Compact tree plus algorithms for application-level multicast communications in multihome networks

Nobuo Funabiki
Okayama University

Megumi Isogai
Okayama University

Toru Nakanishi
Okayama University

Teruo Higashino
Osaka University, Osaka

Compact Tree Plus Algorithms for Application-Level Multicast Communications in Multihome Networks

Nobuo Funabiki* Megumi Isogai* Toru Nakanishi* Teruo Higashino†
* Department of Communication Network Engineering, Okayama University,
3-1-1 Tsushimanaka, Okayama 700-8530, Japan
† Graduate School of Information Science and Technology, Osaka University,
1-5 Yamadaoka, Suita, Osaka 565-0871, Japan

***Abstract*— *Application-level multicast (ALM)* communications replicate packets on host level to deliver them from a single source to multiple clients, so that it can efficiently realize a variety of network applications using moving pictures such as video conferences, distance learning, and video-on-demands. In this paper, we propose the *CT+ (Compact Tree Plus)* algorithm for finding a better ALM routing tree in terms of delay minimization between hosts. *CT+* consists of a tree construction stage from the existing *CT* algorithm, and a newly added iterative tree improvement stage. Then, we define the *extended ALM routing problem* and its heuristic algorithm *ExCT+*, to optimize the effectiveness of the *multihome network* in ALM communications by selecting multihomed hosts and connections in the ALM routing tree simultaneously. For their evaluations, we construct a network simulation model named *MINET (Multiple-ISP NETwork simulator)*, where the topology is composed of multiple ISP backbone networks with IX connections, and the network traffic is generated by following the $M/M/1$ queuing process. The simulation results using MINET verify the effectiveness of our algorithms.**

I. Introduction

Recently, a variety of network applications with delivering moving pictures such as video conferences, distance learning, and video-on-demands have been demanded due to the spread of broadband networks in every place. In these applications, the multicast communication plays a key technology of delivering high bandwidth packets from a single source to multiple destinations while reducing server loads and saving network transmission bands. In multicast communications, intermediate nodes on a routing path replicate packets to deliver them to multiple clients. Currently, the *application-level multicast (ALM)* communication has been noticed as a practical multicast, where packets are replicated on host level, instead of router level as in the *IP multicast (IPM)* [1]-[22]. ALM has several advantages over IPM, that it does not require sophisticated routers to handle IPM functions and multicast IP addresses, and it allows the flow control and the packet retransmission scheme at the transport layer, because each pair of hosts is connected through the unicast connection. Furthermore, ALM provides the flexibility of selecting connections between hosts by users.

In ALM, the routing path between hosts usually becomes a tree, where each vertex represents a host and each edge represents a unicast connection between two hosts. Therefore, the routing path is called an *ALM routing tree* in this paper. The proper selection of an ALM routing tree is very important for the delay minimization that is essential in various ALM applications involving motion picture streaming and large data sharing among distributed hosts while concerning the resource limitation at hosts. This *ALM routing problem* has been formulated as an *NP-hard* combinatorial optimization problem, and several algorithms have been reported [8]-[12]. The *compact tree (CT)* algorithm [9] has been known as a typical algorithm for this problem. *CT* greedily constructs a tree by selecting connections one-by-one such that resulting partial trees minimize the maximum delay between any pair of hosts while satisfying the constraint. However, the solution quality of *CT* may be insufficient, because it does not adopt the improvement stage that has usually been adopted in heuristic algorithms for *NP-hard* problems [25]. Based on a local search method, the improvement stage sometimes drastically refines an initial solution of the construction stage.

ALM has several drawbacks in the increase of delay due to longer paths than IPM, the increase of host loads due to packet replications and plural connections at hosts, and the increase of consumed network bands due to transmissions of duplicated packets on network links. These drawbacks are particularly undesirable for streaming applications including video conferences where the data synchronization between hosts is inevitable. For this solution, we have proposed the introduction of the *multihome network* to ALM. In the multihome network, each host may have connections with one or more *internet service providers (ISPs)*. By selecting the best ISP under the current network condition after measuring RTT and the available bandwidth [23], the multihome network can alleviate these drawbacks in ALM. To be more precise, the multihome network can reduce communication loads on

1-4244-0000-7/05/$20.00 ©2005 IEEE.

the access links between hosts and ISP nodes (host access points) by using different ISP links, and on the links in *internet exchangers (IXs)* by exchanging ISPs at hosts instead of exchanging them at IXs. In addition, the multihome network provides the possibility of drastically shortening the routing path by using *single-ISP connections* where both end hosts are connected with the same ISP.

