) requirements. To support real time communication, computer networks need to optimize the Delay and Delay-Variation Bounded Multicast Tree (DVBMT). The problem is to satisfy the end-to-end delay and delay-variation within an upper bound. The DVBMT problem is known to be NP complete. In this paper, we propose an efficient core selection algorithm for satisfying the end-to-end delay and delay-variation within an upper bound. The efficiency of the proposed algorithm is validated through the simulation. The simulation results reveal that our algorithm performs better than the existing heuristic algorithms.

Keywords: *QoS routing; Multicast routing; delay-variation, end-to-end delay; DVBMT problem.*

I. INTRODUCTION

The proliferation of Internet has led to the increase in demand for new communication services involving multicast communications and real time multimedia applications. In multicast communications, messages are delivered from a single source to a selected multiple destinations that belong to the same multicast group. Such multicast communication is done via tree structured communication path during a multicast session. Since the resources need to be reserved along a given path to each destination in a given multicast tree for guaranteeing QoS requirements, the efficient solution for multicast communications includes the construction of a multicast tree that has the best chance to satisfy the resource requirements [1-4].

The general problem of multicast tree generation have been studied in the area of computer networks. The multicast tree algorithms

are classified into two categories such as Source-Based Algorithms (SBA) and Core-Based Trees (CBA)[4]. In SBA the multicast tree generations are based on one-to-many concept. The construction of a tree in SBA starts and rooted from a node called source node and sends messages to each destinations in multicast group during a multicast session. All SBAs store per-source state of information which is required to maintain information at every node in a network[5-7]. The algorithm KPP[2] and CSDCM[8] have been developed for multicast tree construction that depends upon end to end delay bound and minimum cost of the links.

On the other hand, the CBAs are based on many-to-many concept. In CBAs only one shared tree known as Core Based Tree (CBT) is established for all of the nodes in the multicast group. The CBT established by the CBA is rooted at a center called core. The routes are the shortest paths from the core to the members of the multicast group. Many researchers [9-11] have pointed out that the location of core may affect the performance of the CBT routing in CBA. Thus, the core plays an important role in CBT and hence it is very important to select the core node. In CBA, messages are sent to the core and distributed to the selected destinations along the path from the core node. Multicast protocols based on CBT that use CBA are Protocol Independent Multicast Sparse Mode (PIM-SM) [12-13] and the Core Based Tree protocol (CBT) [14-17].

Network applications supporting real-time communications are required to receive messages from the source within a certain amount of time span, otherwise the messages, are treated as lost. Therefore, to support real-time multicast communications, computer networks have to guarantee an upper bound on the end-to-end delay from the source to each of the destination nodes. This is referred to as multicast end-to-end delay problem [2]. There are several situations,

in which the inconsistency problem may arise among the users. This happens because the same message fails to arrive at each destination node at the same time. This relates to the multicast delay-variation problem.

In this paper, we propose an efficient core selection algorithm which selects the core node from a set of candidate core nodes, that satisfies the delay-variation bound. KIM et.al. proposed a novel core selection algorithm [19] which outperforms DDVCA [18]. However, the performance analysis of KIM's algorithm shows that his algorithm performs better than DDVCA only in some cases. However, our algorithm performs better than KIM's algorithm as it constructs the multicast tree by connecting the core node with the source node choosing the best path from k-paths.

The rest of the paper is organized as follows. Section II gives a formal definition of the delay and delay-variation bounded multicast tree (DVBMT) problem. Some heuristics recently proposed in literature are discussed in Section III. The proposed algorithm and its operation followed by an illustration and complexity analysis is presented in Section IV. The simulation results of our algorithm are presented in Section V. Finally, we conclude in Section VI.

II. THE DVBMT PROBLEM

In this paper we represent a computer network by a weighted graph $G = (V, E)$ with n nodes ($|V|$) and l links, where V denotes the set of nodes and E denotes the set of links respectively.

Each link $e = (v_i, v_j) \in E$ is associated with delay of link denoted as $d(e) \geq 0$. For each link e we define a link-delay function $d(e) : E \rightarrow R^+$, where R^+ denotes the set of positive real numbers. The delay of the link $d(e)$ is the sum of queuing delay, transmission delay and propagation delay.

