Round-Efficient Broadcast Authentication Protocols for Fixed Topology Classes

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Talk Outline

- Background / Motivation
- Optimizations for the Path Topology
- Summary of Other Results

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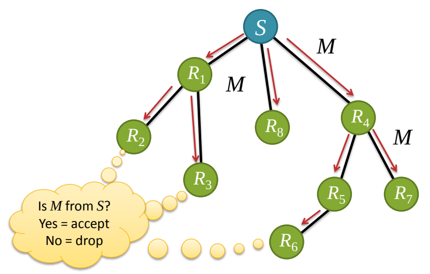
Multi-receiver Authentication in Sensor/Ad-hoc Networks



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Authentication Methods

- Signature: Sender S signs M using private key
  - Need support for public key crypto
- Multi-receiver Message Authentication Codes
  - Additional O(n) overhead in message size
- TESLA [Perrig et al, 2002]:
  - Need time synchronization
- **Communication-Efficient with Minimal Assumptions**
  - Guy Fawkes [Anderson et al. 1998]
  - Hash Tree-based [Chan & Perrig 2008]

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Assumptions

- Sender knows full network topology
- Sender shares a unique symmetric key K_i with each receiver R_i

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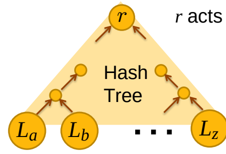
Hash Tree Based Broadcast

- Construct a hash tree with MACs at the leaves



r acts as an authenticator for M

$L_i = \mathrm{MAC}_{K_i}(M)$

- Idea: Adversary can't compute r for forged M' since it does not know any of the MAC values of the legitimate nodes

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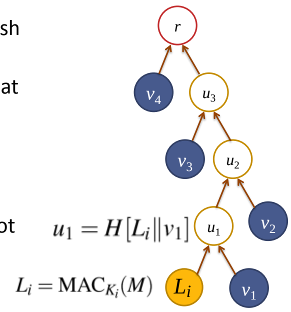
Receiver Verification

- Given Message M, hash tree root vertex r
- Receiver R_i verifies that $L_i = \mathrm{MAC}_{K_i}(M)$ is a leaf in hash tree with root r
- Verification path = all siblings on path to root



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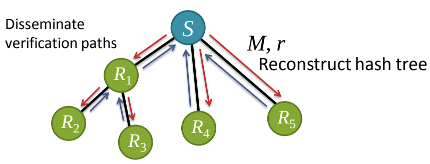
General Tree Topology: 3 Passes

1. Sender broadcasts message M with hash tree root r
2. Receivers reconstruct hash tree with leaves $L_i = \mathrm{MAC}_{K_i}(M)$
3. Verification paths disseminated



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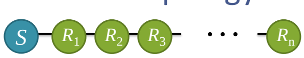
Path Topology



- Common applications
  - Actual linear topologies (roadway, corridor)
  - Path from leaf to root in spanning tree
  - Along a routing path
- 1 round = one interaction between neighbors
- Message from S to R_n takes n rounds
- Unoptimized: 3 passes = $3n$ rounds

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Observation

- Can start reconstructing the hash tree immediately upon receiving M
- "Piggy-back" the two outgoing passes together
  - Achieve $2n$ rounds
  - Outgoing pass: left-siblings computed
  - Incoming pass: right-siblings computed

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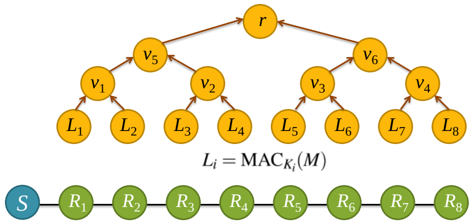
2n-Round Protocol



S precomputes the whole tree

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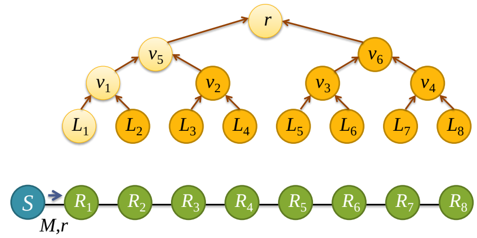
2n-Round Protocol



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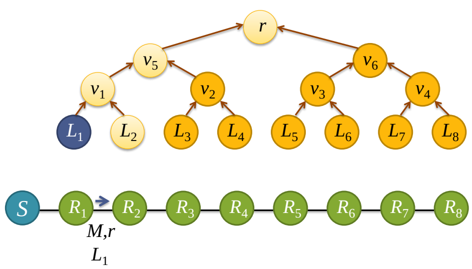

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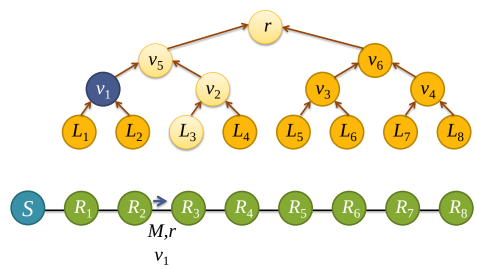

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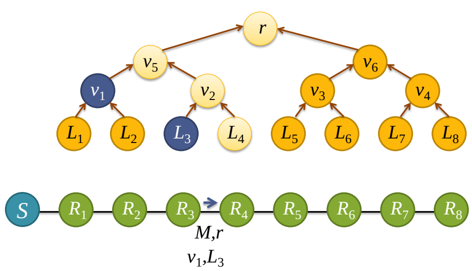

