P2P Live Streaming

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Outline

- Introduction
- P2P multicast algorithms
- Comparison
- Future work
- Summary

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- Introduction
- Infrastructure-based (two-tier) approaches
- Single tree approaches
- Improved single tree approaches
- Mesh-based approaches
- Multiple tree approaches
- Mixed approaches
- Comparison
- Future work
- Summary

Introduction

- P2P multicast algorithms:
  - Infrastructure-based (two-tier) approaches
  - Single tree approaches
  - Improved single tree approaches
  - Mesh-based approaches
  - Multiple tree approaches
  - Mixed approaches

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- Introduction
- Infrastructure-based (two-tier) approaches
- Mesh-based approaches
- Single tree approaches
- Improved single tree approaches
- Multiple tree approaches
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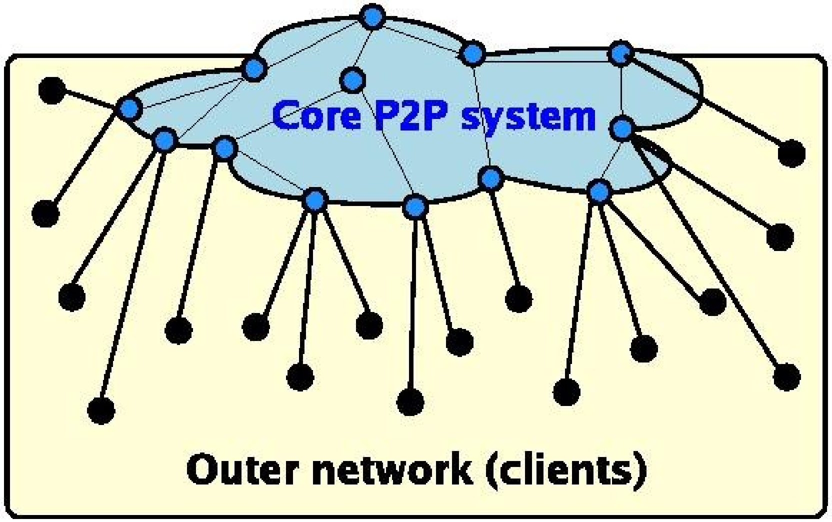
Infrastructure-based Approaches

- Two separate sections:
  - The actual p2p network
    - Core of system
    - Generally resourceful nodes
  - The outer network
    - End users
    - Doesn't take active part in distribution of information



Related Algorithms

- Overcast [1]
- Scattercast [2]

Overcast

Overcast

- Main parts of overcast:
  - Central source
  - Internal Overcast nodes (pool of nodes)
  - Standard HTTP clients

- Tree of internal nodes rooted at the source

- Maximize the available bandwidth from the source to all nodes

Overcast (Join internal nodes)

- At booting up, the node contacts a global, well-known registry
- Registry provides a list of Overcast networks to join.
- Initially chooses the root as its parent.
    - Calls it current parent

Overcast (Join internal nodes)

- Begins a series of rounds
  - Attempts to locate itself further away from the root
  - Without sacrificing bandwidth back to the root

- In each round
  - Considers its bandwidth to current parent
  - Considers bandwidth to current parent through each of current parent's children
  - If the bandwidth through any of the children is about as high as the direct bandwidth to current parent

- A node periodically re-evaluates its position in the tree.

Overcast (Leave/Failure internal nodes)

- When a node detects that its parent is unreachable:
  - It will relocate beneath its grandparent, if not ...
  - Continues to move up its ancestry until it finds a live node.
- Nodes maintain an ancestor list
  - Avoid cycles

Overcast (Join client nodes)

- Joining a group consists of:
  - Selecting the best server
  - Redirecting the client to that server

- The client issues an HTTP GET request with a URL to group.
  - The host name of URL is the name of root.

- The root decides where to connect the client to the multicast tree.

Scattercast

Scattercast

- The same as Overcast, but ...
- The nodes in core network adapt dynamically their connectivity to the client load

Advantages & Drawbacks

- Advantages
  - Transparent to the user
    - They can use standard client applications
  - Total control over network traffic by owner
  - The problem of fairness, security and dishonest nodes are marginal

- Drawbacks
  - Vulnerable to DoS attacks
    - The number of core hosts is finite and their location may be known
  - Doesn't cope very well with flash crowd and sudden increase of traffic

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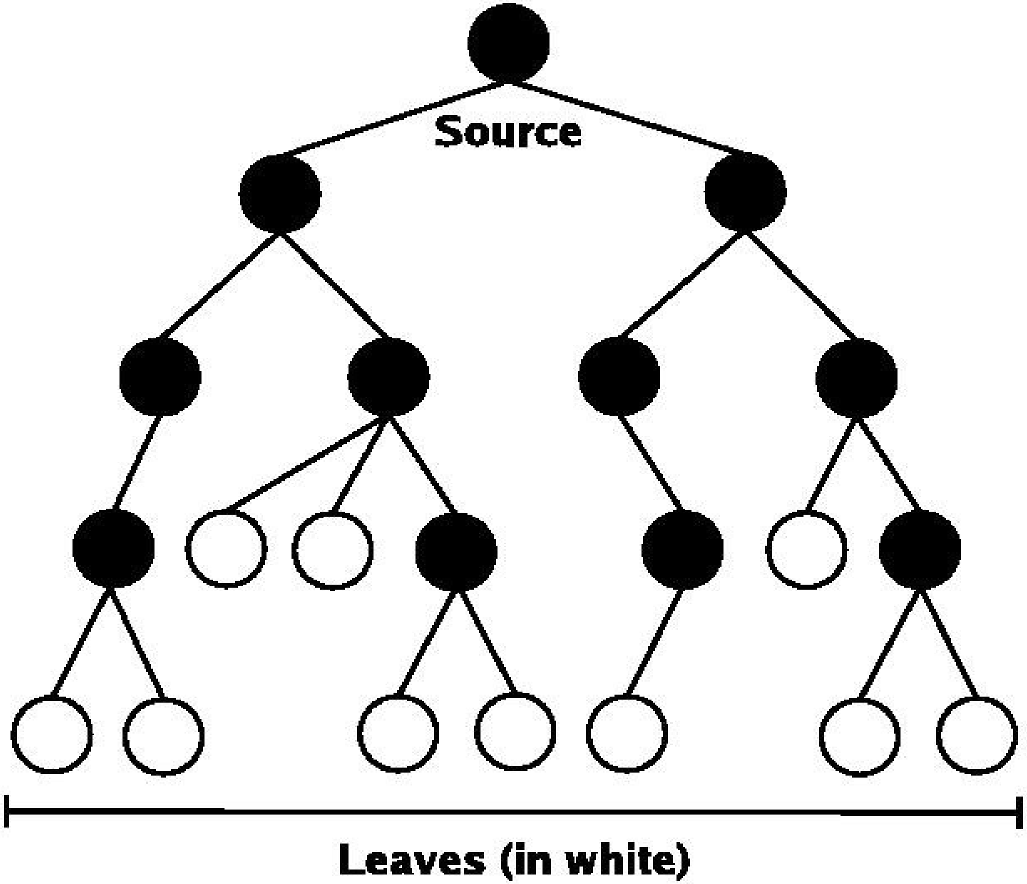
Single Tree Approaches



Related Algorithms

- PeerCast [5]
- Scribe [6]
- NICE [7]

Peercast

PeerCast

- PeerCast is today a fully deployed application
  - Mostly used for independent, small-scale Internet radio broadcasts

- Organizing the group members into a self-organized, source-specific, spanning tree.