In this paper, we define the *ALM routing problem in the multihome network*, and propose its *compact tree plus algorithm (CT+)* by adding the improvement stage to *CT*. This improvement stage repeats the replacement of a randomly selected connection by another one that does not only satisfy the constraint but also minimizes the delay among candidates. This replacement is always processed regardless of the increase of the delay, as long as such a connection exists. This mandatory replacement avoids the convergence to a poor local minimum.

In reality, the current network environment does not allow every host to have connections with multiple ISPs. Besides, the multihome network usually costs more than the conventional singlehome network. In practical, only a part of hosts participating ALM applications should be multihomed. Therefore, in this paper, we define the *extended ALM routing problem in the multihome network* to select multihomed hosts and connections simultaneously under the limitation of the multihomed cost, and present its *extended CT+ algorithm (ExCT+)*. We also study the effect of the increase of multihomed hosts in the delay minimization in ALM.

For evaluations of our algorithms and schemes for ALM, we construct a network simulation model named *MINET (Multi-ISP NETwork simulator)*. The network topology consists of multiple ISP backbone networks and one IX for ISP connections. The IX directly connects one node in each ISP with a node in any other ISP. The ISP backbone network exists on the same square area. The topology is generated by following the Waxman method [24], and the node nearest to the center of the square is connected to a node in IX. The delay of each link is given by the sum of the *transmission delay*, the *switching delay*, and the *buffering delay* [26]. The background traffic is provided through random generations and terminations of unicast connections by following the $M/M/1$ queuing model [27]. Each connection is routed along the shortest path when any buffering delay is zero. When a new connection arrives, its requested bandwidth is consumed on every link along the path. When the total consumed bandwidth exceeds the link capacity, the buffering delay occurs there.

The rest of this paper is organized as follows: Section II formulates the ALM routing problem in the multihome network and presents *CT+*. Section III defines the extended ALM routing problem and presents *ExCT+*. Section IV outlines *MINET*. Section V evaluates the performance of our algorithms using MINET with the increase of multihomed hosts. Section VII concludes this paper with some discussions on further studies.

II. *CT+* FOR ALM ROUTING PROBLEM

A. *ALM Routing Problem in Multihome Network*

In the ALM routing problem in the multihome network, connections between hosts are described by a directed weighted graph $G = (V, E, W)$. A vertex $v \in V$ represents a host in the ALM application. A directed edge $e \in E$ is assigned a weight $d(e) \in W$ to represent the delay of the packet transmission through the corresponding connection. When one end host of a connection has connections with a ISPs and another one does with b ISPs in the multihome network, the number of directed edges corresponding to this connection is given by $2 \times a \times b$.

In ALM, a host may replicate packets to send them to multiple hosts individually. If the number of packet replications is too large, both the loads of the host and the access link connecting the host and the access point of an ISP become too high. Thus, the limit of the number of replications or host connections for host v in the ALM routing tree T is given as the *degree constraint* Δ^v_{degree}. In T, the both-way delay between any pair of hosts should be minimized for motion picture streaming applications.

From the above discussion, the ALM routing problem in the multihome network is summarized as follows:

< ALM routing problem in multihome network >

- **Input:** a connection graph $G = (V, E, W)$ with multiple edges, a degree limit Δ^v_{degree}.
- **Output:** an ALM routing tree $T = (V, E_T)$ with $E_T \subset E$.
- **Constraint:** the number of packet replications at host v is less than or equal to its limit:
$$degree_T(v) \leq \Delta^v_{degree} \quad (1)$$
where $degree_T(v)$ is the number of children of host v in T.
- **Objective:** to minimize the maximum delay between any pair of hosts E:
$$E = \max_{i,j} \left\{ \sum_{e \in P_{ij}} d(e) \right\} \rightarrow \min \quad (2)$$
where P_{ij} represents the routing path between host i and host j in T.

B. *Delay Observation*

The delay of a connection is observed by sending a probe packet from the source host to the destination and calculating the difference between the sending time and the receiving one, before the algorithm is applied. The synchronization of clocks in every host is necessary in this scheme where it can be realized by using GPS (global positioning system) or NTP (network time protocol). Here, we note that if we always observe the delay for every connection, the load of this delay observation becomes very high, because n hosts require $O(n^2)$ observations even for a singlehome network. Thus, we need to confine connections for delay observations in the implementation of *CT+* by pruning the connections whose delays have been very large in past observations.

