Resilient Peer-to-Peer Streaming

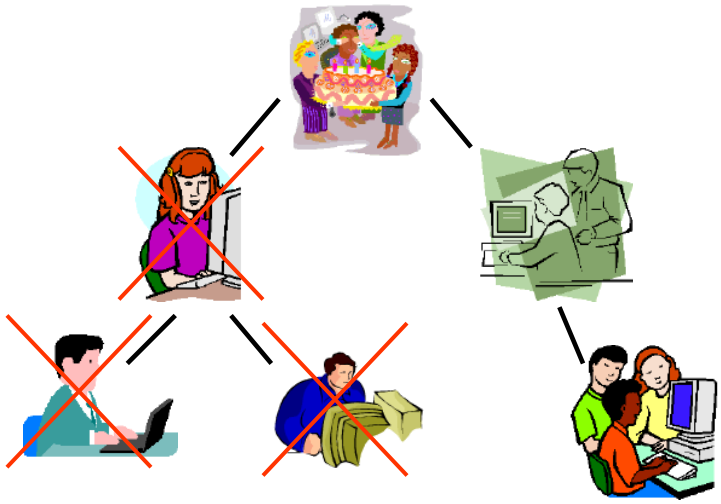
Venkata N. Padmanabhan
Helen J. Wang
Philip A. Chou

CoopNet Project
Microsoft Research
ICNP 2003

Problem Statement

- Problem:
  - live Streaming to a large audience in the wide-area Internet
- Peer-to-Peer Multicast is appealing
  - Self scaling
  - Easy to deploy, low cost
- A key challenge in supporting live streaming: *resilience*
  - Unreliable peers

Existing Peer-to-Peer Multicast



Vulnerable to node departures and failures

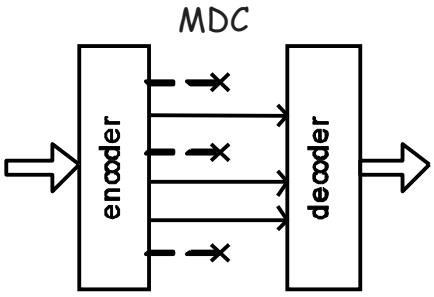
Our Approach

- Resilience through redundancy
  - Redundancy in network paths
  - Redundancy in data
- Place minimal demands on the peers
  - Only involve interested peers for traffic forwarding
  - Peer contributes only as much upstream bandwidth as it consumes downstream
    - natural incentive structure (enforcement is a hard problem!)

Path Redundancy: Multiple, Diverse Distribution Trees

Tree diversity provides robustness to node failures.

Data Redundancy: Multiple Description Coding



- MDC codes data stream into *independent* descriptions (or substreams), *any* subset of which is decodable
- Intelligent striping + FEC

Outline

- Problem Statement
- Overview of our approach
- Our solutions to resilience:
  - Path diversity: multiple distribution trees
  - Data redundancy: multiple description coding
- Performance evaluation
- Related work
- Summary and ongoing work

Tree Management: Goals

- Short trees
  - Fewer ancestors →less disruption
- Diversity
- Key to robustness
- Efficiency (stretch factor and link stress)
- Quick join and leave
- Scalability
- Conflicts:
  - Shortness vs. Efficiency
  - Diversity vs. Efficiency
  - Speed vs. Scalability

Centralized Approach

- Leverage the availability of resourceful server
- Centralized tree management anchored at the server (like Napster)
- Nodes inform the server when they join and leave
  - they indicate available bandwidth, delay coordinates
- Avoid repair request implosion at the server →*scalable tree repair*:
  - upon high loss at a node, it checks with its parent first, only when the link is broken with the parent, the node contacts the server for new parent

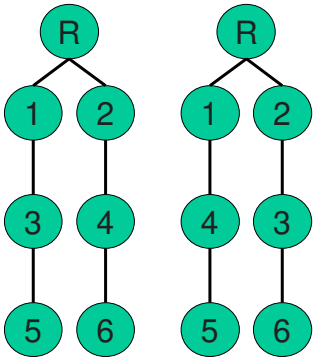
Pros and Cons

- Advantages:
  - availability of resourceful server simplifies protocol
  - quick joins/leaves: 1-2 network round-trips
- Disadvantages:
  - single point of failure
    - but server is source of data anyway
  - not self-scaling
    - but still self-scaling with respect to bandwidth
    - tree manager can keep up with ~400 joins/leaves per second on a 1.7 GHz P4 box

Randomized Tree Construction

- For shortness: the server places a joiner as high up in the tree as possible
- For diversity: randomly selects eligible parents who still have bandwidth to take more children
- Reported in our NOSSDAV '02 paper

Why is this Suboptimal?