PeerCast (Join)

- The node contacts the source of the stream
  - Each live stream has a unique URL
  - The source information is embedded in it

- If source is unsaturated
  - Accepts a data transfer session setup request.
- If not,
  - the request is send to source immediate children.
    - Which child:
      - Random
      - Round-Robin
      - Smart placement

- The process continues iteratively,

- If node is unable to find an unsaturated node sends unavailable error to the upper application-layer

PeerCast (Leave/Failure)

- On leave, it forwards a valid target t to its descendants.
- Each node is aware of two nodes:
  - Its parent
  - Source
- After leaving
  - Each descendant tries to recover by contacting targets
  - Or only children of unsubscribed node attempt to recover by contacting target.
- In failure, only source is identified as target.

Scribe

Scribe

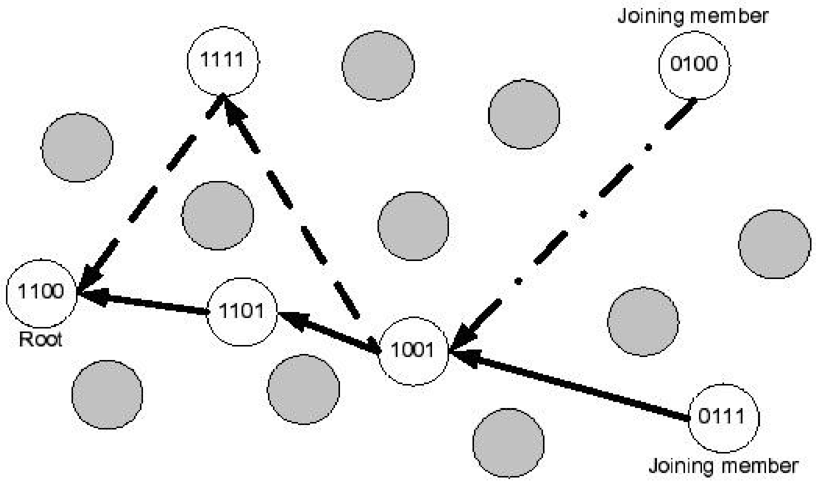
- Scribe is a scalable application-level multicast infrastructure
- It is built on top of Pastry
- A Scribe node
  - May create a group
  - May join a group
  - May be the root of a multicast tree
  - May act as a multicast source

Scribe (Creating group)

- Each group has a unique group-Id.
  - Hash of the group's textual name
- Sends CREATE message
  - With group-id
- Pastry delivers this message to the node with closest numerical node-Id: rendezvous point.
- The rendezvous point is the root of tree for the group

Scribe (Join)

- Send JOIN message
  - With group-id



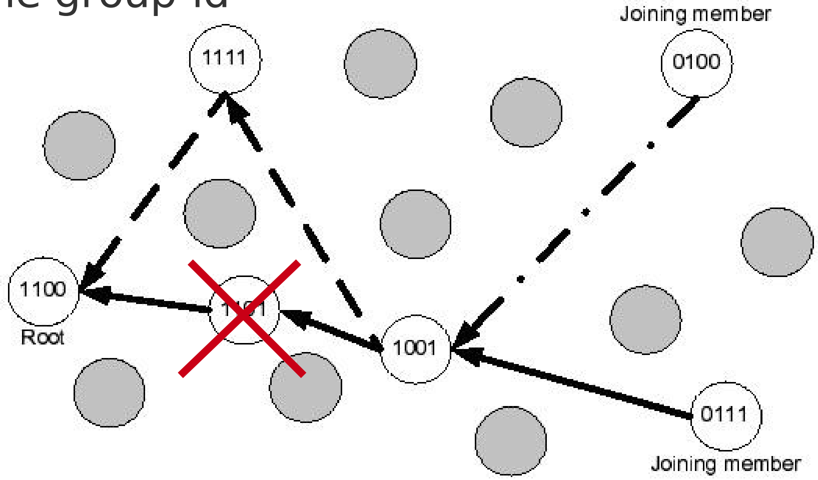
- Pastry routes to rendezvous point
  - If intermediate node is forwarder
    - Adds the node as its child
  - If intermediate node is not a forwarder
    - Creates child table for the group, and adds the node
    - Sends a JOIN towards the rendezvous point
      - becomes forwarder
  - Terminates JOIN message from the child.

Scribe (Leave/Failure)

- If the node has no children in its table, it sends a LEAVE message to its parent
  - The message travels recursively up the multicast tree
  - The message stops at a node which has children after removing the departing node

Scribe (Leave/Failure)

- Non-leaf nodes send heartbeat message to children
  - Multicast messages serve as implicit heartbeat
- If child does not receive heartbeat message
  - Assumes that the parent has failed
  - Sends a JOIN message to the group-id



- If rendezvous point fails
  - The state associated with a rendezvous point is replicated across k closest nodes
  - The children detect the failure and send a JOIN message which gets routed to a new node-id numerically closest to the group-id

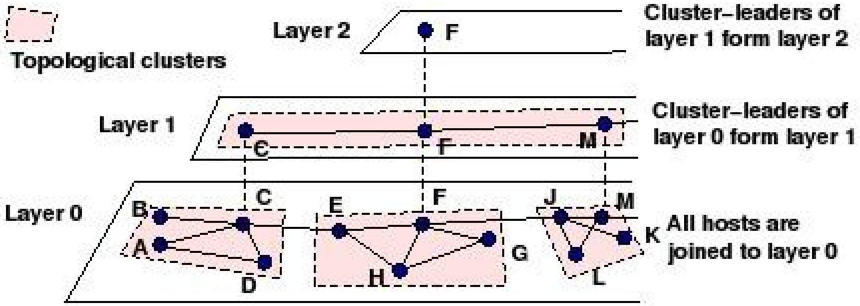
Scribe (Data Delivery)

- Source sends MULTICAST message to the rendezvous point
- Source caches the IP address of the rendezvous point
  - So that it does not need Pastry for subsequent messages

NICE

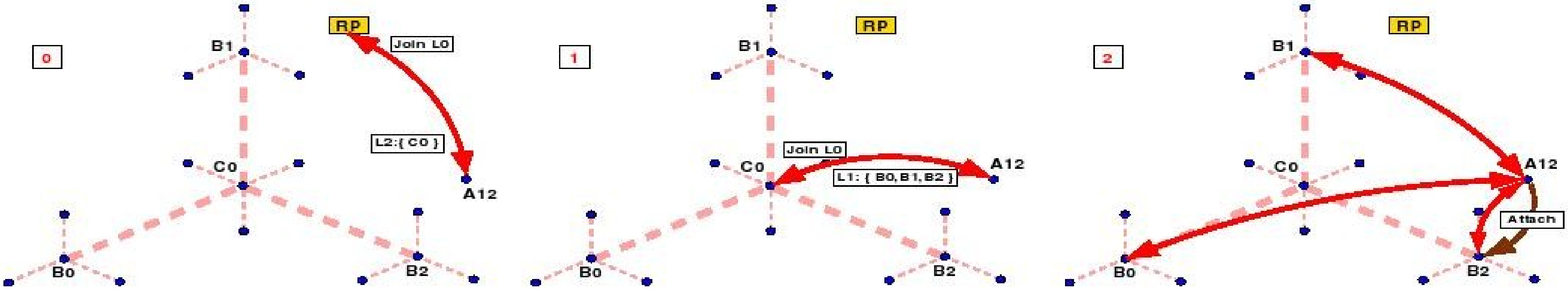
NICE

- Support large receiver sets with small control overhead
- Hierarchical membership
  - Clients are assigned to different layers
  - Each layer is partitioned into a set of clusters
    - The size between k and $3k – 1$ (k is a constant).
  - All hosts belong to the lowest layer L_0
  - One host selected as leader
  - Leaders of clusters of L_i join layer L_{i+1}



