An Efficient Approach to Enhance Throughput in Layered Overlay Multicast using Network Coding Technique

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Abstract— In overlay networks, the available bandwidth between sender and different receivers are different.In this paper, a solution is proposed to improve the throughput of an overlay multicast session with heterogeneous receivers by organizing the receivers into layered data distribution meshes and sending substreams to each mesh using layered coding.Recent advances in information theory show that the throughput of a multicast session can be improved using network coding.The solutions utilize alternative paths and network coding in each mesh.The problem is first formulated into a mathematical programming,whose optimal solution required global information.Hence we present a distributed heuristic algorithm. The heuristic progressively organizes the receivers into layered meshes. Each receiver can subscribe to a proper no of meshes to maximize its throughput by fully utilizing its available bandwidth. The benefits of organizing the topology into layered mesh and using network coding are demonstrated clearly through extensive simulations. Numerical results indicate that the average throughput of a multicast session is significantly improved (up to 50% to 60%) with only slightly higher delay and network resource consumption.

Index Terms— Heterogeneity, Network Coding, Overlay Multicast.

1 Introduction

OVERLAY NETWORKS:

An overlay network is a computer network which is built on top of another network. Two types of network namely physical and logical network exist. Nodes in the overlay can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network. For example, many peer-to-peer networks are overlay networks because they run on top of the Internet. Dial-up Internet is an overlay upon the telephone network.

Uses of Overlay Networks:

Overlay networks can be constructed in order to permit routing messages to destinations not specified by an IP address. For example, Freenet and Distributed hash tables can be used to route messages to a node storing a specified file, whose IP address is not known in advance.

Overlay networks have also been proposed as a way to improve Internet routing, Such as through quality of service guarantees to achieve higher-quality streaming media. Previous proposals such as IntServ, DiffServ, and IP Multicast have not seen wide acceptance largely because they require modification of all routers in the network.

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List of overlay network protocols:

- Distributed hash tables
- Many peer-to-peer protocols
- Including Gnutella, Freenet and I2P
- Solipsis: a France Télécom system for
- Massively shared virtual world internet
- Relay Chat

Layered Overlay Multicast:

In this paper, a layered overlay multicast framework with network coding is proposed to address end-system heterogeneity.Here the sender can provide layered data at different rates as in layered IP multicast.This paper seeks to improve the throughput of a multicast session by organizing the receivers into layered meshes and using network coding in each mesh.Earlier works built single or multiple data distribution meshes, LION fully leverages multipath property in a network and builds multiple data distribution meshes.

A receiver subscribes to a proper number of meshes to maximally utilize its available bandwidth.A source data layer is sent to a corresponding mesh.In each mesh,a receiver has multiple paths to receive the source data.This uniqueness in data distribution mesh distinguishes LION from existing works in layered multicast.The challenge in constructing layered meshes lies in how to build lower layer meshes to maximally utilize the advantage of network coding and to leave more residual bandwidth for higher mesh layers.

Existing mesh construction methods cannot be directly applied to the layered overlay multicast to achieve the above goal.In this paper, a path-overlapping method is proposed that takes advantage of network coding to address this problem. Simulation results in this paper show that the proposed

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heuristic of layered overlay multicast handles heterogeneity very well and improves multicast session's throughput by up to 50%-60%.

2 REVIEW OF THE PREVIOUS WORK

A significant amount of research efforts have been directed towards overlay multicast throughput improvement.Existing works are classified into single-path and multipath schemes. Many of the existing works have advocated building a single-data distribution tree root at sender.Therefore, each receiver has only one path from the sender along the tree.Narada [1], which constructs a spanning tree for data delivery on the initial mesh structure, is a typical single path scheme. Both CoopNet [2] and SplitStream [3] build multiple trees among overlay nodes and send one stream to each tree using multiple description coding. OEvolve [4] is proposed to improve the throughput by measuring each receiver's available bandwidth periodically.