C. *Proposal of* CT+

The proposed *CT+* is a two stage heuristic algorithm for the ALM routing problem. The tree construction stage adopts the procedure of *CT*, and the tree improvement stage adopts the state transition method that is a variant of a local search method [25].

1) Tree Construction Stage by CT*:* *CT* greedily constructs an ALM routing tree T by initially including only one host in V into T and then, sequentially expanding T by adding a connection one-by-one that satisfies the degree constraint and minimizes the maximum delay between any pair of hosts in the resulting tree. In our implementation, every host is tried as the initial host in T, and the best result in terms of the delay among all the trials is selected as the final solution from *CT*, to improve the solution quality.

< **CT** >

1) Initialize $T = (V_T, E_T)$ by $V_T = v \in V$ and $E_T = \phi$.
2) Terminate the procedure if $V_T = V$.
3) Add one connection to T such that (1) it connects a host in V_T and another one in V/V_T, (2) it satisfies the degree constraint in T, and (3) it minimizes the maximum delay between two hosts in T among candidates.
4) Return to step 2).

2) Tree Improvement Stage: The tree improvement stage repeats modifications of T by replacing a randomly selected connection in T by a different one that satisfies the degree constraint if it exists. This compulsory replacement aims the avoidance of a poor local minimum convergence that can often occur in heuristic algorithms.

< **CT+** >

1) Adopt T from *CT* as an initial tree, set the best found tree $T_{best} = T$, and initialize the number of iterations t by 0.
2) Terminate the procedure if $t = K \times |V|$, and output T_{best}.
3) Randomly select a connection in E_T and remove it from T. This operation separates T into two partitions.
4) Add a different connection to T such that (1) it connects the two partitions, (2) it satisfies the degree constraint, and (3) it minimizes the maximum delay among candidates. If such a connection does not exist, return the removed connection to T.
5) Memorize T as T_{best} if the maximum delay between two hosts in T is smaller than that in T_{best}.
6) Increment t by 1, and return to step 2).

3) Time Complexity of CT+*:* In the construction stage, step 3) requires $O(|V|^2)$ time. In the improvement stage, step 4) requires $O(|V|^3)$ time where each of $O(|V|^2)$ connections in E is evaluated with $O(|V|)$ delay calculations. As a result, the time complexity of *CT+* is $O(K|V|^4)$.

III. *ExCT+* FOR EXTENDED ALM ROUTING PROBLEM

A. *Extended ALM Routing Problem in Multihome Network*

As mentioned in Section I, every host in an ALM application may not be multihomed due to the cost and ISP infrastructures. If the total cost for multihomed hosts is limited, multihomed hosts should be selected with appropriate ISP connections simultaneously when the ALM routing tree is constructed. Therefore, we define the *extended ALM routing problem in the multihome network* to cope with this issue. As the *input* to this problem, we assume the following conditions:

1) Every host has already been connected with one ISP.
2) The list of available ISPs is given at each host, and the delay of any connection between hosts using an additional ISP in the list can be observed without an extra cost.
3) The total cost for multihomed hosts is limited by a constant Δ_{cost}.

Then, for this problem, the following *multihome cost constraint* is imposed additionally to the ALM routing problem:

$$\sum_{(v,k)\in M} c(v,k) \leq \Delta_{cost} \quad (3)$$

where $c(v,k)$ is the cost for using the k-th ISP connection at host v, and M is the set of additionally used ISP connections in T.

B. *Proposal of* ExCT+

In the proposed *ExCT+*, any additional ISP connection is used only if it satisfies the multihome cost constraint. Specifically, in step 3) of the construction stage and step 3) of the improvement stage in *CT+*, an additional ISP connection is selected there when either of the following two conditions is satisfied in addition to satisfying the conditions for *CT+*:

- the additional ISP connection has already been used at the host,
- the total cost does not exceed Δ_{cost} when the ISP connection is newly used at the host.

Besides in the implementation, in step 2) of the improvement stage, if the removed connection from T uses an additional ISP connection and no other in T uses it at the host, the multihome cost is decreased by its cost.