NICE (Join)

- Rendezvous Point (RP)
  - All hosts know the RP host
- Join procedure
  - Contact RP to get the cluster members of the highest layer
  - Loop until reach layer 0
    - Query the members of the returned cluster and find the closest one, *X*
    - Get the members of the child-cluster of *X*



NICE (Leave/Failure)

- On leave
  - Send a leave message to all clusters it belongs
- On failure
  - *Other hosts detect the leave by not receiving the periodic refresh of H*
- If *H is leader*
  - *Each remaining member, J, select a new leader independently*
  - *Multiple leaders are resolved by the exchange of refreshes*

NICE (Maintenance)

- Cluster-leader periodically checks the size of its cluster in layer L_i
  - If the cluster size exceeds the 3*k* - 1 limit
    - Split the cluster into two equal-sized clusters
  - If the cluster size is under *k*
    - The leader finds a closest host in layer L_{i+1} and merge with it

- Each member, *H*, in any layer L_i periodically probes all members in its super-cluster, to identify the closest member
  - If a host, *J* is found, then H joins to the cluster under the *J*

NICE (Data Delivery)

- Control paths
  - Exchange periodic state refreshes
  - For a host *X*, the peers on its control topology are the other members of the clusters to which *X* belongs

- Data paths

Procedure : $MulticastDataForward(h, p)$

$\{\ h \in \ layers\ L_0, \ldots, L_i\ in\ clusters\ \mathrm{Cl}_0(h), \ldots, \mathrm{Cl}_i(h)\ \}$

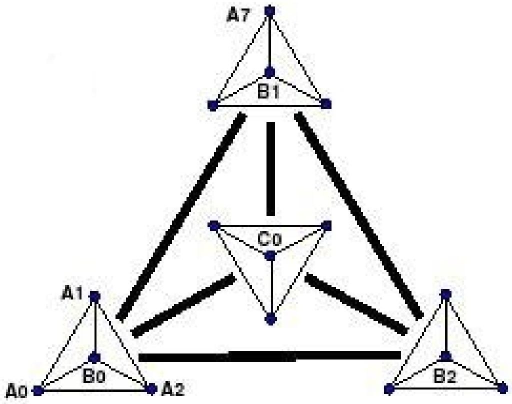
for j **in** $[0, \ldots, i]$

  if $(p \notin Cl_j(h))$

    $ForwardDataToSet(Cl_j(h) - \{h\})$

  end if

end for



Advantages & Drawbacks

- Advantages
  - Optimal with respect to transmission delay
- Drawbacks
  - Doesn't share the load in even way
  - Reacts badly to node failure

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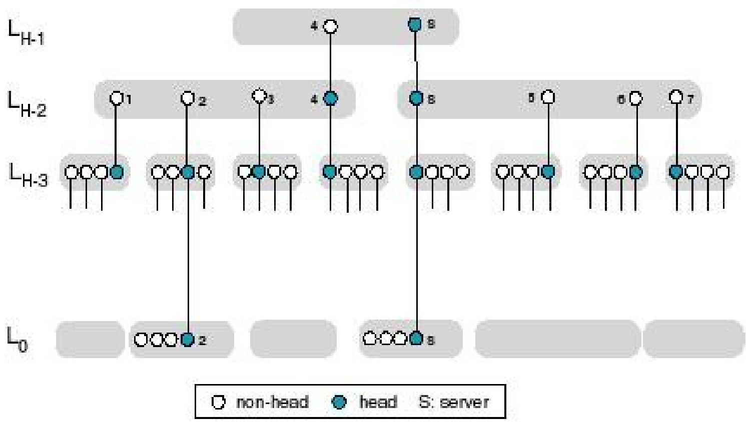
Related Algorithms

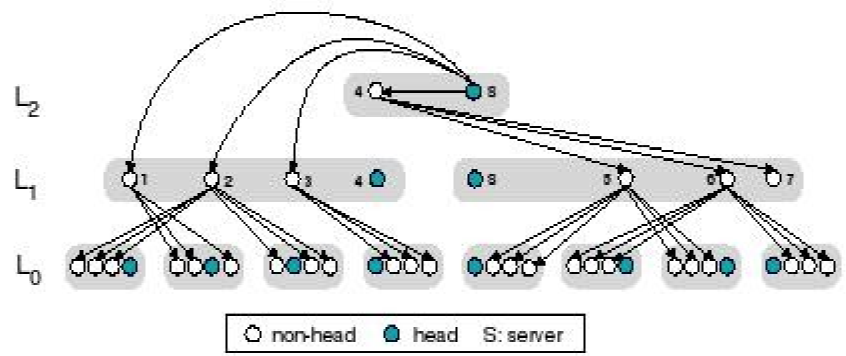
- ZigZag [8]
- BulkTree [9]

ZigZag

ZigZag

- It organizes the receivers into bounded size clusters and makes a multicast tree based on them
- Two important entities:
  - Administrative organization
    - Logical relation among peers
  - Multicast tree
    - Physical relation among peers



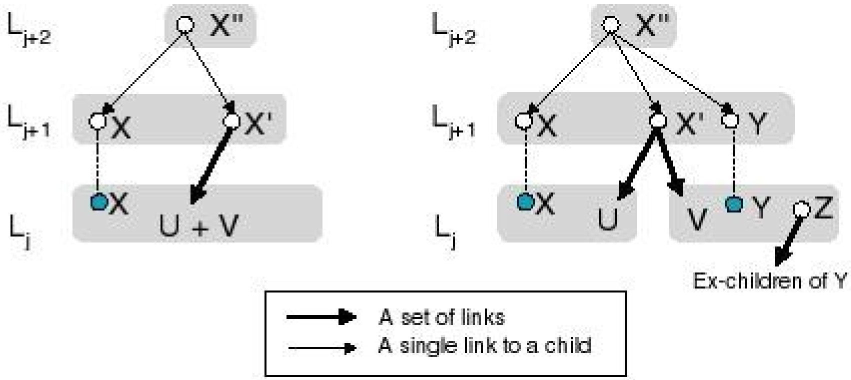


ZigZag (Rules)

- When a peer is not at its highest level can not have link to other peers.
- When a peer is at its highest level, can only link to its foreign subordinate.
- The members of a cluster at any layer get the content from their foreign head.
- The peers in each cluster periodically sends some control messages to its clustermate, its parent and its children
  - Reachable
  - Addable
  - ...