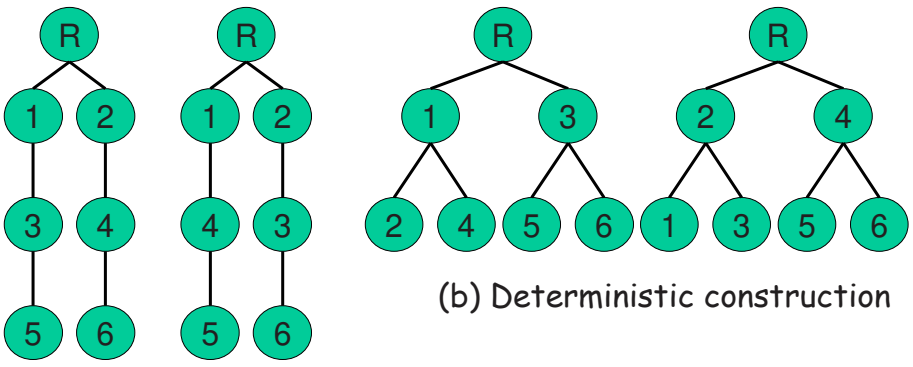


- We ask nodes to contribute only as much bandwidth as they consume
- So T trees $\Rightarrow$ each node can support T children in total
- Q: how should a node's out-degree be distributed?
- Randomized tree construction tends to distribute the out-degree randomly
- This results in deep trees that not very bushy

Deterministic Tree Construction

- Motivated by SplitStream work [Castro '03]
  - Lots of leaves -- cumulative upstream bandwidth abundant
  - A node needs be an interior node in just one tree;
  - Diversity can be achieved by making the interior nodes of the trees disjoint
- Distinctions:
  - Deterministic tree construction guarantees the disjointness, i.e., diversity, of the set of interior nodes across the trees
  - Only interested nodes are involved in forwarding

Randomized vs. Deterministic Construction



(b) Deterministic construction

(a) Randomized construction

Outline

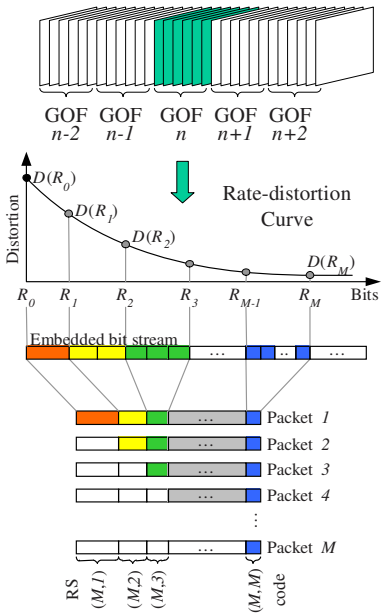
- Problem Statement
- Overview of our approaches
- Our solutions to resilience:
  - Path diversity: multiple distribution trees
  - Data redundancy: multiple description coding
- Performance evaluation
- Related work
- Summary and ongoing work

Multiple Description Coding

- Key feature: independent descriptions
  - No ordering of the descriptions
  - Any subset is decodable
  - In contrast with layered coding where loss of the base layer makes received enhancement layer useless
- State-of-the-Art MDC construction
  (Puri & Ramchandran '99, Mohr '00)
  - Uses layered coding and FEC as building blocks
  - Output M descriptions/packets

State-of-the-Art MDC

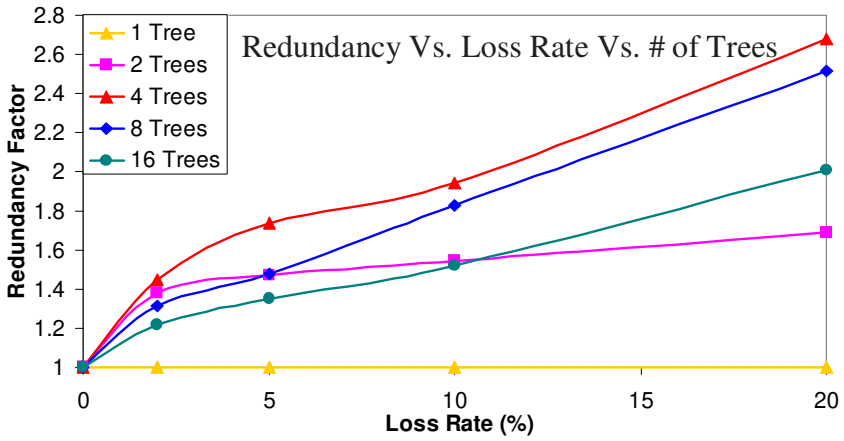
- Divide the stream into Group Of Frames (GOF)
- Prioritize the streaming data using *layered coding*
- For each GOF, apply different levels of *FEC* protection to data units depending on their importance
- FEC profile optimized given the packet size, # of descriptions M, and the distribution of the number of received descriptions/packets, p(m)
- Pure FEC, a *special* case of MDC where all clients have the same loss rate



