Scaling Bloom filter-based multicast via filter switching

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Presentation at a glance

- LIPSIN [JOK2009]
  - Packet forwarding with in-packet Bloom filters
  - Stateless multicast forwarding
  - Scales w.r.t. number of multicast groups
  - Poor scalability w.r.t. group/network size

Presentation at a glance

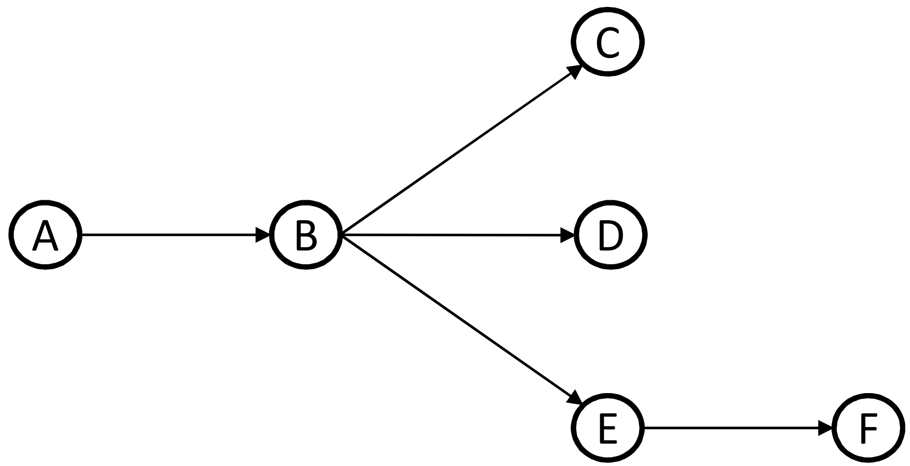
- LIPSIN [JOK2009]
  - Packet forwarding with in-packet Bloom filters
  - Stateless multicast forwarding
  - Scales w.r.t. number of multicast groups
  - Poor scalability w.r.t. group/network size
- Bloom filter switching
  - Use of relay points
  - Scale w.r.t. group/network size
  - Sacrifice fully stateless operation
  - Measure the trade-offs

Presentation Outline

- Problem statement
  - Bloom filter-based packet forwarding
  - Scalability issues w.r.t. to group/network size
- Bloom filter switching
- Evaluation
  - Compare state requirements with other multicast schemes
- Conclusion and future work

In-packet Bloom filters (iBF)

- Source-routing scheme
- Path links encoded to Bloom filters



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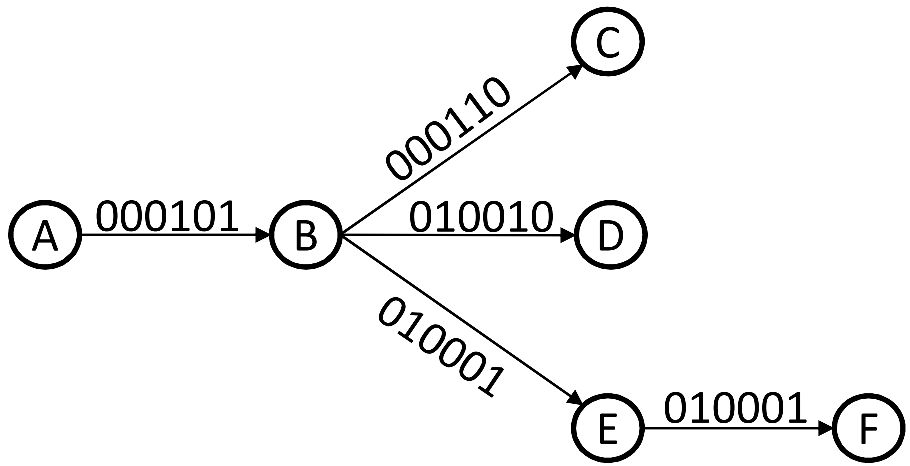
  - Link IDs (LID)
    - m bits, k bits set to 1 ($k << m$)
    - Unidirectional



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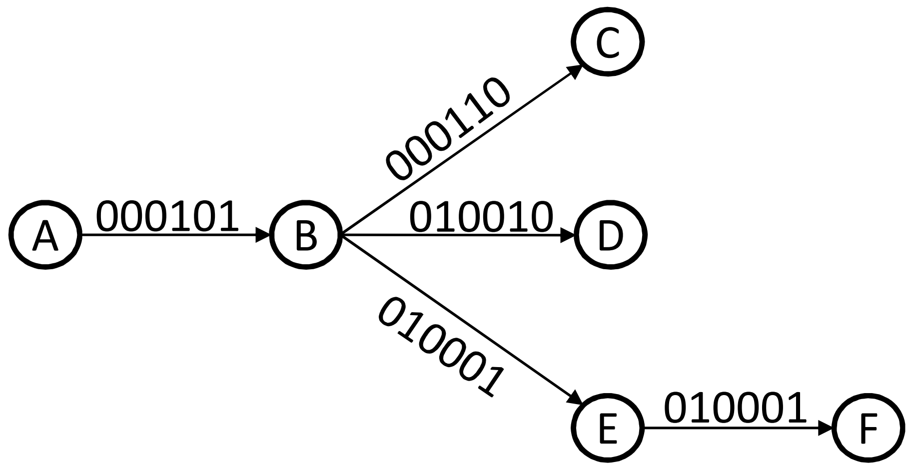