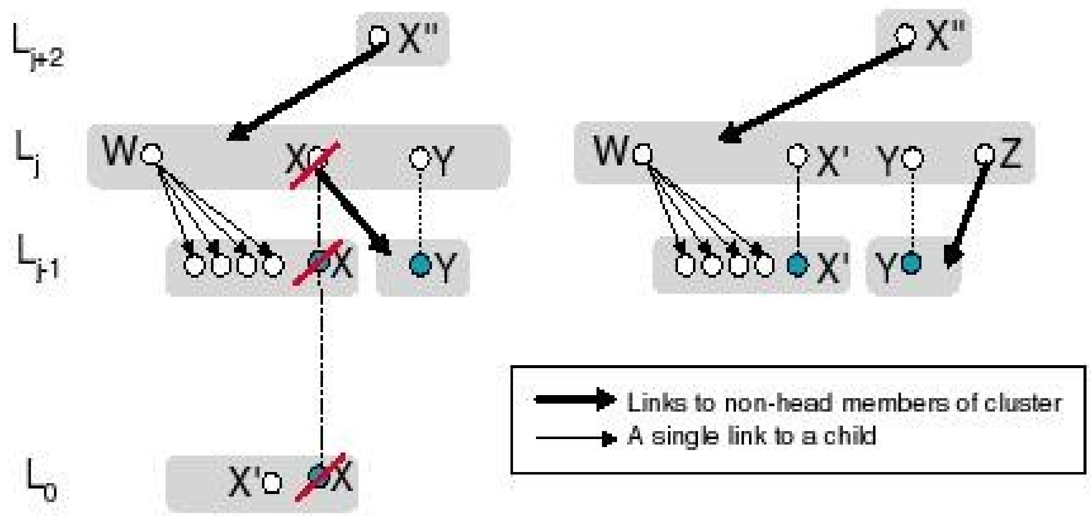
ZigZag (Join)

1. If X is a leaf
2. Add P to the only cluster of X
3. Make P a new child of the parent of X
4. Else
5. If $Addable(X)$
6. Select a child Y:
   $Addable(Y)$ and $D(Y)+d(Y, P)$ is min
7. Forward the join request to Y
8. Else
9. Select a child Y:
   $Reachable(Y)$ and $D(Y)+d(Y, P)$ is min
10. Forward the join request to Y



(a) Before Splitting (b) After Splitting

ZigZag (Leave/Failure)



(a) Before Failure

(b) After Recovery

Bulktree

BulkTree

- Main idea:
  - Organizing a set of close nodes (weak-nodes) into a strong super node
  - Construct a tree structure over super nodes

- The size of each super node is [k, 3k-1] and size of each leaf super node is [1, 3k - 1].

- Each super node has a leader and a backup leader

- The leader nodes collect information about parent super node, other weak nodes in the same super node and their children super nodes
- The other weak nodes only collect information about parent super node and children super nodes.

BulkTree (Join)

- First contacts to the server and the server redirects it to its children

1. Select a node *X* from *Leader*(*S*): *D*(*H*, *X*) is min;
2. If *Super*(*X*) is a leaf
3. Add *H* to the *Super*(*X*);
4. Else
5. If *Addable*(*X*)
6. Add *H* to the *Super*(*X*);
7. Else if another node *Y* in *Leader*(*S*) is addable
8. Add *H* to the *Super*(*Y*);
9. Else send *Leader*(*X*) to *H* for contact;

- If after joining the new node, the size of super node is exceeded, it should be splited and balanced

BulkTree (Leave/Failure)

- If H is the leader of super node, the backup leader becomes leader.
- If after departing a node the size of super node becomes lower than k, merging should be taken.

BulkTree (Data Delivery)

- First scheduled inside super node, and if needed ask its parent super node

- If the parent has the data, the leader chooses k good nodes and these k nodes then send 1/k data to receivers

Advantages & Drawbacks

- Advantages
  - Optimal with respect to transmission delay
- Drawbacks
  - Doesn't share the load in even way

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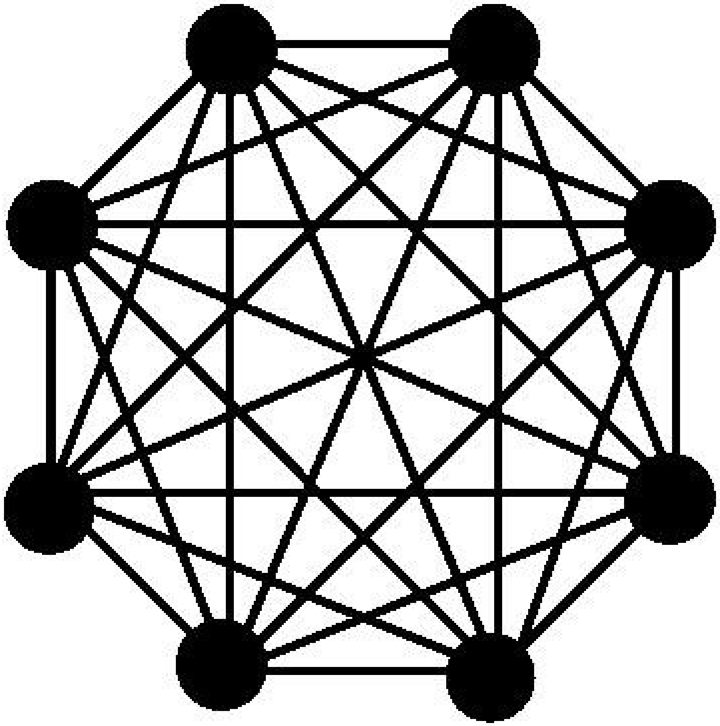
Mesh-based Approaches



Related Algorithms

- Narada [3]
- Yoid [4]

Narada

Narada

- Narada is a multiple-source multicast overlay infrastructure

- It uses
  - Mesh as a control infrastructure
  - Tree as data delivery infrastructure

- The tree is constructed in a two-step process:
  - It constructs a mesh with desirable performance properties
    - Path Quality
      - Application interested metric: delay, bandwidth, ...
    - Limiting the number of neighbours
      - Controls the overhead of running routing algorithms

  - It constructs spanning trees of the mesh,
    - Each tree rooted at the corresponding source

Narada (Join)

- Each node gets a list of group members
  - By an out-of band bootstrap
  - Does not need to be complete or accurate
  - Must contain at least one currently active group member

- Selects randomly a few group members from the list

- Sends requesting message to them to be added as a neighbour.
  - It repeats until it gets a response

Narada (Leave/Failure)

- On leave, it notifies its neighbours,
  - Propagated to the rest of the group members along the mesh.
- The leaving member continues forwarding packets for some time
  - To minimize transient packet loss
- Failures should be detected locally
  - By not receiving refresh messages from some node for a while
  - Propagate to the rest of the group
- Nodes are capable of detecting and repairing partitions.