The scheme dynamically adds new trees spanning the receivers which have residual bandwidth. Receivers with available bandwidth can improve throughput by joining more trees. Recent advances in network coding [5] showed that with the presence of relay nodes the multicast throughput can be further improved by allowing coding operation at intermediate nodes in the network's et.al.[8] applied network coding to overlay network to improve throughput, by constructing a 2-redundant multicast graph such that each receiver has two disjoint paths from the sender.

3 BACKGROUND AND MOTIVATION

Layered data multicast is a commonly used multirate approach. Adding data layers to receivers with higher min-cut may further utilize the available capacity to improve throughput. The problem is, given a multicast session with heterogeneous receivers, the aggregate throughput of the session may be improved by providing multirate to receivers.

4 PROBLEM FORMULATION

A) NOTATIONS

The source data layers are encoded into L layers $\{l_1, l2,\ldots,l_L\}$.Layer k has bit-rate B_k.Layer k can be decoded only when layer 1 to k-1 are all available. The network is modeled as a directed graph G(V,E) where

V->set of nodes

E->set of edges.

There are 3 disjoint node sets in V, namely, S, R, T, which denote sender, relays and receivers respectively. If there are total M edges in the network

$E=\{e_{1,e2},\ldots,eM\}$, $|E|=M$.The available bandwidth of edge e_m is Cm.Each receiver's layer subscription matrix Z is denoted by,

$z_{k,i=\{1,}$ if receiver I can get layer k
0, otherwise
¥i=1… N_T, ¥k=1….L.

If receiver ti has N_i possible paths from the sender, the set of these paths is denoted by

$$\text{Path}(t_i) = \{P(t_i, 1),P(t_i,2),\ldots..P(t_i,N_i)\}$$

B) MULTILAYER FORMULATION

The main objective is to maximize the multicast session's throughput. In the setup, it is to maximize the total bit rate of all receivers' subscription. Each receiver joins layers in an incremental order. Before receiver ti joins layer k, it needs to join all the lower layers (1 to k-1) first. If t_i's paths have additional available bandwidth that can support $B_{k,}$ it can join layer k.

Network Coding guarantees that all receivers which joined layer k can have bit-rate $B_{k,}$ since each receiver in layer k has available bandwidth B_k from the sender. The data of layer k are distributed in a mesh rather than a tree since each receiver may have multiple paths from the sender. Though it is possible to code the data from different layers, combining data belonging to different layers makes it difficult to recover all original data for receivers that only receive partial layers.

C) LAYER DECOMPOSITION

Construct the mesh for each layer iteratively to ensure more receivers join the lower layer first. The problem is solved by letting receiver's first join layer one. After the flows are assigned on each edge in layer one, update the available bandwidth C_m of each edge.Edges with no available bandwidth will be removed. The paths containing these removed edges will also be deleted. The receivers which cannot receive layer one are also removed. The resultant ILP (for k=2) is solved again and a mesh for layer two is obtained.

The approximation is iteratively used until there are no receivers in the residual graph. As layers are added in an incremental order, the available bandwidths are first allocated to maximize the number of receivers which join lower layers.Receivers with additional available bandwidth can then join a higher layer to further increase throughput.Adding a higher layer will not cause the lower layer's quality decrease.and therefore fairness is satisfied.

D) HEURISTIC APPROACH

To obtain the optimal solution even within one layer, all receivers must be coordinated. We propose a heuristic algorithm which can be implemented in a distributed manner to approximate the solution. The heuristic not only considers each layer in isolation, but also considers each receiver in isolation. The receivers join layers in an incremental order.

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The basic idea of the heuristic is to encourage overlapping among the paths of different receivers. During the construction of data distribution mesh for a layer, each receiver selects paths independently but tries to select as many paths as possible such that the probability of overlapping with other receiver's paths is high, so that network coding can be applied.

Each receiver ti first runs the Ford-Fulkerson Algorithm to find the maximum achievable flow rate, or maxflow, from the sender as well as the flow rate on the paths to achieve the maxflow.We denote the obtained path set as maxflow paths as MFPath(t_i).

5 Design Steps

The following steps clearly depict the working approach in this paper.