IV. MULTI-ISP NETWORK SIMULATOR *MINET*

A. *Topology*

The topology of MINET consists of multiple ISP backbone networks (10 ISPs in simulations) and one IX as illustrated in Figure 1. The topology of an ISP backbone network is generated by the Waxman method [24], where nodes (100 nodes in simulations) are randomly located on a square called the *network field* ($3,000km$ on each side in simulations). In each ISP network, the node nearest to the center in the network field is selected as a node in IX. IX connects any pair of nodes directly.

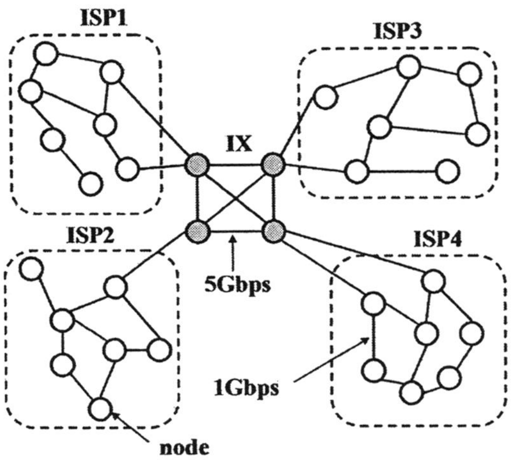

Fig. 1. MINET topology.

B. Link Delay

The delay of a link is given by the sum of the *transmission delay*, the *switching delay*, and the *buffering delay*. The transmission delay is the time required to propagate packets physically through the signal transmission line, and is given by dividing the line length with the light speed ($300,000km/s$). The switching delay is the time to switch received packets to their destination ports at the router, and can be constant ($10ms$ in simulations). The buffering delay is the time for packets to stay in buffers to wait for their delivery from output ports, and is given by dividing the queued packet size with the transmission bandwidth of the link. The buffering delay appears when the amount of *packet flows* through a link exceeds the *link capacity*. In simulations, the link capacity is set $5Gbps$ for IX and $1Gbps$ for ISP.

C. Background Traffic

The goal of the algorithms in this paper is to find an ALM routing tree with the minimum delay between any pair of hosts under conventional network conditions. As the network background traffic in MINET, unicast connections are randomly generated and terminated between any pair of nodes by following the $M/M/1$ queuing model at each node. That is, a connection arrives at a node by the Poisson probability with a randomly selected destination node, and it continues by the exponential probability. The connection is routed through the shortest path from the source node to the destination when any buffering delay is zero. The amount of packet flows of the links along the path is increased by the given traffic of the connection, which is randomized between $100Kbps$ and $10Mbps$ in simulations.

In order to generate heterogeneous network loads, we introduce the dispersion of connection arrival rates and burst connections. In the former scheme, all the nodes are categorized into a high-load group and a low-load group by a constant ratio (1 : 4 in simulations). Then, the connection arrival rate is randomly selected between the highest value and the lowest one for each node. In simulations, these values are set $0.8s^{-1}$ / $0.2s^{-1}$ for the high-load group, and $0.4s^{-1}$ / $0.1s^{-1}$ for the low-load group. The termination rate is randomly selected between $1s^{-1}$ and $0.1s^{-1}$ at any node. For the latter scheme, a constant fraction of connections (10% in simulations) is selected as burst connections, where the link capacity ($1Gps$) becomes fully occupied for $1s$.

V. Evaluations by Simulations

A. Simulation Steps

The performance of the proposed *CT+* and *ExCT+* is evaluated through simulations using MINET. Actually, each MINET simulation is performed through the following steps:

1) The host configuration is set up.
2) The network state transits from the initial one to a stationary one by calculating background traffics for $1,000s$.
3) The delay of a connection between each pair of hosts through every available ISP connection is observed for $100s$.
4) The algorithm finds an ALM routing tree.
5) The delay of a connection between each pair of hosts through the ALM routing tree is observed for $100s$, and the maximum delay between two hosts is calculated, while an ALM application ($1.5Mbps$) is executed.

B. Host Configuration

The number of hosts n for an ALM application is set 10 and 50 in our simulations. The host locations are randomized within the network field. The number of additional ISP connections at each host is fixed to one. Thus, two ISPs are selected randomly for each host, where the first one becomes the established connection, and the second is the additional one. The nearest node in the corresponding ISP backbone network from the host location is selected as the access node to the host. The same tree degree limit Δ^v_{degree} is set 3 or 4 for every host. The multihome cost $c(v, k)$ is set 1 for any ISP connection at any host. Thus, the cost limit Δ_{cost} is equivalent to the upper bound on the number of multihomed hosts.