Narada (Maintenance)

- Allows incremental improvement of mesh quality
  - By adding and dropping of overlay links
- Members probe each other at random
  - New links may be added depending on the perceived gain in *utility* in doing so.
- Members continuously monitor the utility of existing links,
  - Drop links perceived as not useful

Yoid

Yoid

- Each member acts relatively independently

- It uses:
  - Tree
    - Efficiency
    - Multicast of application content
  - Mesh
    - Robustness
    - Broadcast of control and application content

- Each group has a groupId
  - yoid://rendezvous.name:port/groupName

Yoid (Rendezvous host)

- It is not part of tree-mesh
- Primary purpose of the rendezvous host is bootstrapping members.
  - By informing each member of several current member, and optionally various other information about the tree.
- Each node talk to rendezvous in several cases:
  - When joining
  - When leaving
  - Sends ping message to it (I'm alive)
  - Informs rendezvous when the node becomes root of tree

Yoid (Mesh construction)

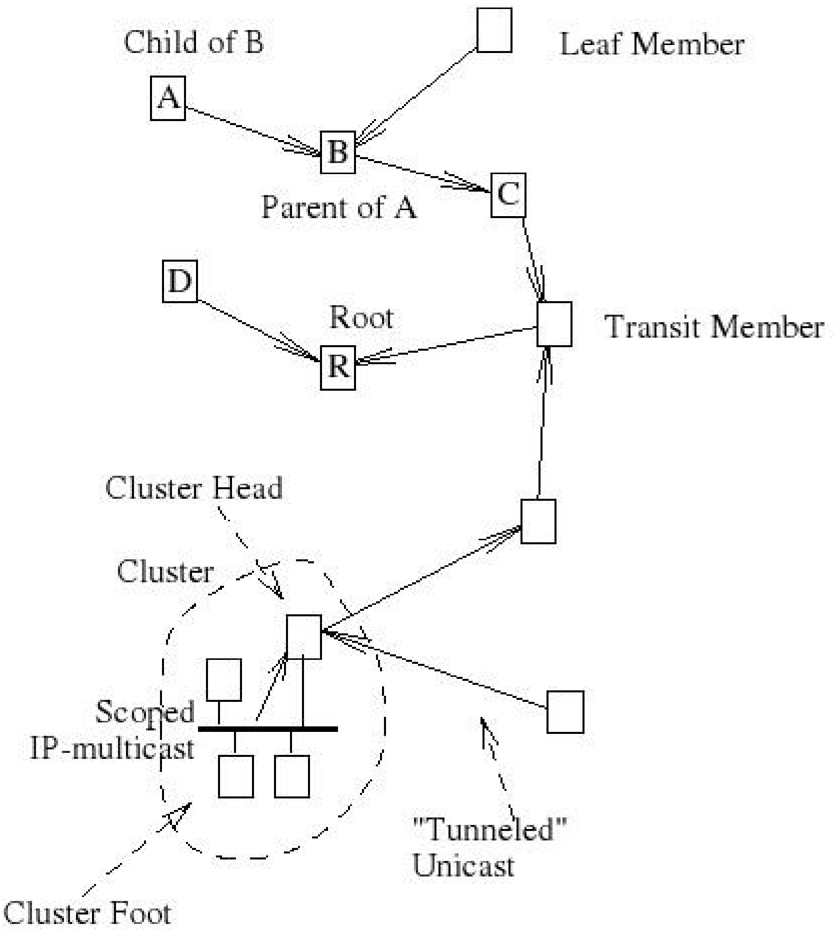
- Each member maintains a small number of neighbours

- To insure a non-partitioned mesh topology:
  - Each member M establishes a small number of other members
    - Three or four
  - Selected randomly
  - Must not include members that are tree neighbours
  - Must not include members that have already established a mesh link to this member M

Yoid (Tree construction)

- A member may receive and transmit frames via:
  - Unicast IP
  - Scoped IP multicast
    - One hop
- Where multicast IP is used, a set of members are grouped as a cluster.
  - One member of the cluster is elected the head,
    - Is responsible for establishing a (unicast IP) parent neighbour
  - The other cluster members are called feet
    - Transmit and receive to/from the tree via the head
- Each member that cannot join a cluster or is the head of a cluster:
  - Is responsible for either finding a parent in the tree
  - Or deciding that no other member can be a parent
    - Becoming the root of the tree
- No loop prevention, but detection using Root Path

Yoid (Tree construction)



Advantages & Drawbacks

- Advantages
  - A true p2p network
    - All nodes have the same role regardless of their placement, capabilities and resources
  - Doesn't have single point of failure
  - Resilient to massive host crashes and disconnects
  - Support both single-source and concurrent multiple-source

- Drawbacks
  - Complexity of management
  - Steady flow of control messages between all nodes
    - limited size

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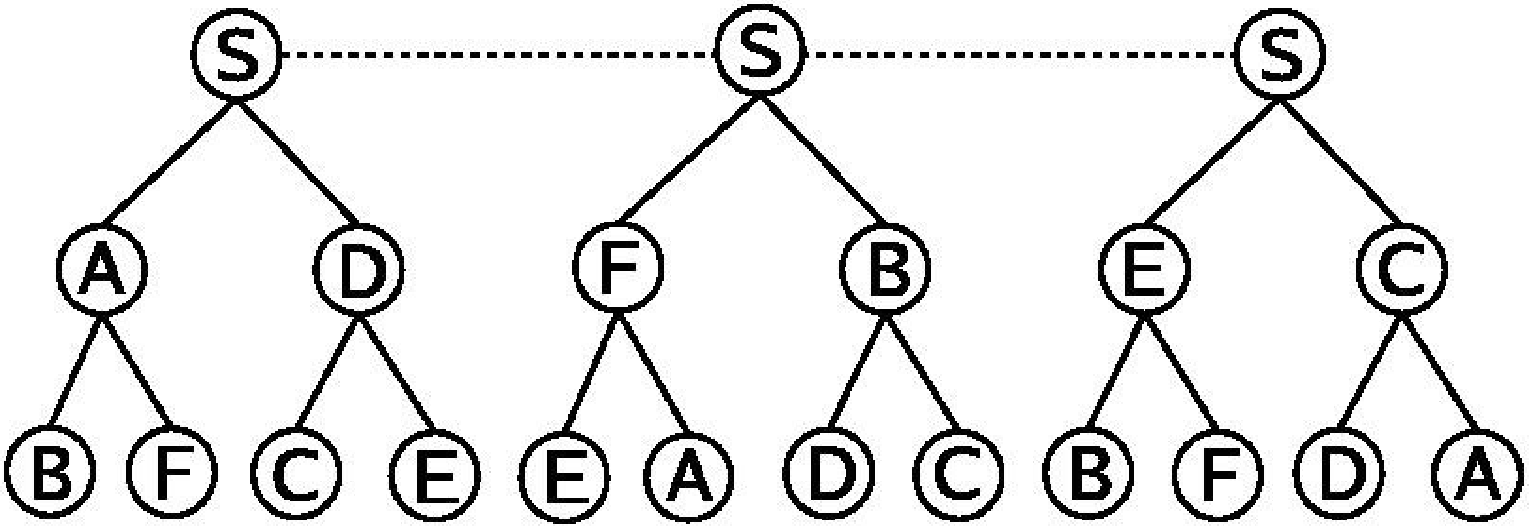
Multiple Tree Approaches



Related Algorithms

- Zebra [10]
- CoopNet [11]
- SplitStream [12]
- Orchard [13]