A) Basic Overlay Network Construction:

In this section, the existing bootstrapping techniques, the approach used in Narada is used to form a well-constructed basic overlay network.

Layered meshes on top of the basic overlay network are built. The links in the basic overlay network have two weights (B,D),representing available bandwidth and delay respectively. Each node periodically probes other non-neighbours and measures (B,D) to see if new links can be added.If (B,D) satisfies a predefined threshold,the link is added.Otherwise the link is dropped.

Construction of data distribution mesh within each layer is carried in two steps: selecting path and reserving path. Using flooding technique, to find all possible paths for each receiver and then each receiver selects a number of paths to construct a data distribution mesh. Each receiver then sends a request back to sender to reserve the selected paths and assign the amount of stripes along each path. As the mesh is constructed, each receiver updates all the (B, D) of its paths.

By iteratively repeating the above approach, the construction of layered meshes on top of the basic overlay network is effected.

B) Finding Path:

Before constructing layered meshes, each receiver needs to exploit multiple paths from the sender which are potentially suited for network coding.

The algorithm is illustrated below.

ALGORITHM
Sender S:
Send FP to all neighbours.
Upon receiving FP,
Relay R:
Check if it is included in FP and if the last –hop link satisfies the delay and bandwidth requirements;
If FP satisfied all requirements
Forwards FP to all neighbours;
Else
Drop FP;
Upon receiving FP,
Receiver T:
Record the path;
Discard FP;

C) Constructing Layered Mesh
ALGORITHM:

Receiver T:
Update the available bandwidth of each path in maximal disjoint paths;
Assign stripes on the max disjoint paths;
Reserves the assigned stripes back to the sender along the path;
Relay R:
Aggregates the reservation from different receivers;
Forwards the reservation along the path;
Sender S:
Terminates the reservations;
Sends the required number of stripes to its downstream links;

D) Network Coding:

After each layer's mesh is constructed, the practical random network coding approach is used to distribute the stripes of this layer. Each node combines its received stripes from different upstream links with random linear operations over a large Galois field and sends the coded stripes to downstream links.

To ensure easy operation, it is assumed that the network coding is only performed within each layer. Combining stripes using network coding among different layers makes it difficult to decode for receivers with low available bandwidth.

6 Simulations

The simulation results to be illustrated will be based on the following criteria's.

A) Throughput Gaps:

In order to illustrate the effectiveness of the heuristic, the numerical results that compare the throughputs among the m-layer,1-layer and the heuristic approach is compared.

B) Overlay Network Construction:

In this section, comparison of LION with NARADA and CODED MULTICAST is made using the following metrics.

1) Throughput

Here the application layer throughput at each receiver is measured. The multicast session's throughput is available over all receivers.

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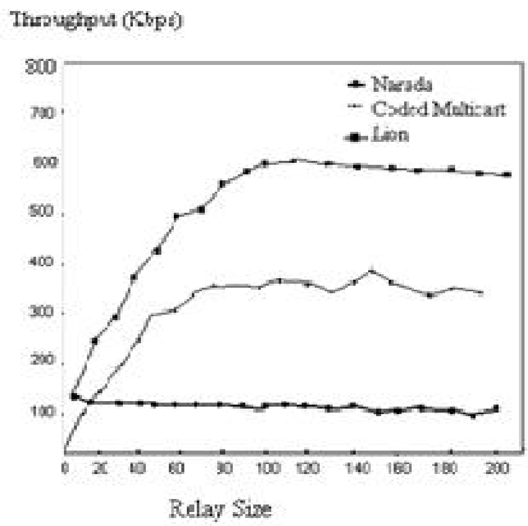

Fig .1.Average throughput versus relay size for Narada, Coded Multicast and Lion.

Fig 1 shows the throughput as a function of relay size for Narada, Coded Multicast and Lion.It is clearly noted that since both Coded Multicast and Lion need dedicated relay nodes, the session's average throughput increases with relay size.

2) Delay

The end-to-end delay is defined as the time interval between the time a packet is being sent at the sender and the time the packet is correctly decoded at the receiver.