In multicast communication, a message is generated from a certain source node $v_s \in V$, it traverses through some other nodes to arrive at a set of destination nodes $D \subseteq V - \{v_s\}$, where D represents the destination node set. The number of destination node say $m = |D|$ and every node in D is called as destination node. We denote the resultant multicast tree as T' generated by the traversal of the message from the source node to the destination nodes in D . We also define the path $P(v_s, v_j)$ as the path from the source node v_s to the destination node v_j in T' . When a message is transmitted from a source v_s to v_j through the path P , the delay is $\sum_{e \in P(v_s, v_j)} d(e)$.

We define Δ and δ as the delay bound and delay-variation bound constraints which are two important multicast communication parameters [20]. The multicast end-to-end delay bound constraint Δ is the upper bound of all the end-to-

end delay associated with the paths from the source node v_s to each of the destination nodes v_j and is defined as follows:

$$\max_{v_j \in D} \sum_{e \in P(v_s, v_j)} d(e)$$

The other parameter multicast delay-variation δ is the maximum difference between the end-to-end delays along the paths from the source to any two destination nodes and is defined as follows:

$$\delta = \max \left\{ \left| \sum_{e \in P(v_s, v_j)} d(e) - \sum_{e \in P(v_s, v_k)} d(e) \right|, \forall v_j, v_k \in D \right\}$$

The said parameters are required to be evaluated to minimize the multicast delay-variation bound under multicast end-to-end delay constraints. This problem is referred to as *Delay and Delay-Variation-Bounded Multicast Tree (DVBMT)*.

Thus, based upon the above definition we can now state mathematically the DVBMT problem in our paper as for a given weighted graph $G=(V,E)$, a source node $v_s \in V$, a destination node set $D \subseteq V - \{v_s\}$, a link-delay function $d(e) : E \rightarrow R^+$, $e \in E$ and a constant Δ , determine an optimal multicast tree T' such that

$$\Delta' = \max_{v_j \in D} \sum_{e \in P(v_s, v_j)} d(e) \leq \Delta$$

$$\delta' = \max \left\{ \left| \sum_{e \in P(v_s, v_j)} d(e) - \sum_{e \in P(v_s, v_k)} d(e) \right|, \forall v_j, v_k \in D \right\} \leq \delta$$

III. RELATED WORK

In recent years, several research efforts have been directed towards the development of multicast routing algorithm which satisfy end-to-end delay and delay-variation constraints [10][21]. The issue of minimizing multicast delay-variation problem under the multicast end-to-end delay constraints are defined and discussed in [20]. This problem is referred to as the *Delay and delay-variation bounded multicast tree (DVBMT)* problem. The DVBMT problem is proved to be NP-complete. The two well known approaches to construct multicast tree for the DVBMT problem have been proposed in [18][20]. Those are *Delay Variation Multicast Algorithm (DVMA)* [20] and *Delay and Delay Variation Constrained Algorithm (DDVCA)* [18].

The working of DVMA starts with a spanning tree satisfying the delay constraints. Then the algorithm searches through the candidate paths satisfying the delay and delay-variation constraints. It is based on the principle of finding the k-shortest path algorithm. The algorithm finds larger paths in the event of not satisfying the delay constraints. The computer simulation shows that the performance of DVMA is good in terms of multicast delay-variation. However,

the time complexity of DVMA is very high i.e. $O(klmn^4)$. In the worst case the maximum value of the parameters k and l can take depends upon the number of paths satisfying the delay bound between any two nodes; where m and n represents number of destination nodes and total number of nodes in the computer network respectively. Although the spanning tree built by DVMA satisfy the delay constraints, such a high time complexity of the algorithm does not fit in modern high speed computer network environment.

The other approach to solve the DVMT problem is DDVCA [18]. It is based on the Core Based Tree (CBT) [14-17] that is the prime focus of our proposed algorithm. The DDVCA first calculates the delay of the least delay path from the destination nodes to all the nodes. The node that has the minimum delay-variation is selected as the core node. The source node sends a single copy of the message to the core node. Then the core node forwards the message to all the receivers through the minimum delay path. In comparison with the DVMA, the DDVCA possesses a significant lower time complexity i.e. $O(mn^2)$ where m represents number of destination nodes and n represents the total number of nodes in the computer network.