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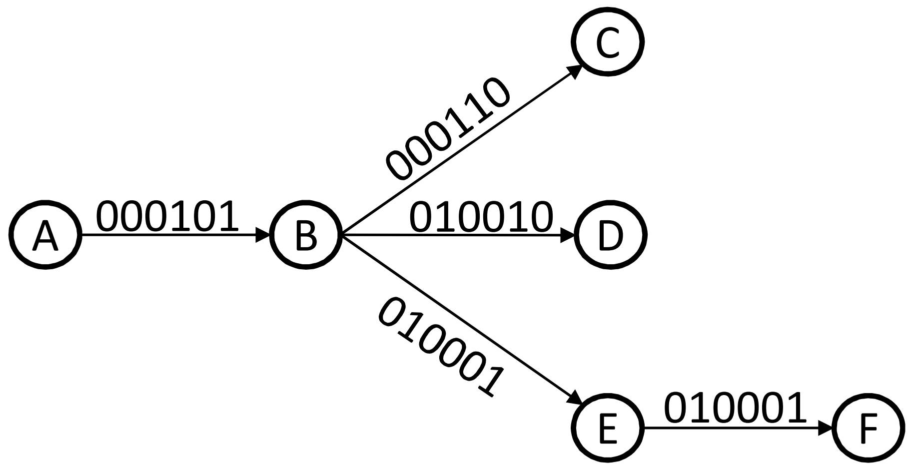

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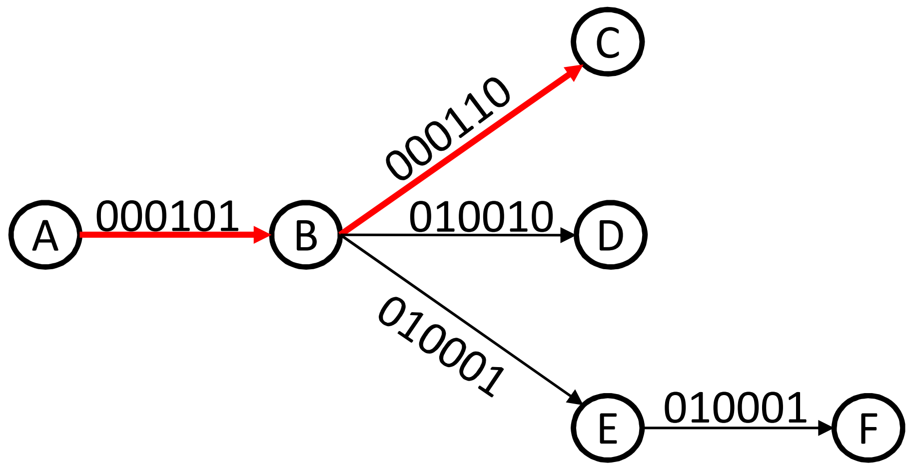
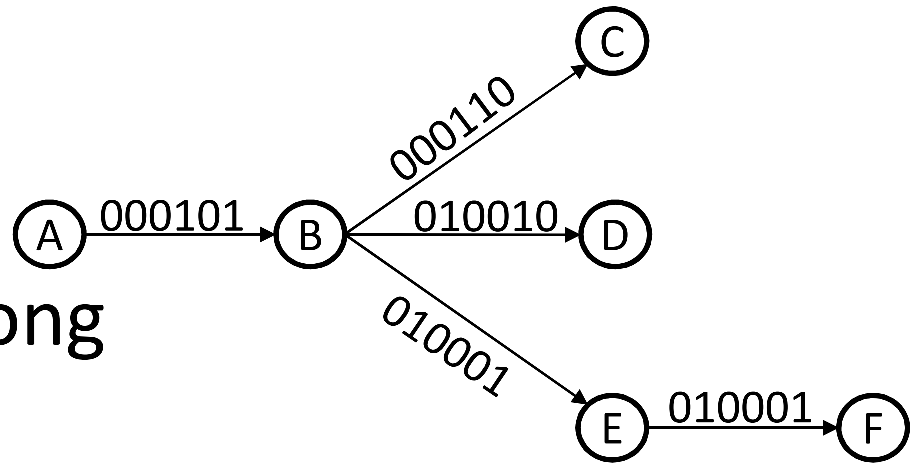
- E.g., $iBF_{AC} = LID_{AB} \mid LID_{BC} = 000111$