In the case of LION and CODED MULTICAST, the end-to-end delay is defined as the longest delay among all the paths involved.

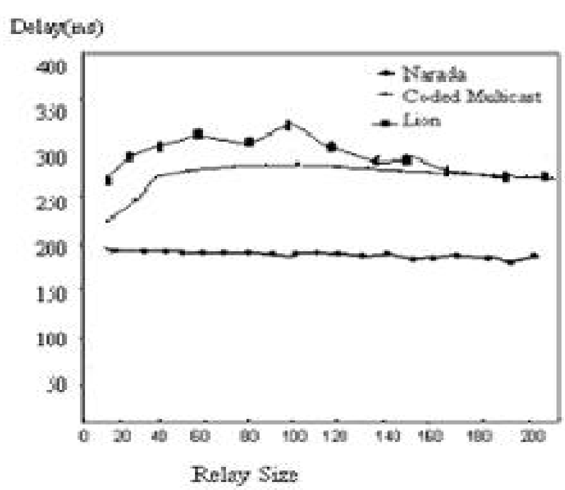

Fig.2.Average Delay versus relay size for Narada, Coded Multicast and Lion.

Fig.2. plots the average delay as a function of relay size for Narada,Coded Multicast and Lion.

Here the changes in delay under Narada are small.Coded Multicast and Lion's delay first increase with relay size when the relay size is small.However, the delay decreases or remains the same when the relay size is larger than receiver size,since receivers may find better relays in the paths,which results in smaller delay.

3) Normalized Resource Usage Ratio (NRUR)

Resource Usage Ratio (RUR) reflects the network resource efficiency ie, how much network resource is consumed to achieve a unit throughput.

The higher the value of RUR is, the more network resource the multicast session consumes to deliver a bit of data.NRUR reflects the overlay multicast's penalty compared with Traditional IP multicast.

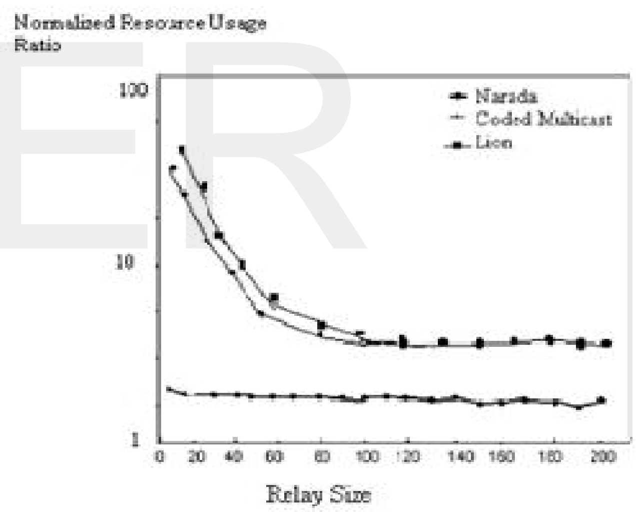

Fig.3.Normalised resource usage ratio Vs relay size

Here the NRUR's of Coded Multicast and LION are much higher than that of Narada when the relay size is small.this is due to the fact that there is no degree constraint while constructing overlay. Thus, when relay size is small, some receivers cannot find relay nodes and therefore cannot join the multicast session which results in zero throughputs.

In short, Lion improves the session's throughput significantly while keeping the delay and network resource consumption under a reasonable value.

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7 CONCLUSION

This paper seeks to improve the multicast session throughput in hetereogeneous overlay networks using network coding with the presence of relay nodes. Given that the available bandwidths between multicast sender and receivers are heterogeneous in nature, a layered overlay multicast is proposed to cope up with heterogeneity and improve the throughput Instead of building single or multiple trees, the data distribution topology is built as multiple meshes.

LION has still some applicable scenarios such as small-scale overlay networks or a network which has relative static node membership.It is sensitive to node join and leave.Future works include implementing LION in the internet and combining LION with layered coding such as FGS or PFGS to provide scalable video delivery in a heterogeneous environment.

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