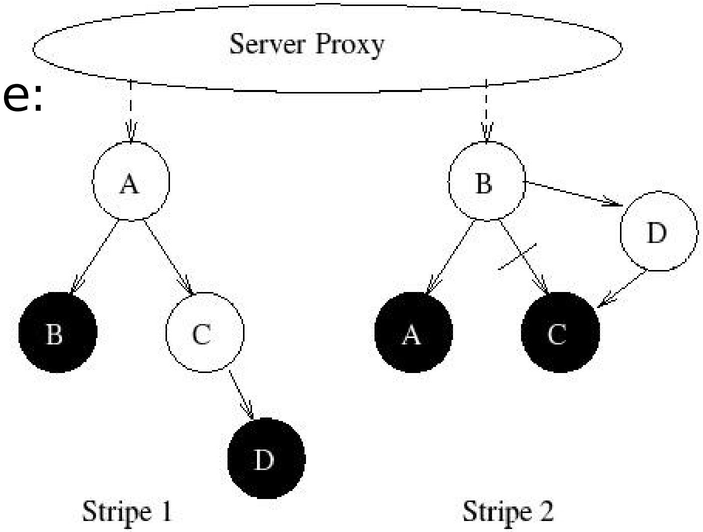
Zebra

Zebra

- Serves high quality live media to up to 100 clients.
- Two trees
  - A serving node in one tree should be leaf in other tree.
- Two parts of system:
  - Server proxy
    - Divides the media into two stripes
    - Maintains full system state
  - Client proxy
    - Update the server proxy on occurring events
    - Forwards data to its children
    - Sends data to its media player

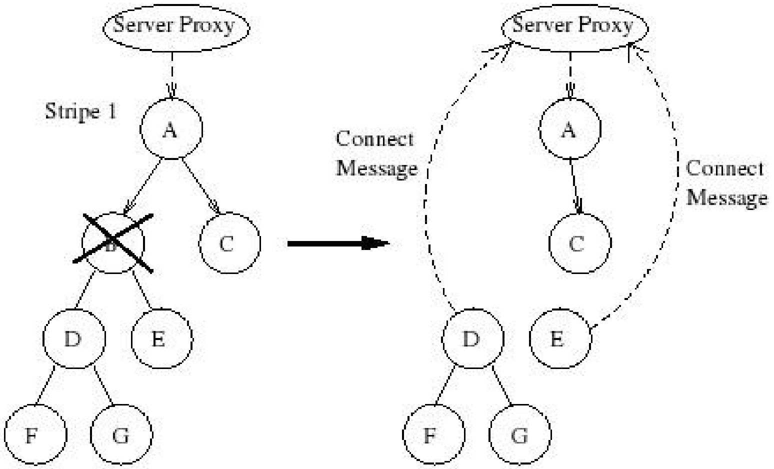
Zebra (Join)

- New node communicate with server proxy.
- Server proxy determine which stripe should be served by new node.
  - Based on number of node serve each stripe.
- Server proxy return up to 10 node:
  - Available nodes
  - Splice-able nodes



Zebra (Leave/Failure)

- Immediate children of disconnected node keep their sub tree
- Inform the server proxy and they try to reconnect to system



CoopNet

CoopNet

- CoopNet complements the client-server framework rather than replaces it.
  - There is still a directly connection between serves and clients
  - CoopNet is only invoked when the server is unable to handle the load imposed by clients.

- Uses MDC

CoopNet (Tree Management)

- Goals in constructing and maintaining trees:
  - Short and wide tree
  - Efficiency versus tree diversity
    - Diversity: minimizes chance of disruption
    - Efficiency: matches underlying network topology
  - Quick join and leave
  - Scalability

CoopNet (Join)

- The new node contacts the server
  - Informs its available network bandwidth
- The server responds with a list of designated parent nodes, one per distribution tree
  - Using a top-down approach until find nodes with spare capacity
  - Select randomly between them
- Upon receiving the server's message, the new node sends (concurrent) messages to the designated parent nodes
  - To get linked up as a child in each distribution tree.

CoopNet (Leave/Failure)

- On leave the departing node informs the server
  - The server identifies the children of the departing node
  - Executes a join operation on each child

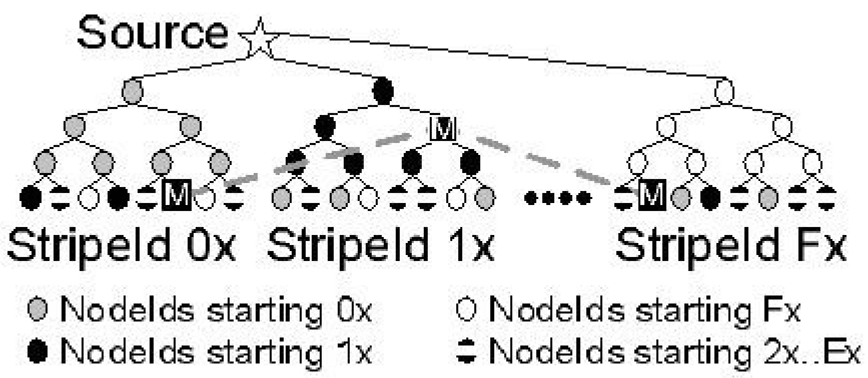
- Each node monitors the packet loss rate of each distribution tree

- If the packet loss rate reaches an unacceptable level
  - The node contacts its parent to check if the parent is experiencing the same problem.
  - If so, the source of the problem is upstream of the parent and the node leaves it to the parent to deal with it.
    - The node also sets a sufficiently long timer
  - If the parent is not experiencing a problem or it does not respond, the affected node will contact the server and execute a fresh join operation for it

SplitStream

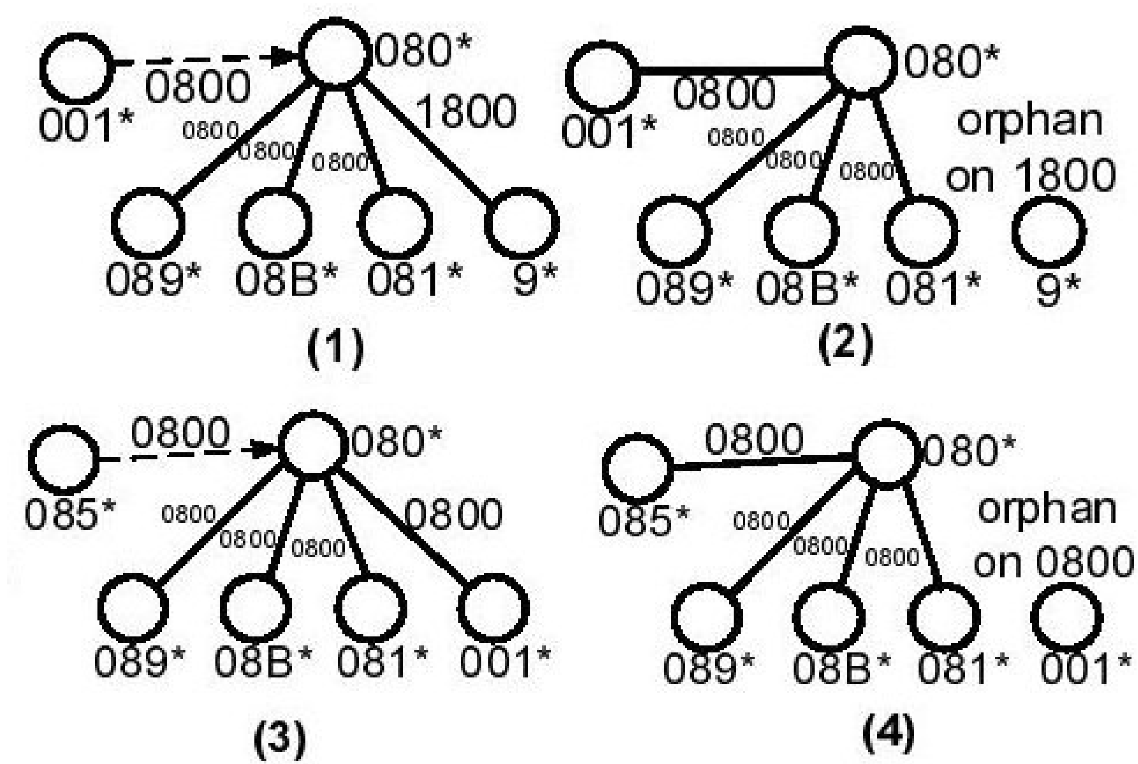
SplitStream

- It is implemented based on Pastry and Scribe.
- Pastry key is used as groupId.
- The union of routes from the group members toward each groupId form the group multicast tree.
- The content is splited into k stripes.
- Using a separate tree to multicast each of them.
- A node is an interior node in at most one stripe tree and is a leaf node in all the other ones.
  - interior-node-disjoint.