C. Delay Observation

The delay of a connection is calculated by the sum of delays associated with the links along the path from its source host to the destination. For accuracy, the delay observation is applied 100 times at every 1 second for any connection, and their average value is used for evaluations.

D. Simulation Results

Figures 2-5 show changes of the maximum delay between two hosts by using ALM routing trees found by *CT* (dashed line), *CT+* (double dashed line), and *ExCT+* (solid line), when the percentage of multihomed hosts among all the hosts increases from 0% to 100%.

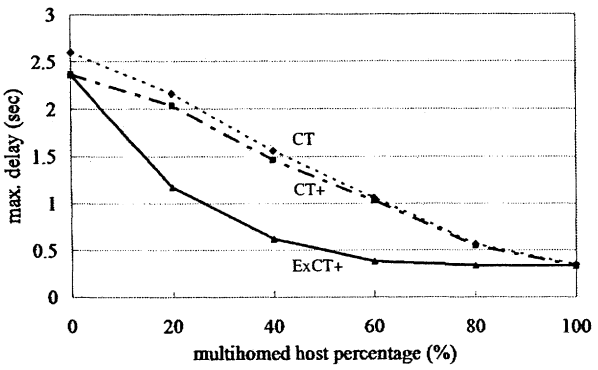

Fig. 2. Maximum delay at ALM application (n = 10, Δ^v_{degree} = 3).

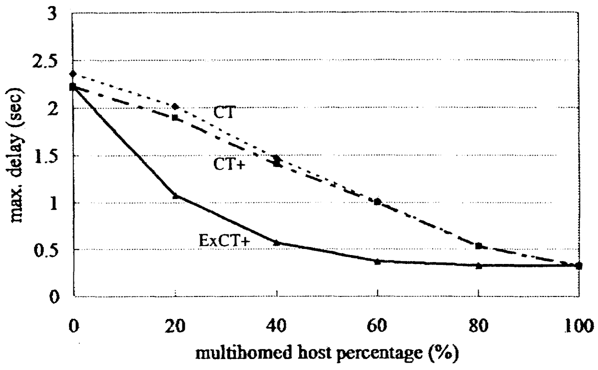

Fig. 3. Maximum delay at ALM application (n = 10, Δ^v_{degree} = 4).

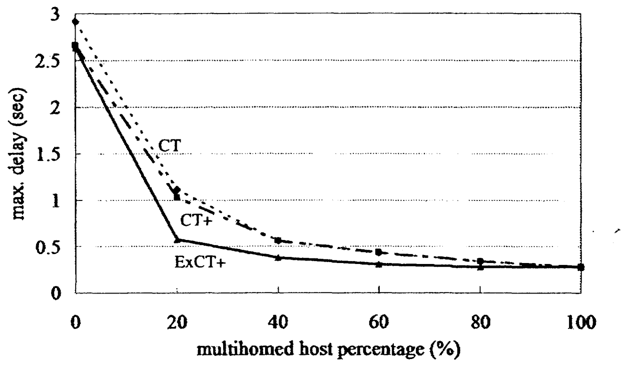

Fig. 4. Maximum delay at ALM application (n = 50, Δ^v_{degree} = 3).

1) Comparison between Three Algorithms: In any figure, the delay by *CT+* is slightly smaller than the delay by *CT*, whereas the delay by *ExCT+* is much smaller than the delays by others when a part of hosts are multihomed. The combination of the improvement stage and the multihomed host selection in *ExCT+* is very effective in reducing the delay of the ALM routing tree. Thus, the repetition of the simultaneous selection of connections and multihomed hosts is critical for providing a high-quality ALM routing tree.

2) Effect of Multihome Network: In any figure, the delay decreases as the percentage of multihomed hosts increases. Thus, the results confirm the effectiveness of the multihome network in reducing the delay in ALM by increasing the number of single-ISP connections in the tree. However, this effect becomes small for the case of n = 50, because many connections even in the singlehome network can be single-ISP ones, as the number of ISPs is fixed 10. We note that when 20% of hosts can be multihomed, *ExCT+* achieves almost the same delay for 100%. Thus, a small number of multihomed hosts can reduce the delay in ALM. The detailed investigation on the relationships between the number of multihomed hosts, the number of ISPs, and the delay reduction by our algorithms will be in our future studies.