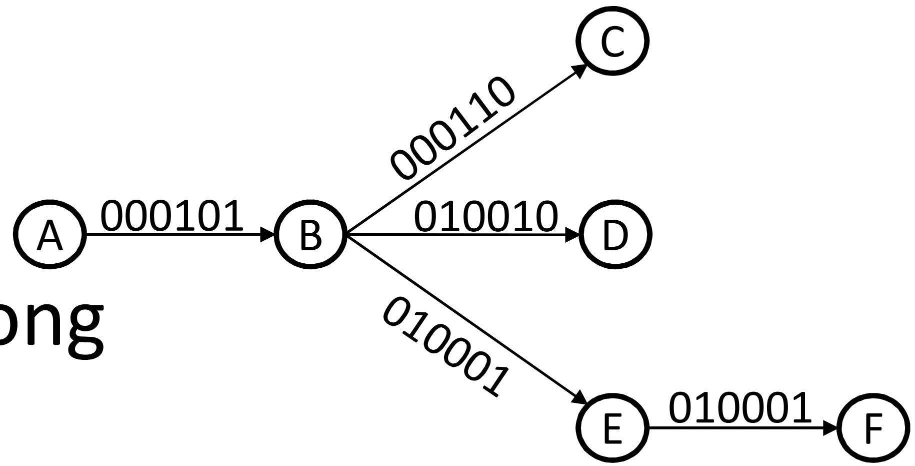
Data Plane

- Routers extract iBF
- Check which of their outgoing LIDs belong to the iBF



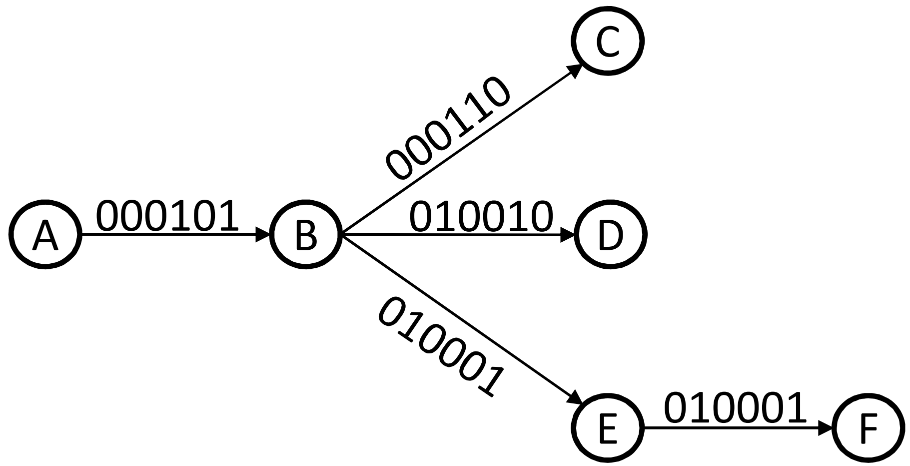
Data Plane

- Routers extract iBF
- Check which of their outgoing LIDs belong to the iBF
- Bitwise AND operation
  - *iBF & LID_i == LID_i*



Single-Source Multicast

- Add multicast tree links



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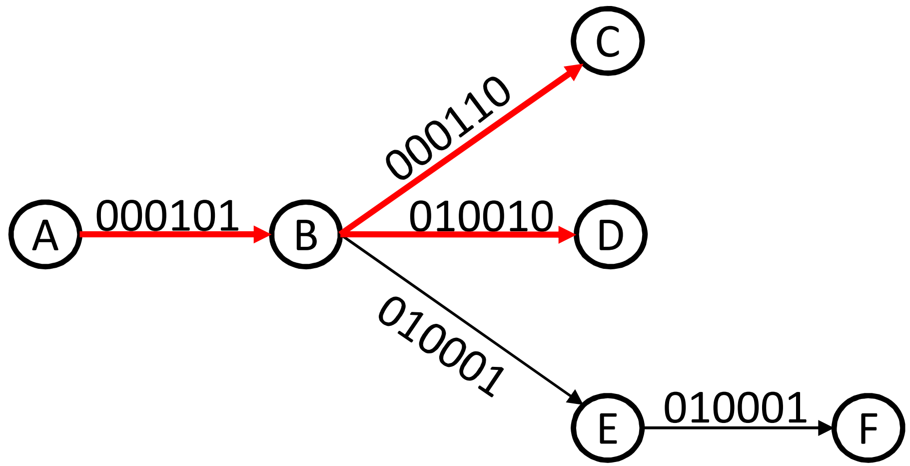

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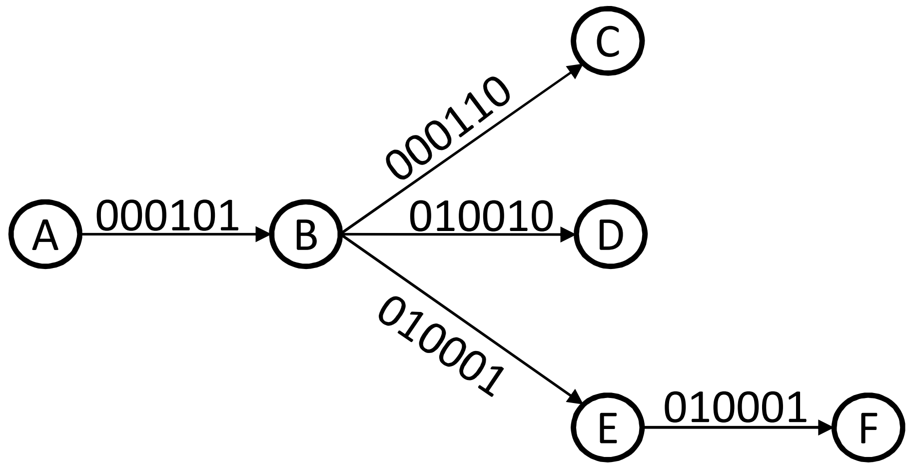

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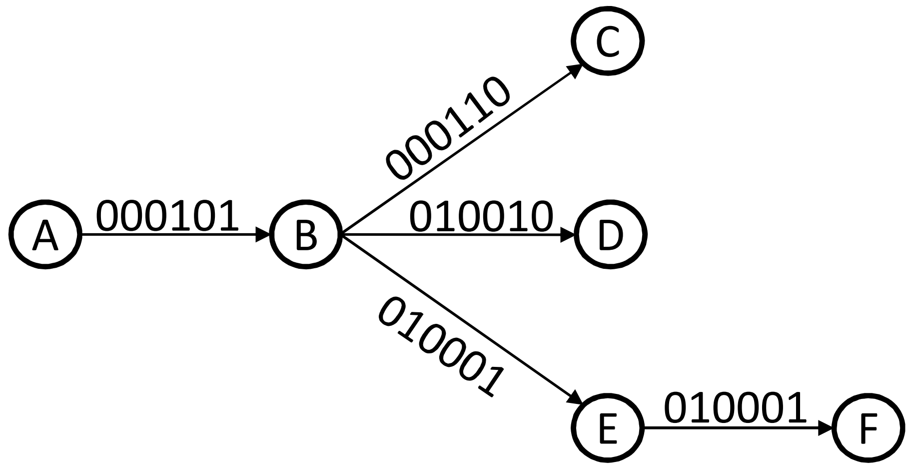
✓ No multicast state at routers

✓ Fixed size header
  - Line-speed operation [JOK2009]