Outline

- Problem statement
- State-of-the-art
- CoopNet approach to resilience:
  - Path diversity: multiple distribution trees
  - Data redundancy: multiple description coding
- Performance evaluation
- Summary and ongoing work

MDC Overhead



Processing: 1 Ghz CPU, 768MB RAM, Windows XP, C# implementation, < 20 ms for 1 second GOF

Tree Algorithms + MDC Evaluations: Methodology

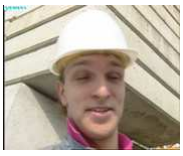
- Use a flash crowd trace to simulate a streaming session
- Use real video clips as streaming data
- Perceived PSNR using averaged distortion across all clients, as the streaming quality metric

Flash Crowd Traces

- MSNBC streaming logs from Sep 11, 2001
  - Join time and session duration
  - Assumption: session termination ⇒ node stops participating
- Live streaming: 100 Kbps Windows Media Stream
  - up to ~18,000 simultaneous clients
  - ~180 joins/leaves per second on average
  - peak rate of ~1000 per second
  - ~70% of clients tuned in for less than a minute
    - high churn possibly because of flash crowd congestion

Video Data

Akiyo



Foreman

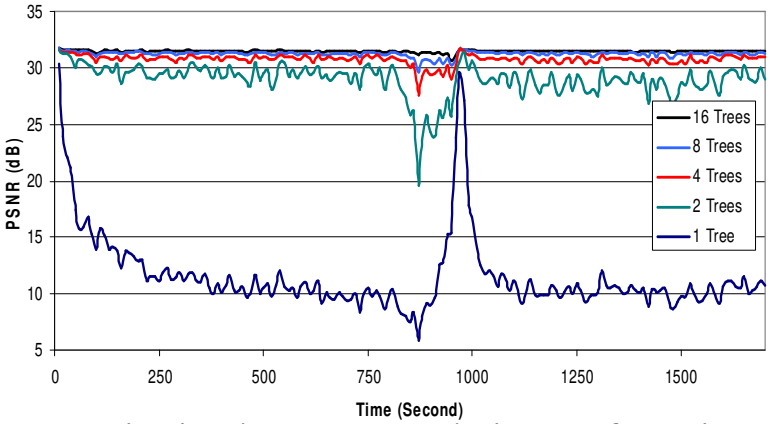
Stefan

- We don't have the actual MSNBC video content
- Standard MPEG test sequences (10 seconds each)
- QCIF (176x144), 10 frames per second

Simulation Parameters

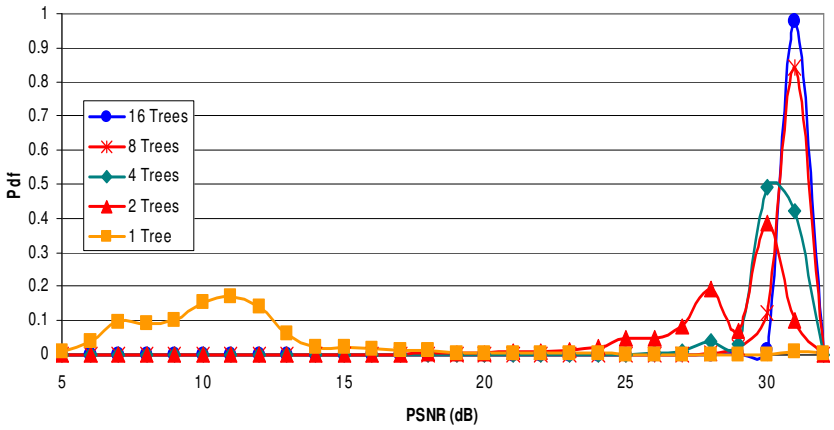
Server bandwidth: 20 Mbps
Peer bandwidth: 160 Kbps
Stream rate: 160 Kbps
Packet size: 1250 bytes
GOF duration: 1 second
desciptions: 16
trees: 1, 2, 4, 8, 16