VI. Related Work

In [1], Sheu et al. first introduced the peer-to-peer technique for video streaming applications. In [2], Aharoni et al. first proposed the concept of ALM communications. In [3], Cohen et al. defined a family of minimum path set problems for ALM communications, and proposed the maximum bottleneck tree algorithm for its maximum bottleneck version. In [4], Pendarakis et al. presented a centralized middleware of generating the minimum spanning tree for ALM communications called *ALMI*. In [5][6], Chu et al. proposed an ALM protocol of generating the shortest widest path tree for ALM communications on a mesh-type overlay network. In [9][10], Shi et al. proposed *CT* for ALM communications using *MSNs (multicast service nodes)* that have been deployed around networks as multicast routers performed at host level. They also proposed several modifications of *CT* so that as many ALM requests as possible can be afforded in the MSN network. In [11], Banerjee et al. formulated the minimum average-latency degree-bounded directed spanning tree problem for the MSN network, and proposed its distributed iterative approach where the performance is compared with optimum solutions and *CT* solutions. In [12], Yun et al. proposed a genetic algorithm for an ALM routing problem with two objectives. In [13], Tran et al. proposed an ALM solution called *ZIGZAG* organizing an efficient routing tree with height logarithmic by the number of clients and a node degree bound by a constant. In [14], Zhang et al. proposed a hybrid multicast framework called *Host Multicast* of automating the interconnection of IP-multicast enabled islands and providing the multicast delivery to end hosts where IP multicast is not available. In [15], Cheuk et al. also proposed the similar scheme called *Island Multicast* using overlay connections between IP-multicast enabled islands and supporting IP-multicast for intra-islands. In [16], Bawa et al. argued that masking peer transience is the primary challenge of ALM communications for short lifetime hosts participating

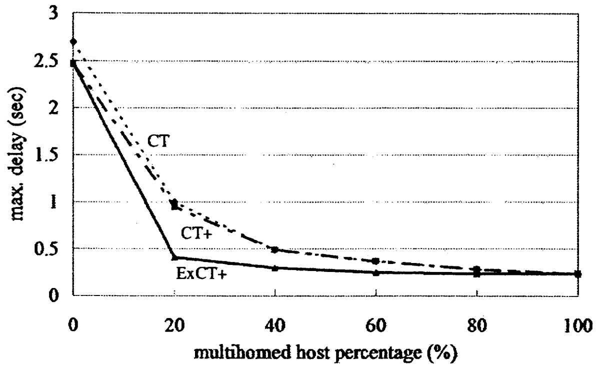

Fig. 5. Maximum delay at ALM application ($n = 50$, $\Delta^{v}_{degree} = 4$).

in long-durationed multicast sessions, and outlined the *peering layer* to separate policy decisions in handling peer behaviors from end-applications. Based on their concept, they proposed an ALM solution called *PeerCast* [17]. In [18], Mimura et al. presented a middleware with the multipath routing for reliable ALM communications. In [19], Yamashita et al. presented a middleware for multiparty video communications. In [20], Li et al. proposed a QoS-aware routing protocol for ALM communications on overlay networks called *QRON*. In [21], Zhu et al. proposed schemes of applying the network coding with a two-redundant multicast graph to improve end-to-end throughput in ALM. In [22], Abad et al. surveyed a variety of ALM solutions, and classified them according to characteristics such as overlay building technique, management, and scalability.

VII. Conclusion

This paper has presented the *CT+ (Compact Tree Plus)* algorithm for the *ALM (Application-Level Multicast) routing problem*, and the *ExCT+ (Extended CT+)* algorithm to optimize the effectiveness of the multihome network in ALM communications. Using the *MINET (Multiple-ISP NETwork simulator)*, the effectiveness of these algorithms is verified. Our future studies will include discussions on the ALM routing tree modification to deal with joins and/or leaves of hosts during ALM applications, the use of available bandwidth at connections in algorithms, and the introduction of host delay concepts in MINET.

References

[1] S. Sheu, K. A. Hua, and W. Tavanapong, "Chaining: a generalized batching technique for video-on-demand systems," Proc. ICMCS, pp. 110-117, 1997.

[2] E. Aharoni and R. Cohen, "Restricted dynamic Steiner trees for scalable multicast in datagram networks," IEEE/ACM Trans. Networking, vol. 6, no. 3, pp. 286-297, June 1998.