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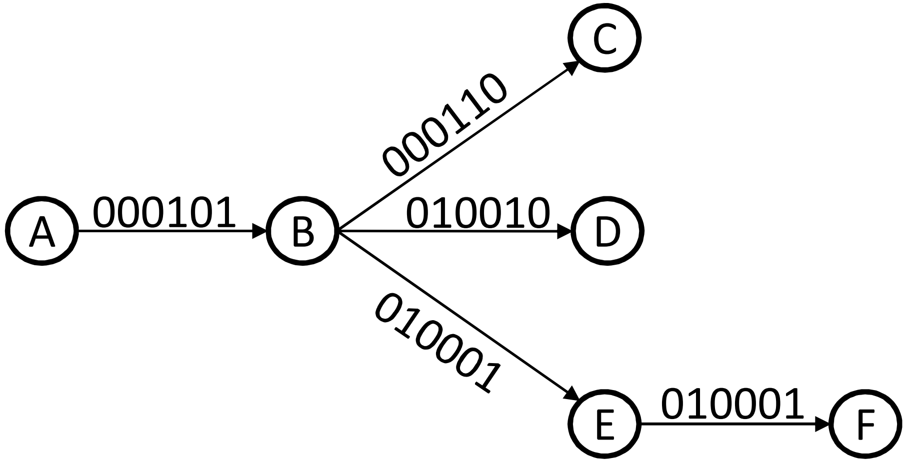


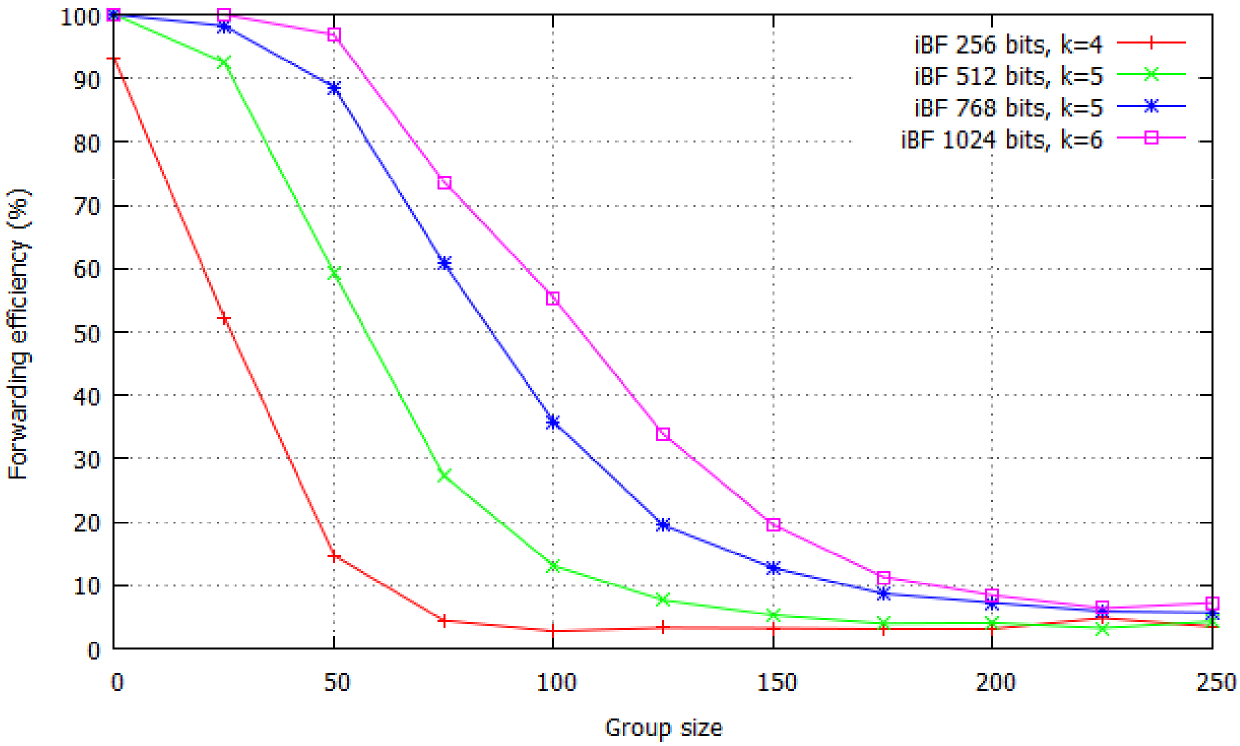
✓ No multicast state at routers

✓ Fixed size header
  - Line-speed operation [JOK2009]

✘ False positives in Bloom filters
  - $fpp = (1 - e^{-kn/m})^k$

False Forwarding Decisions

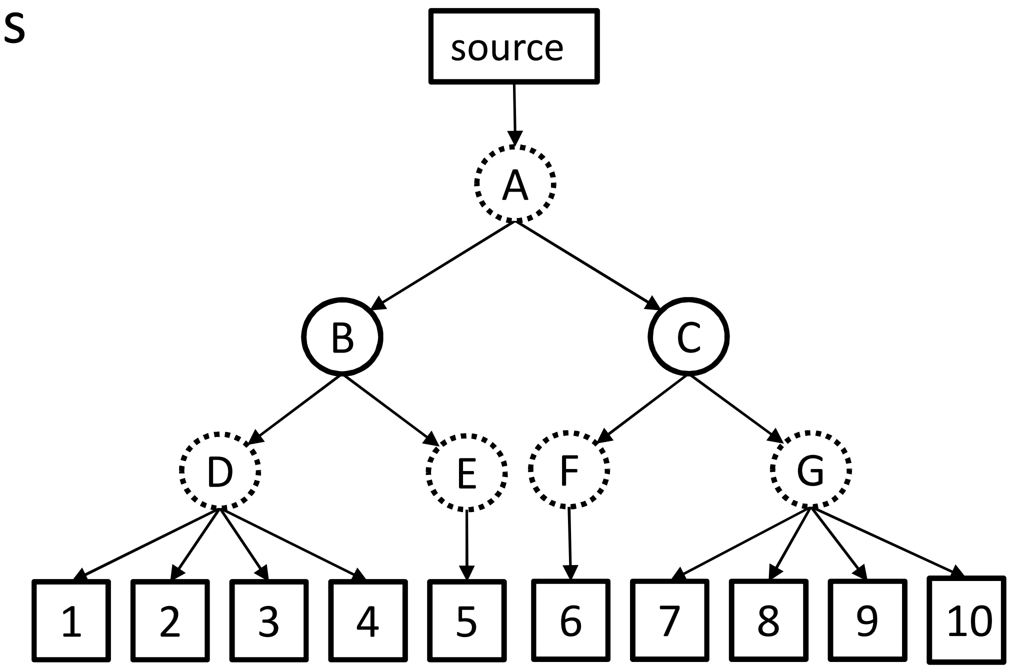
- False positives probability increases as more LIDs are added
- Poor scalability w.r.t. group/network size