Impact of Number of Trees

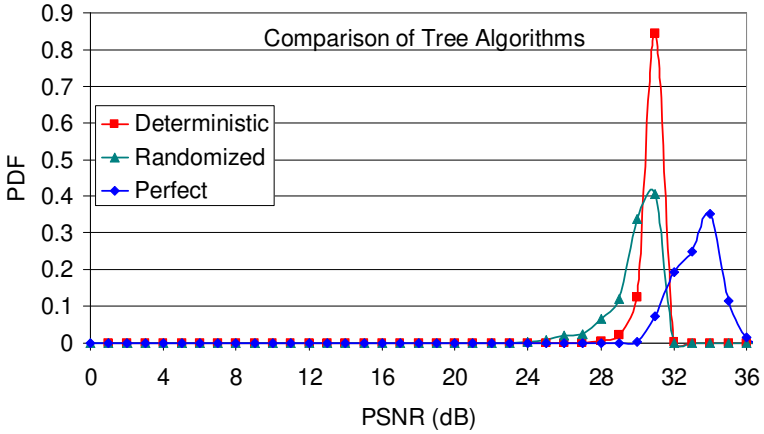


Multiple, diverse trees help significantly.
Much of the benefit is achieved with 8 trees.

Impact of Number of Trees

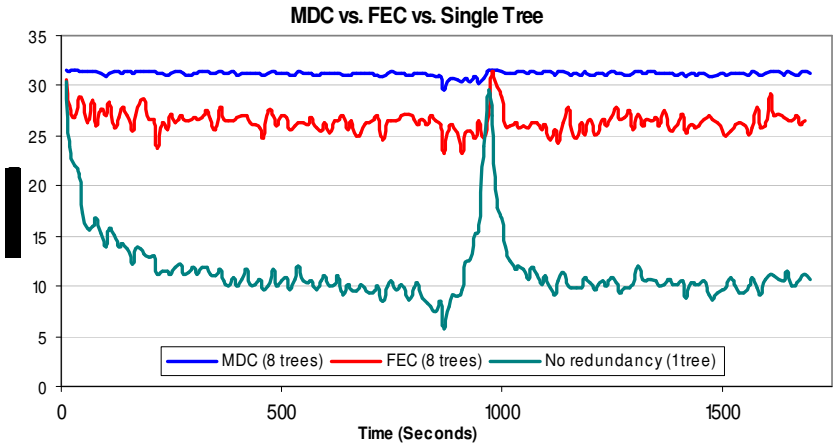


Randomized vs. Deterministic Tree Construction vs. Perfect Tree



Deterministic algorithm results in shorter trees that are less prone to disruption

MDC vs. Pure FEC



MDC is better able to adapt to a wide spatial distribution in packet loss than pure FEC.

Related Work

- Application-level multicast
  - ALMI [Pendarakis '01], Narada [Chu '00], Scattercast [Chawathe'00]
    - small-scale, highly optimized
  - Bayeux [Zhuang '01], Scribe [Castro '02]
    - P2P DHT-based
    - nodes may have to forward traffic they are not interested in
    - performance under high rate of node churn?
  - SplitStream [Castro '03]
    - layered on top of Scribe
    - interior node in exactly one tree ⇒ bounded bandwidth usage
- Infrastructure-based CDNs
  - Akamai, Real Broadcast Network, Yahoo Platinum
  - well-engineered network but for a price
- P2P CDNs
  - Allcast, vTrails

Related Work (Contd.)

- Coding and multi-path content delivery
  - Digital Fountain [Byers '98]
    - focus on file transfers
    - repeated transmissions not suitable for live streaming
  - Parallel downloads [Byers '02]
    - take advantage of lateral bandwidth
    - focus on speed rather than resilience
  - MDC for on-demand streaming in CDNs [Apostolopoulos '02]
    - what if last-mile to the client is the bottleneck?
  - Integrated source coding & congestion control [Lee '00]

Summary

- P2P streaming is attractive because it has the potential of being self-scaling
- Resilience to peer failures, departures, disconnections is a key concern
- CoopNet approach:
  - minimal demands placed on the peers
  - redundancy for resilience
    - multiple, diverse distribution trees
    - multiple description coding

Ongoing and Future Work

- Heterogeneity support:
  - Layered MDC
  - Congestion control framework
- More info:
  http://research.microsoft.com/projects/coopnet/
- Includes papers on:
  - case for P2P streaming: NOSSDAV '02
  - layered MDC: Packet Video '03
  - resilient P2P streaming: MSR Tech. Report
  - P2P Web content distribution: IPTPS '02

A typical client's experience on 911

Single-tree Distribution | CoopNet Distribution with FEC (8 trees) | CoopNet Distribution with MDC (8 trees)

Questions