[3] R. Cohen and G. Kaempfer, "A unicast-based approach for streaming multicast," Proc. IEEE INFOCOM, pp. 440-448, 2001.

[4] D. Pendarakis, S. Shi, D. Verma, and M. Waldvogel, "ALMI: An Application Level Multicast Infrastructure," Proc. USENIX Symp. Internet Tech. Systems (USITS), pp. 49-61, 2001.

[5] Y.-H. Chu, S. G. Rao, S. Seshan, and H. Zhang, "A case for end system multicast," Proc. SIGMWTRICS, June 2000.

[6] Y.-H. Chu, S. G. Rao, S. Seshan, and H. Zhang, "Enabling conferencing applications on the Internet using an overlay multicast architecture," Proc. SIGCOMM, Aug. 2001.

[7] J. Crowcroft and I. Pratt, "Peer to peer: peering into the future," Advanced Lectures on Networking (LCNS 2497), pp. 1-19, 2002.

[8] S. Y. Shi, J. S. Turner, and M. Waldvogel, "Dimensioning server access bandwidth and multicast routing in overlay networks," Proc. NOSSDAV, June 2001.

[9] S. Y. Shi and J. S. Turner, "Multicast routing and bandwidth dimensioning in overlay networks," IEEE J. Select. Area. Commun., vol. 20, no. 8, pp. 1444-1455, Oct. 2002.

[10] S. Y. Shi and J. S. Turner, "Routing in overlay multicast networks," Proc. IEEE INFOCOM, June 2002.

[11] S. Banerjee, C. Kommareddy, K. Kar, B. Bhattachajee, and S. Khuller, "Construction of an efficient multicast infrastructure for real-time applications," Proc. IEEE INFOCOM, 2003.

[12] P. Y. Yun, Y. Zhenwei, and W. Licheng, "A genetic algorithm for the overlay multicast routing problem," Proc. IEEE ICCNMC, 2003.

[13] D. A. Tran, K. A. Hua, and T. Do, "ZIGZAG: an efficient peer-to-peer scheme for media streaming," Proc. IEEE INFOCOM, pp. 1283-1292, 2003.

[14] B. Zhang, S. Jamin, and L. Zhang, "Host multicast: a framework for delivering multicast to end users," Proc. IEEE INFOCOM, June 2002.

[15] K.-W. Cheuk, S.-H. Chan, and J. Lee, "Island multicast: the combination of IP multicast with application-level multicast," Proc. IEEE ICC, pp. 1441-1445, June 2004.

[16] M. Bawa, H. Deshpande, and H. Garcia-Molina, "Transience of peers and streaming media," Proc. HotNets, 2002.

[17] peercast.org, http://www.peercast.org/.

[18] N. Mimura, K. Nakauchi, H. Morikawa, and T. Aoyama, "RelayCast: a middleware for application-level multicast services," Proc. GP2PC, 2003.

[19] T. Yamashita, H. Yamaguchi, K. Yasumoto, T. Higashino, and K. Taniguchi, "Emma middleware: an application-level multicast infrastructure for multi-party video communication," Proc PDCS, pp. 416-421, Nov. 2003.

[20] Z. Li and P. Mohapatra, "QRON: QoS-aware routing in overlay networks," IEEE J. Select. Area. Commun., vol. 22, no. 1, pp. 29-40, Jan. 2004.

[21] Y. Zhu, B. Li, and J. Guo, "Multicast with network coding in application-layer overlay networks," IEEE J. Select. Area. Commun., vol. 22, no. 1, pp. 107-120, Jan. 2004.

[22] C. Abad, W. Yurcik, and R. H. Campbell, "A survey and comparison of end-system overlay multicast solutions suitable for network centric warfare," Proc. SPIE Defense and Security Symp., 2004.

[23] N. Yamai, K. Okayama, H. Shimamoto, and T. Okamoto, "A dynamic traffic sharing with minimal administration on multihomed networks," Proc. IEEE Int. Conf. Commun. (ICC 2001), vol. 5, pp. 1506-1510, June 2001.

[24] B. M. Waxman, "Routing of multipoint connections," IEEE J. Select. Area. Commun., vol. 6, no. 9, pp. 1617-1622, June 1988.

[25] M. Yagiura and H. Ibaraki, "Combinatorial optimization," Asakura, 2001.

[26] I. Toda, "Network QoS technology," Ohm, 2001.

[27] H. Okada, "Information network," Baifukan, 1994.