Forwarding efficiency = (# tree links) / (total packets transmitted)

Bloom filter switching

- Idea: sacrifice fully stateless operation
- Select a *few* nodes that act as relays
  - Install multicast state
- Relay points switch iBFs



Relay Node Selection

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- Bottom-up post-order tree traversal
- At node *i,* if $subtree_i$ has more than n_{max} links
  - *i* becomes relay point
  - Compute iBF for subtree rooted at *i*
  - Install iBF at *i*'s multicast forwarding table
  - Consider *i* as leaf and continue

Algorithm

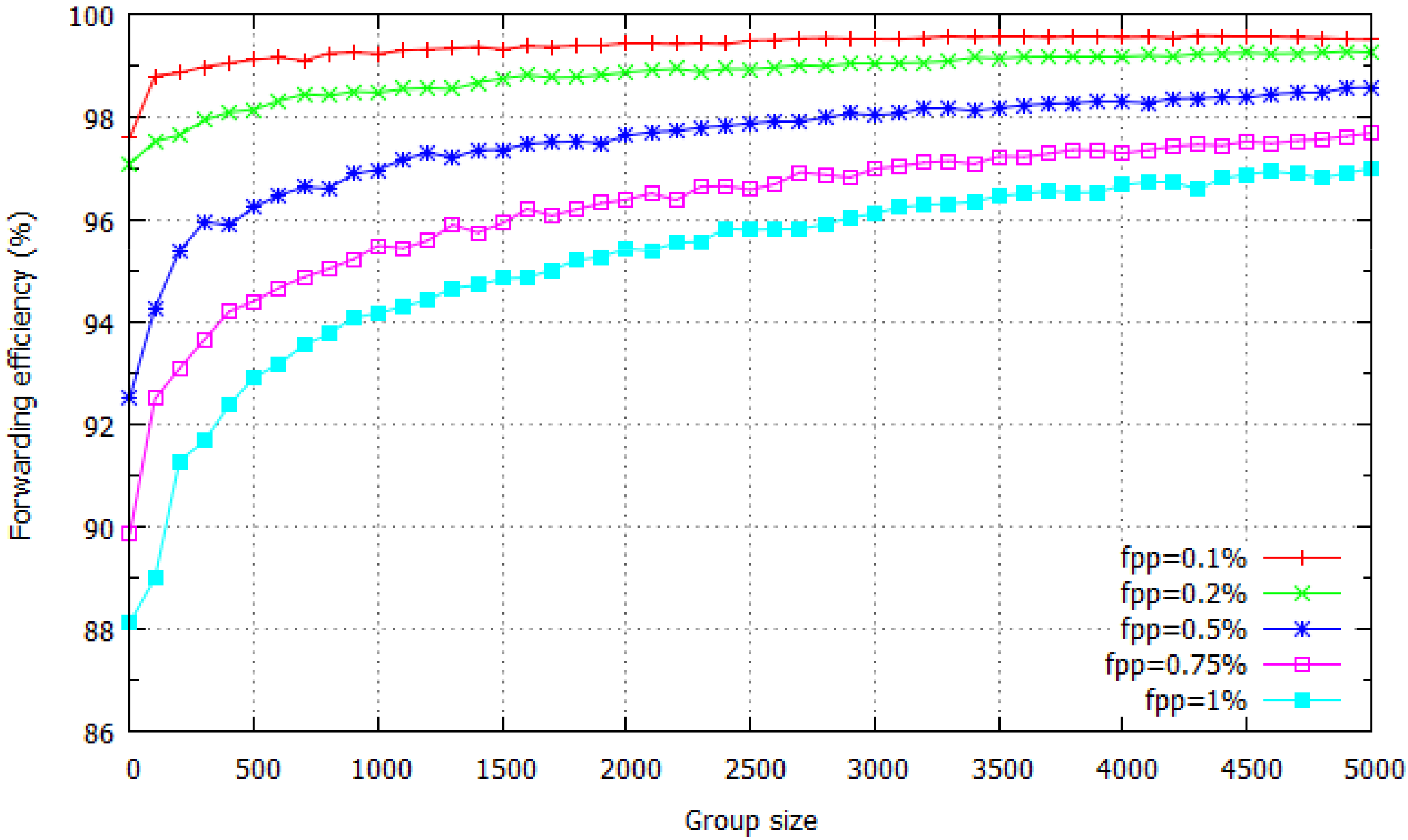
```
Method: sub_tree_traverse
Input: t: multicast tree;
           i: current root node;
           n: maximum number of nodes;
n_i := 0;
for (j in C_i) {
     n_i := n_i + 1 + sub_tree_traverse (t, j, n);
}
if ( n_i ≥ n_max){
     iBF_i := compute_iBF(t, i);
     installState(iBF_i, i);
     removeSubtree(t, C_i);
     n_i = 0;
}
return n_i;
end method
```

Evaluation

- Focus on forwarding efficiency and state requirements
  - Compare state requirements against other multicast schemes
- Input
  - Synthetic scale free graphs
  - Barabási–Albert algorithm [BAR1999]
  - 500 to <u>5000</u> nodes