Another efficient core selection algorithm has been proposed by KIM et.al [19] to produce a core based multicast tree under delay and delay-variation multicast constraint. First, this algorithm finds a set of candidate core nodes that have the same associated multicast delay-variation for each destination node. Then, the final core node is selected from the set of core nodes that has the maximum potential delay-variation. Though, this algorithm outperforms DDVCA, the simulation results reveals that the enhancement is only up to 13.5% in terms of multicast delay-variation.

IV. THE PROPOSED ALGORITHM

In this section, we present our proposed core selection algorithm to construct a multicast tree i.e. superior to both DDVCA [18] and KIM's algorithm [19]. We discuss the working principle of the proposed algorithm followed by the illustration and complexity analysis.

A. Description:

The algorithm starts with calculating the delay of the least delay paths from each destination to other nodes by using Dijkstra's algorithm. The delay-variation $dv(v_i)$ associated with a node v_i is calculated as the difference between the maximum and minimum value of the delays. Then, it selects a set of candidate core nodes that satisfies both end-to-end delay and delay-variation constraints. If there is no candidate node then the algorithm terminates without generating a multicast tree. Otherwise, the algorithm maintains a data structure $pass$ for each destination nodes. If the destination node m_k is visited in the path from the source v_s to a node v_i , then the $pass(v_s, v_i, m_k)$ is the distance from

the destination m_k to v_i . If the destination node is not in the path from source v_s to a node v_i then $pass(v_s, m_k, v_i)$ is 0. Next, the $pass$ value associated with each node v_i is calculated as the maximum of the pass values calculated for each destination. The $compare$ value of the candidate core nodes are calculated as equal to their respective pass values. The node that has the minimum $compare$ value is considered as the best core node.

To construct a better multicast tree than DDVCA and KIM's algorithm, we calculate k-least delay paths from source node v_s to the core node v_c subject to delay

constraint $\Delta - \max_{v_j \in D} (P_{ld}(v_c, v_j))$. then the

multicast tree is constructed by connecting each destination node to the core node and one of the k paths from the k-least delay paths from source to core node. The delay-variation of the multicast tree is calculated after pruning the cycles. The final multicast tree is one of the multicast trees that is having the minimum delay-variation.

The Proposed Algorithm ($G, delay$)

Begin

$T = \phi$, $candidate = \phi$

for each $v_j \in D \cup \{s\}$ do

$P_{ld}(v_j, v_i) =$ the minimum delay between v_j and v_i

where $v_i \in V$ (Computed by Dijkstra's algorithm)

for each $v_i \in V$ do {

$\max_i = \max_{v_j \in M} \{P_{ld}(v_j, v_i)\}$

$\min_i = \min_{v_j \in D} \{P_{ld}(v_j, v_i)\}$

$dv(v_i) = \max_i - \min_i$

if $\left((dv_i \leq \delta) \text{ and } P_{ld}(v_s, v_i) + \max_{v_j \in D} \{P_{ld}(v_i, v_j)\} \leq \Delta \right)$

$candidate = candidate \cup \{v_i\}$

for $\forall l \in P_{ld}(s, v_i)$

if $l = m_k, m_k \in D$ then

$pass(s, v_i, m_k) = P_{ld}(s, v_i) - P_{ld}(s, m_k)$

else

$pass(s, v_i, m_k) = 0$

$pass(s, v_i) = \max_{m_k \in D} pass(s, v_i, m_k)$

if $candidate = \phi$ then print "Tree Construction failed"

for $\forall c_i \in candidate$

$compare_i = pass(s, c_i)$

$c = i$, where index i for min $\{compare_i\}$

Find k paths using k -Bellman Ford Algorithm

such that $p_k(s, v_c) \leq \Delta - \max_{v_j \in D} \{P_{ld}(v_c, v_j)\}$

Calculate $pass_k(s, v_c) = pass(s, v_c)$

$T = T \cup \{l \mid l \in \text{the mean delay path from } m_k \text{ to } v_c\}$

for $i = 1$ to k do {

$tempT = T \cup \{l \mid l \in \text{the mean delay path from } s \text{ to } v_c\}$

if $(pass_k(s, v_c) = 0)$

$dv = \max_i - \min_i$

else

$dv = \max_i + pass_k$

```

if ( $dv < \min$ )
{
     $\min = dv$ 
     $p = k$ 
}
}
 $T = T \cup \{ l \mid l \in \text{the } p^{\text{th}} \text{ min delay path from } s \text{ to } v_c \}$ 
Prunelinks for cycles
Return

```

Figure 1. Pseudo Code for the proposed algorithm

B. An illustration:

For ease of understanding, we present a case study in the example network given below (Fig. 2). In this case the source node is v_1 and the set of destination nodes are $\{v_5, v_6\}$, where the number along each edge represents the delay for that edge. The delay bound Δ and the delay-variation bound δ are assumed 11 and 2 respectively.