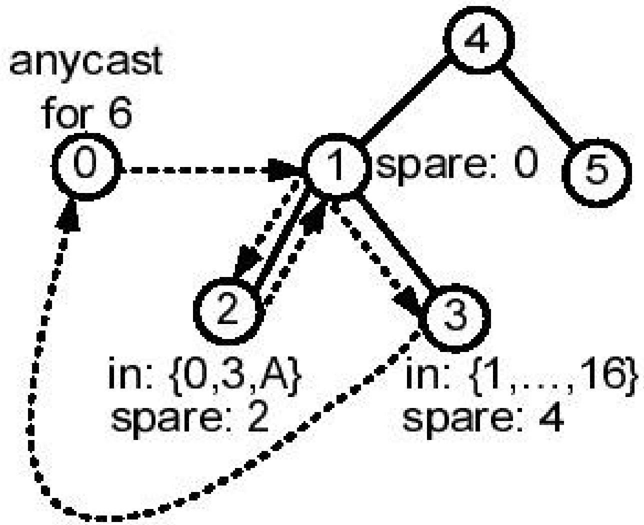
SplitStream (Join – first step)

- Attempting to join the stripe tree directly



SplitStream (Join – second step)

- If first step fails, it looks for a parent in the spare capacity
  - anycast



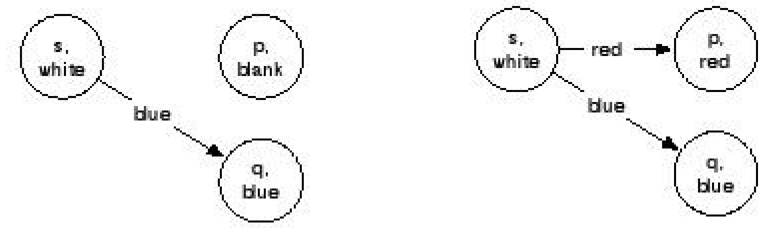
Orchard

Orchard

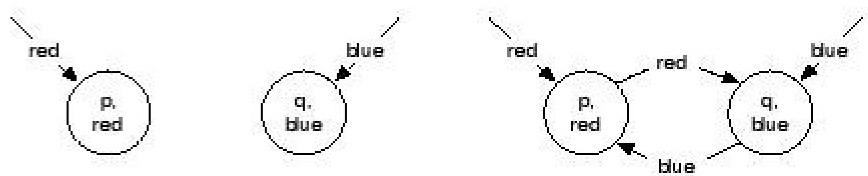
- Orchard is an algorithm for ALM of video streams over unstructured P2P systems.
- Each node maintains a neighbour set.
- No peer forwards more descriptions than it receives.
- A peer does not need to know the source or any other specific peer
- Splitting up into several substreams using MDC.
- Building a forest of separate spanning trees, each tree serving a single substream.

Orchard (Join)

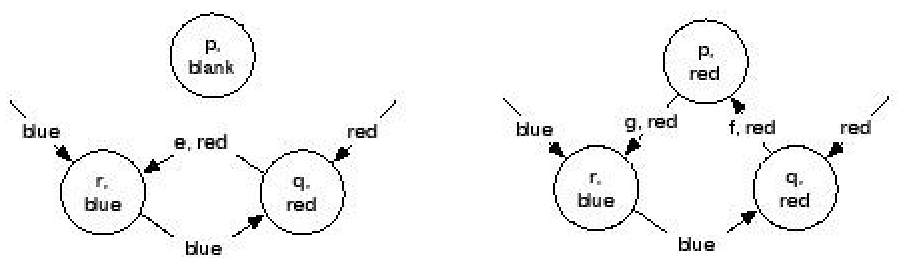
- Join at source



- Exchange Descriptions



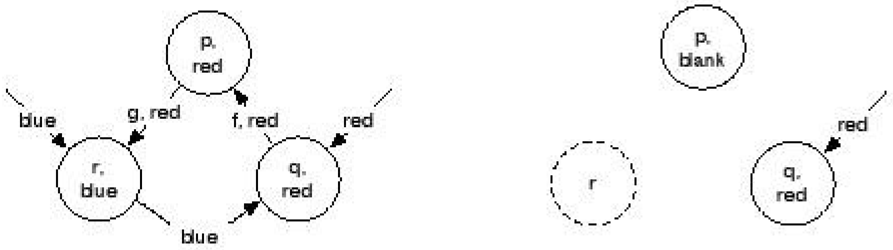
- Redirection



- Redirection through coloured nodes (temporary)

Orchard (Leave/Failure)

- Any deal with departed/failed node will be cancelled
  - Also redirect deals
- Find and use backup parent
- Rejoin



Orchard (Maintenance)

- Changing colour
- Changing parent

Advantages & Drawbacks

- Advantages
  - Shares the load
  - Uses the resources

- Drawbacks
  - Complex management

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Related Algorithms

- Bullet [14]
- PULSE [15]

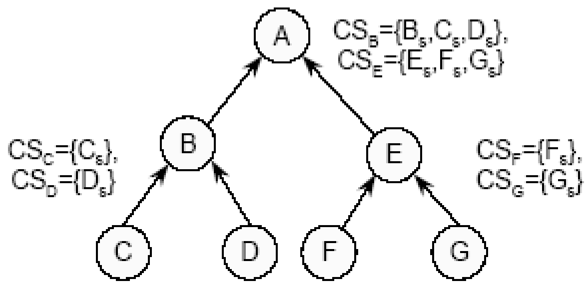
Bullet

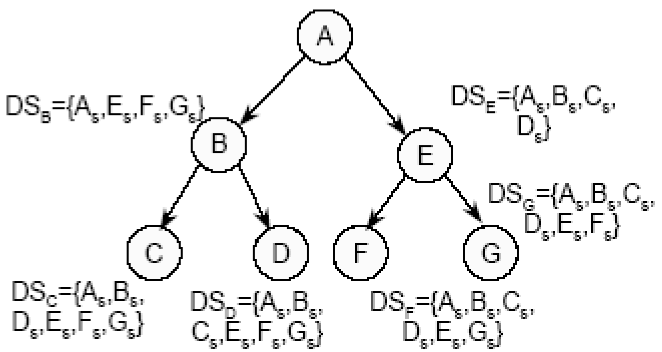
Bullet

- Aimed at maximizing the bandwidth delivered to the receivers through download of disjoint data from multiple peers
- Uses MDC to make data recovery more efficient
- By building a tree, it purposefully disseminate disjoint objects to different clients
- Nodes are responsible for locating peers that hold missing data objects (Using RanSub Protocol)