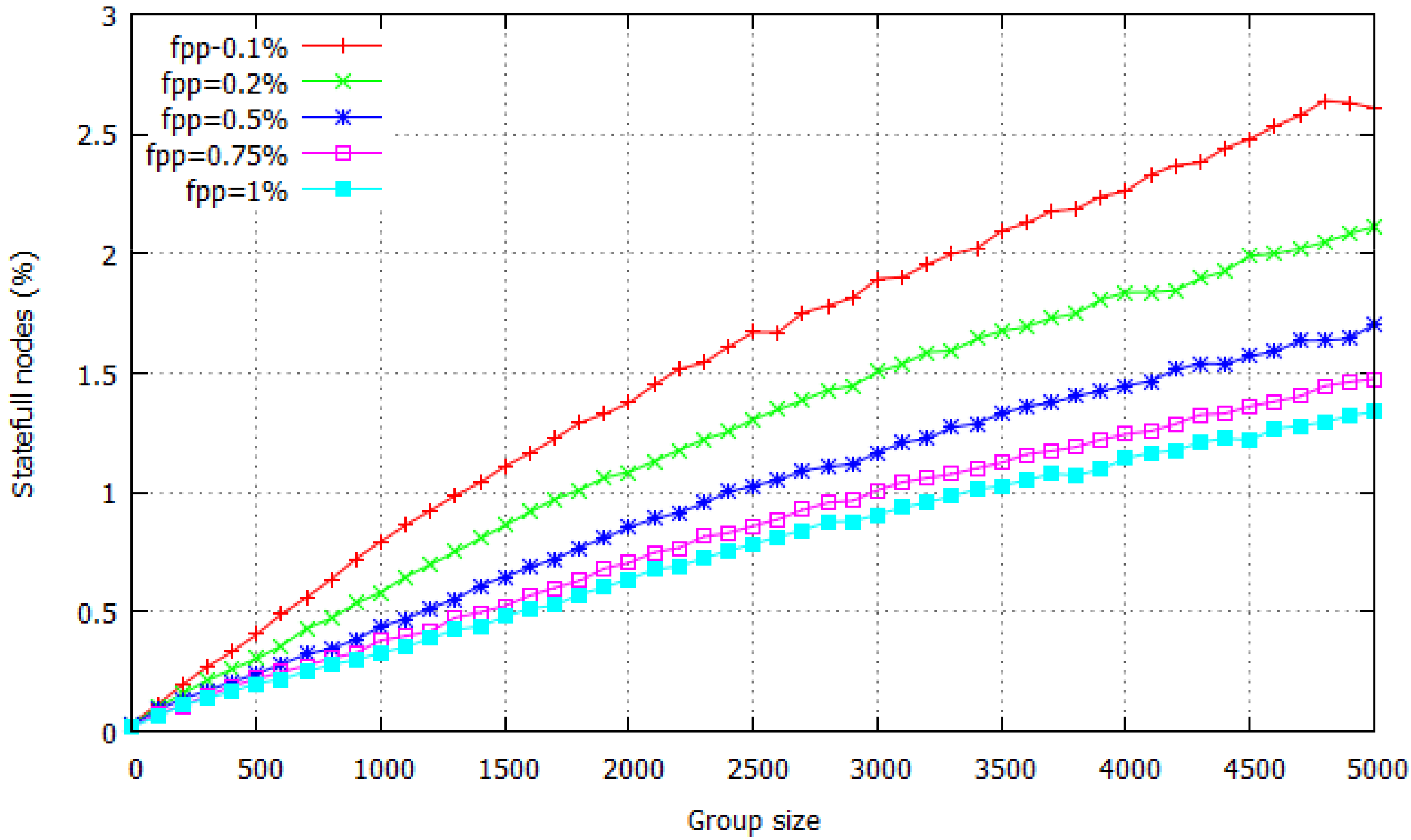
Forwarding Efficiency

- 256-bit iBF, k=4



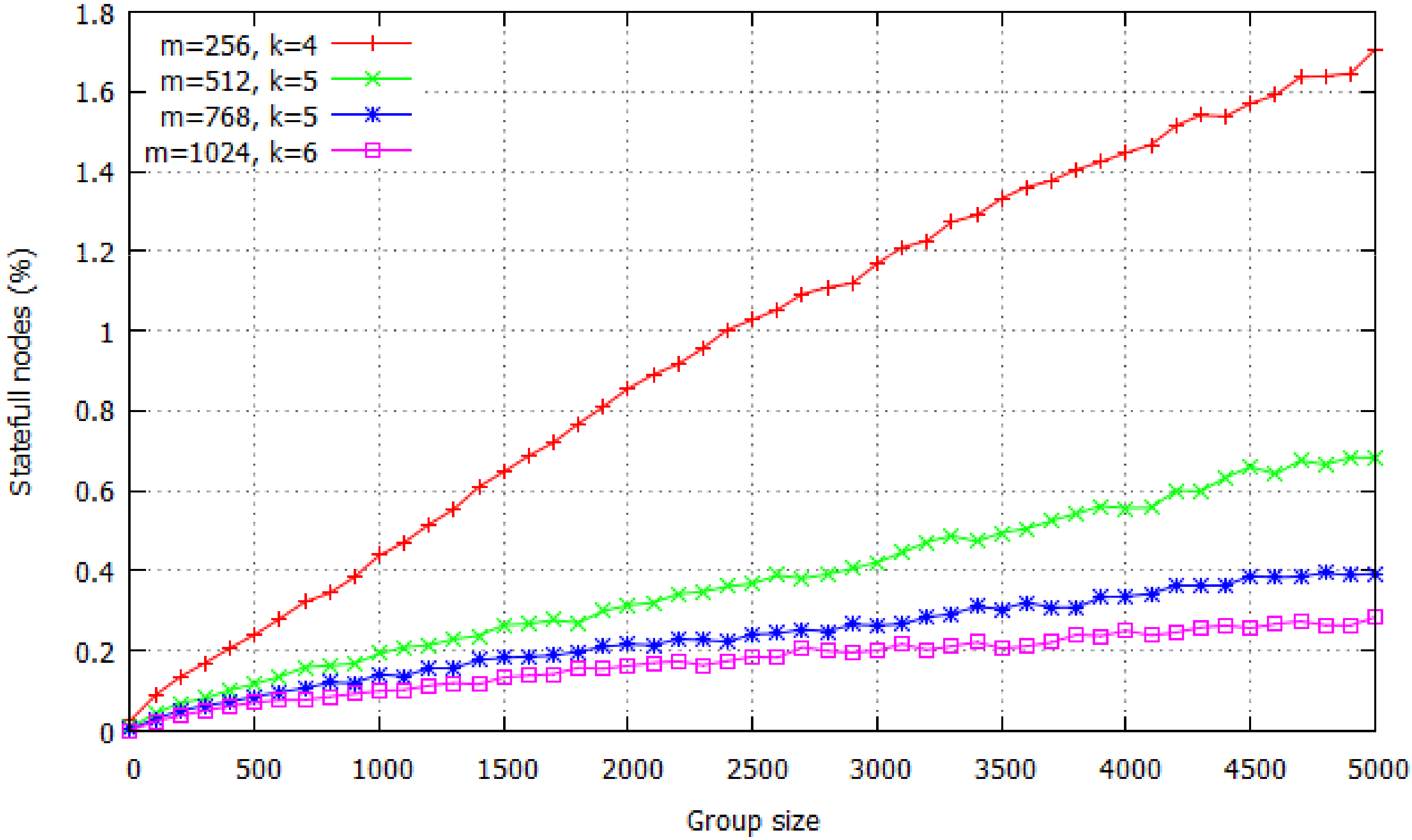
State Requirements (Relay Points)

- 256-bit iBF, k=4



State Requirements - 2

- fpp = 0.5%

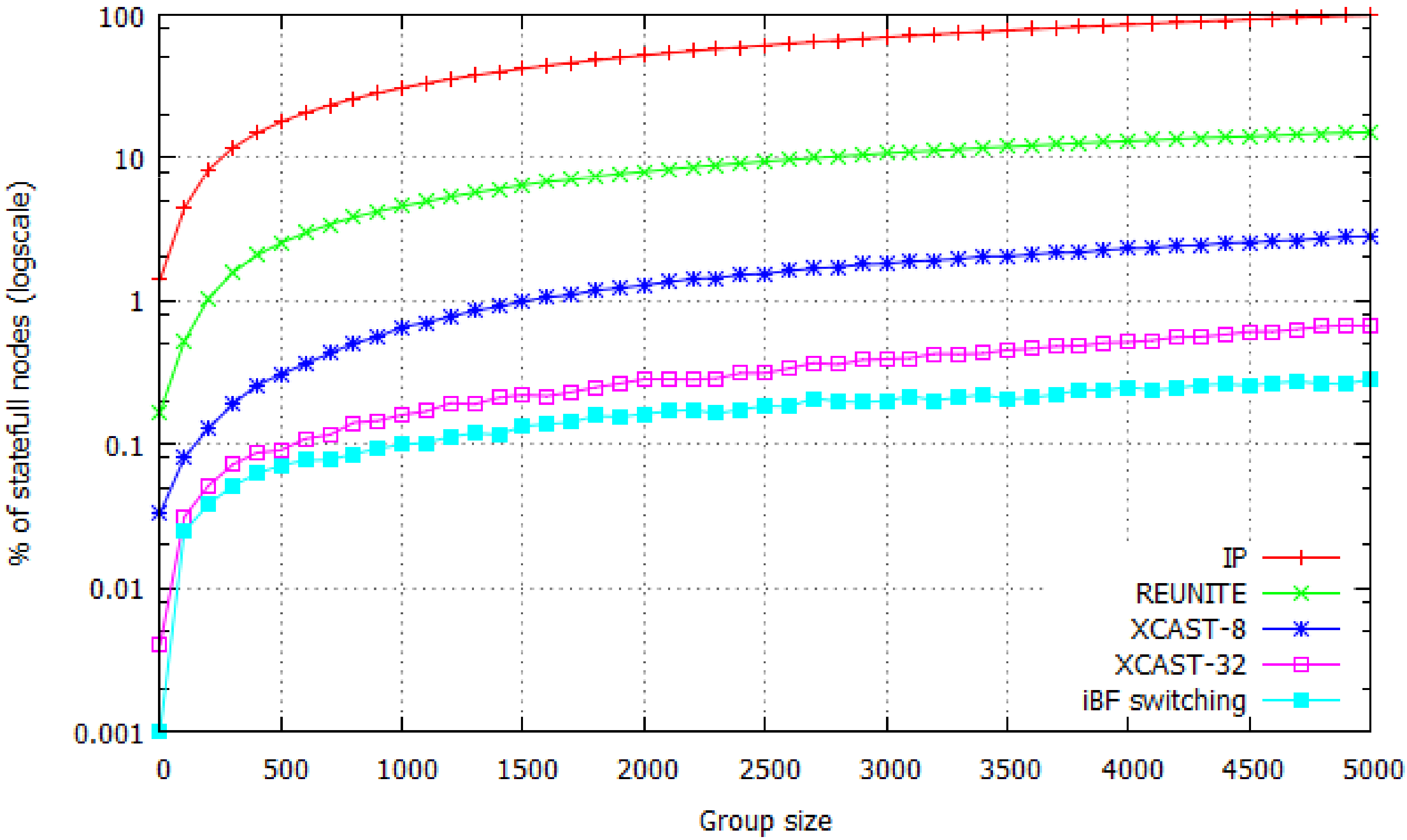


Comparison

- Amount of stateful nodes compared to
  - Hop-by-hop (IP, overlay multicast)
    - Forwarding state per multicast tree at all nodes
  - REUNITE [STO2000]
    - Forwarding state per multicast tree at branching points only
  - Semi-stateful Xcast [NIA2008]
    - List of receiver addresses in packet header
    - Maximum number of receiver addresses in header
    - Use of relay points