Figure 2. The example network ($\Delta=11$ and $\delta=2$)

TABLE I. SELECTION OF CORE NODE USING PROPOSED ALGORITHM

		v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8
Source	v_1	0	2	8	8	4	9	3	6
	v_5	0	0	0	4	0	5	0	2
Pass	v_6	0	0	0	0	0	0	0	0
	v_5	4	2	4	4	0	5	2	2
Destination	v_6	9	7	6	3	5	0	7	3
	max_i	9	7	6	4	5	5	7	3
	min_i	4	2	4	3	0	0	2	2
	$diff_i$	5	5	2	1	5	5	5	1
	$compare_i$				4				2

Table I shows delay-variation associated with each node. Here the candidate core nodes are v_4 and v_8 . The parameter $compare_i$ is calculated for each candidate node and the node v_8 is found to be the best core node. The multicast trees are generated by connecting the destination nodes v_5 and v_6 with core node v_8 via the least delay path and one of the k -least delay paths from source node to core node. The final multicast tree with minimum delay-

variation is shown in Fig. 3. The multicast trees generated by DDVCA and KIM's algorithm are shown in Fig. 4 and Fig. 5 respectively.

Figure 3. Tree generated by our proposed algorithm $\delta=1$ Figure 4. Tree generated by DDVCA $\delta=7$ Figure 5. Tree generated by KIM's algorithm $\delta=5$

V. SIMULATION RESULTS

We have implemented our proposed algorithm in Visual C++. The experiments are performed on an Intel Core 2 Duo @ 2.66 G.Hz. and 1 GB RAM based PC platform.

The positions of the nodes are fixed randomly in a rectangle of size 4000 km x 2400 km. The Euclidean metric is then used to determine the distance between each pair of nodes. Edges are introduced between the pairs of nodes u, v with a probability that depends on the distance between them. The edge probability is given by $P(u,v) = \beta \exp(-l(u,v)/\alpha L)$, where $l(u,v)$ is the distance from node u to v . The maximum distance (L) between two nodes. α and β are set to 0.15 and 2.2 respectively.

The link delay function $d(e)$ is defined as the propagation delay of the link. The source node is selected randomly and destination nodes are picked up uniformly from the set of nodes chosen in the network topology. The delay bound Δ is set to be 1.5 times the minimum delay between the source and the farthest destination node. The simulation is run for 200 times for each case and the average of that is taken as the output.

A. Comparison on multicast delay-variations

The Fig. 6 shows the simulation results of multicast delay-variations versus the number of nodes on a network. The delay and delay-variation bound is considered as 35 ms and 20 ms respectively. The destination nodes in a multicast group occupy 5% of the overall network nodes. The multicast delay-variation of our proposed algorithm is found to be better than that of DDVCA and KIM's algorithm.

The Fig. 7 shows the multicast delay-variation for a network of 100 nodes. The multicast group is between 10% and 80% of the overall nodes of the network. The delay bound Δ and the delay-variation bound δ are set to be 35 ms and 20 ms respectively. The figure shows that the multicast delay-variation in our proposed algorithm is less than that of DDVCA and KIM's algorithm.

B. Complexity Analysis

The time complexity of the proposed algorithm mainly depends on the time required to find the minimum delay path from the nodes of the multicast group (m) to all the nodes (n) of the network i.e. $O(mn^2)$ and the time required to find the k -shortest paths from source node to the selected core node i.e. $O(k^2 n \log n)$. Thus, the time complexity of our algorithm is $O(mn^2 + k^2 n \log n)$.

Figure 6. A comparison on multicast delay-variations for varying network size.

Figure 7. A comparison on multicast delay-variations for varying group size.

VI. CONCLUSIONS

In this paper, we propose a novel core selection algorithm to generate a core based multicast tree for the DVBMT problem. The performance of the proposed algorithm is analyzed through simulation and it is revealed that our algorithm performs better than that of DDVCA and KIM's algorithm in terms of delay-variation.

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