Bullet

- RanSub Protocol
  - Collect message
    - start at the leaves and propagate up the tree, leaving state at each node along the path to the root
  - Distribute message
    - start at the root and travel down the tree, using the information left at the nodes during the previous collect round to distribute uniformly random subsets to all participants





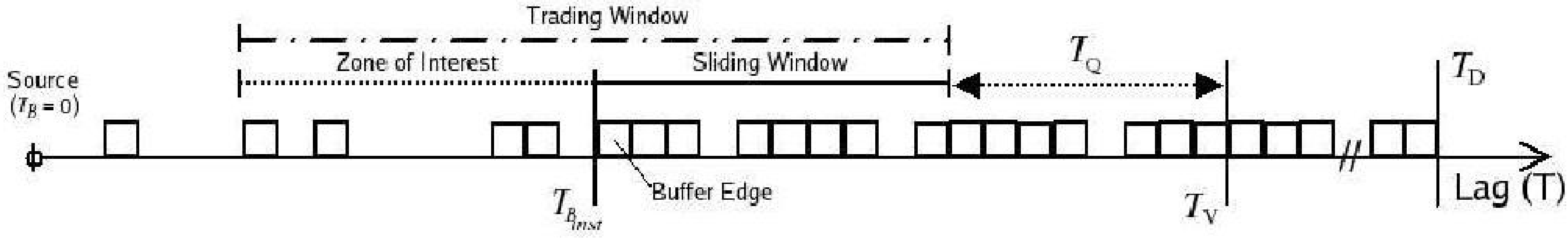
Bullet

- Informed Content Delivery Techniques
  - Messages contain summary tickets of the objects available at a subset of the nodes in the system
  - Nodes uses BloomFilter to perform approximate fine-grain reconciliation
- Request data objects from remote nodes that have significant divergence in object membership

PULSE

PULSE

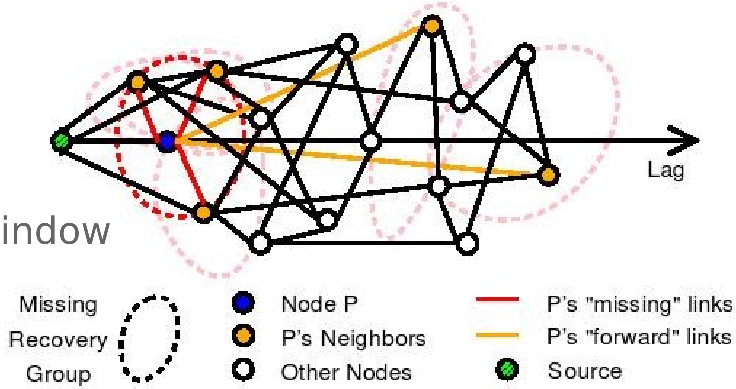
- Some concepts:
  - Lag
    - The age of chunk with respect to the current media clock.
  - Sliding window
    - Is used to output a stream of chunks with desired max. loss ratio
  - Zone of interest
    - Collects the chunks which will be needed soon



PULSE (Cont'd)

- Main components of each peer:
  - Data buffer
    - Is used to collect and store chunks before playing
  - Knowledge record
    - The information about remote peers
  - Trading logic
    - Determines which chunk should be requested neighbours and choose and schedule the chunks that are to be sent

- Two groups of neighbours:
  - MISSING
    - Having overlapped trading window
  - FORWARD
    - No overlap



PULSE (Algorithm)

- Main parts of algorithm:
  - Peer selection
    - BitTorrent tit-for-tat idea
  - Sending chunk selection
    - Latest send first, random
  - Requesting chunk selection
    - Rarest chunk across the neighbourhood

Outline

- Introduction
- Infrastructure-based (two-tier) approaches
- Single tree approaches
- Improved single tree approaches
- Mesh-based approaches
- Multiple tree approaches
- Mixed approaches
- Comparison
- Future work
- Summary

Comparison

- Single tree structures
  - Optimal with respect to the transmission delay
  - Don't share the load in an even way among the participating peers
  - React quite badly to node failures
- Multiple tree structures
  - Good solution
  - Requires a heavy control traffic to manage many trees
- Mesh structures
  - Very robust
  - Adapt well to variations in the network conditions
    - By continuously monitoring multiple paths
  - Costly to maintain
  - Don't scale well for large groups of users
- Mixed structures
  - Robustness and performance advantages of the mesh
  - Smooth management of the single tree

Comparison

Network Type	Target Audience	Control Overhead	Response to Load	Response to Transience	Management Complexity
Two-tier	large (bounded)	low	w/threshold	good	low
Mesh	small/medium	high	good	good	average
Single Tree	any	low/medium	good	bad	variable
Multiple Tree	medium/large	medium	good	quite good	high

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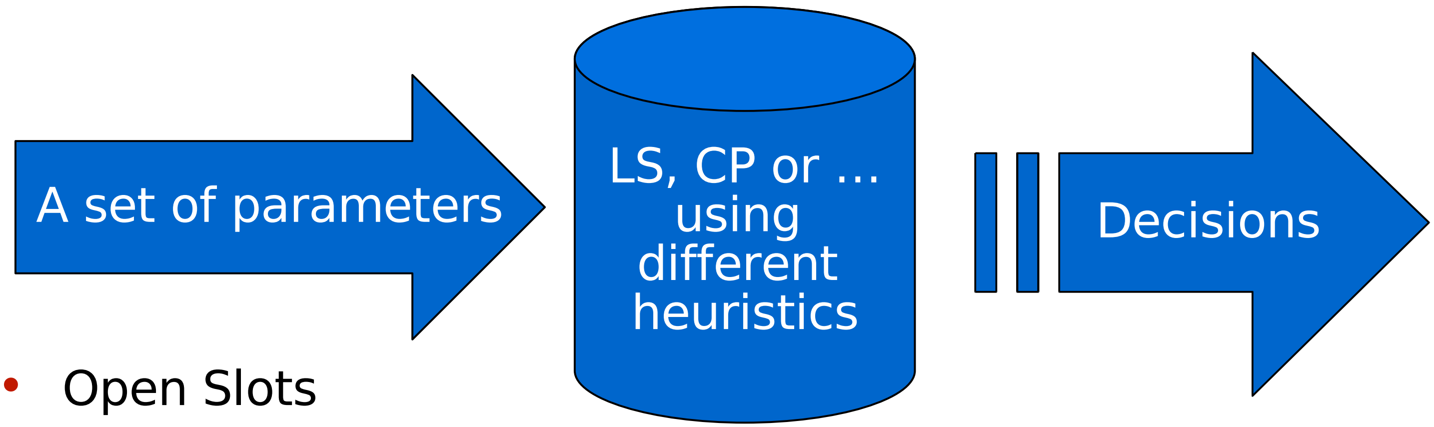
Future work - ForestCast

- Main golas
  - Maximize utility
  - Minize latency

- Nodes can have three roles:
  - source – the node which has the video to be streamed
  - server – central server that constructs the trees
  - peer – a node (customer) which downloads and/or uploads the stream

- The server will have complete information about every peer.
  - New nodes will provide server with their own bandwidth capacity.
  - The server will also approximate the latency of the peer
  - The server will inductively construct trees, which it maintains as peers join, leave, and fail.

ForestCast



- Open Slots
- Total Latency
- State of the existing trees

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Summary

- Infrastructure-based (two-tier) approaches
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- Mixed approaches

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Questions?

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Comments!