Comparison - 2

- 1024-bit headers for iBF and Xcast
- Y-axis in log scale



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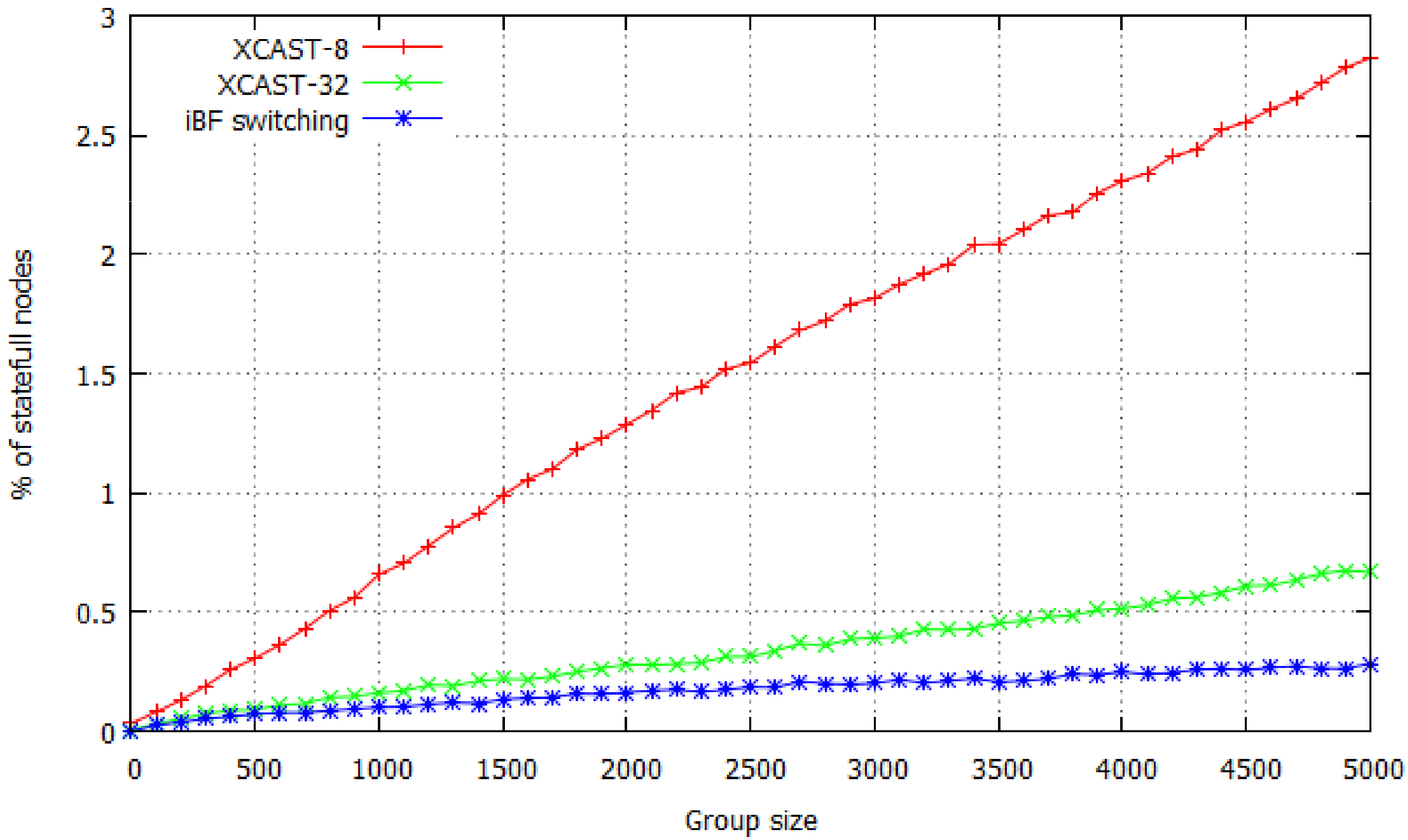

Conclusions

- iBF switching handles scalability w.r.t. group/network size
- Trade-off: place multicast forwarding state at some routers
- Still, far less state requirements than other multicast schemes
- Requires centralized routing module
  - Suitable for multicast applications with low dynamicity, e.g. orchestrated software updates
  - Not suitable with dynamic user behavior, e.g. IPTV channel switching

Future Work

- Distribution of multicast state
  - *Central* nodes tend to concentrate state
  - Relay node selection algorithm
- Distribution of group sizes
  - Zipf distribution
  - Small groups require no state
- Fast Join/Leave operation
  - Dynamic user behavior
  - Distributed operation

Thank you

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References

- [JOK2009] P. Jokela, A. Zahemszky, S. Arianfar, P. Nikander, and C. Esteve, “LIPSIN: Line speed publish/subscribe inter-networking,” in Proc.. ACM SIGCOMM, Barcelona, Spain, Aug. 2009.
- [BAR1999] A. Barabási and R. Albert, "Emergence of Scaling in Random Networks," Science, vol. 286, pp. 509–512, 1999.
- [STO2000] I. Stoica, T.S.E. Ng and H.zhang, "REUNITE: a recursive unicast approach to multicast," in Proc. IEEE INFOCOM, March 2000.
- [NIA2008] De-Nian Yang and W. Liao, "Protocol design for scalable and adaptive multicast for group communications," in Proc. IEEE ICNP, October 2008.