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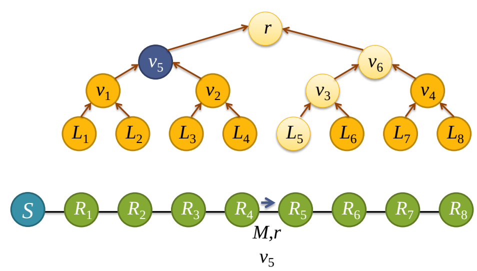

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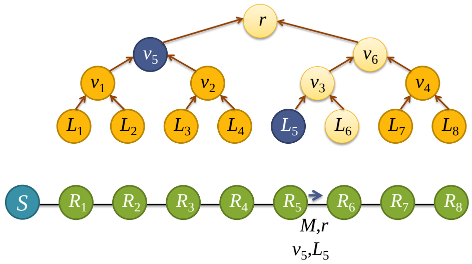

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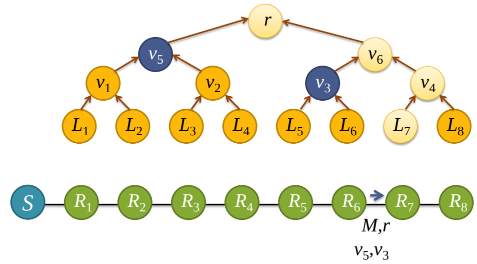

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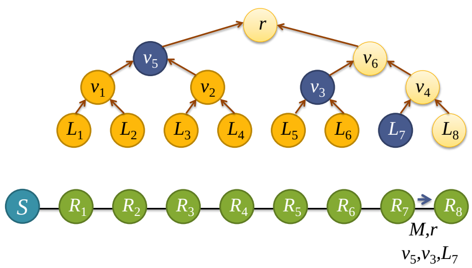

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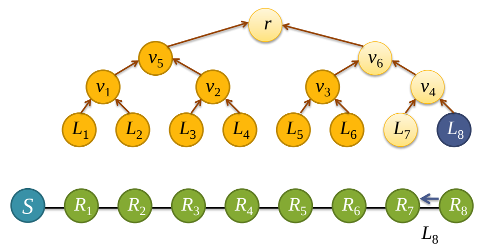

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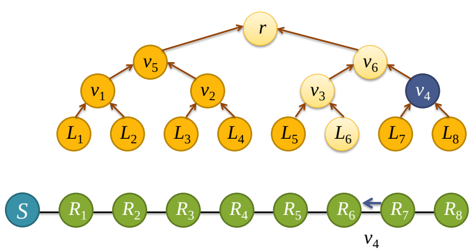

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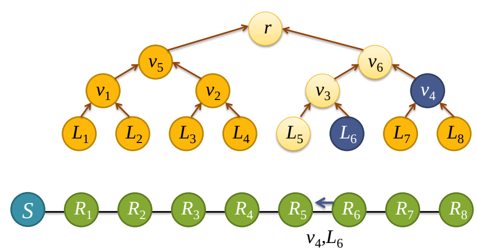

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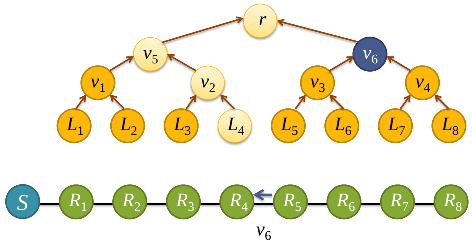

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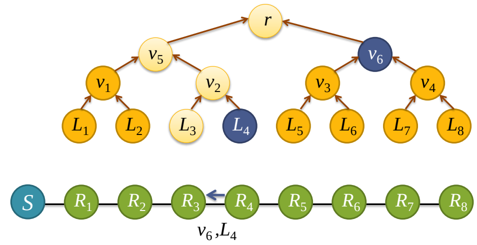

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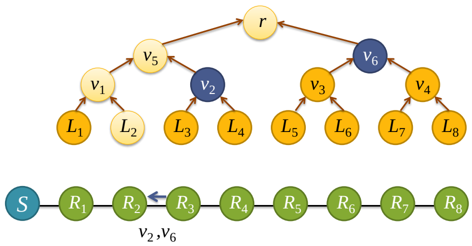

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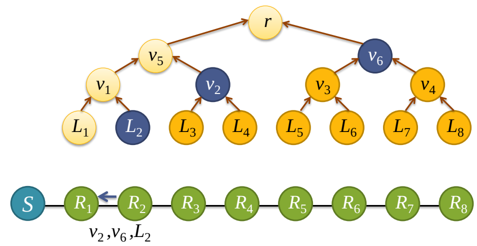

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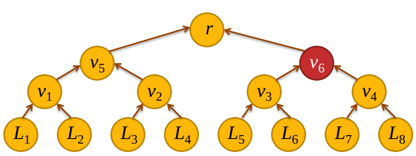
Further Optimizations



- Computation of Node v_6 causes delay
- If Sender precomputes and sends v_6
  - Nodes 1-4 can build verification paths *independently* of 5-8
  - Split apart the two subtrees

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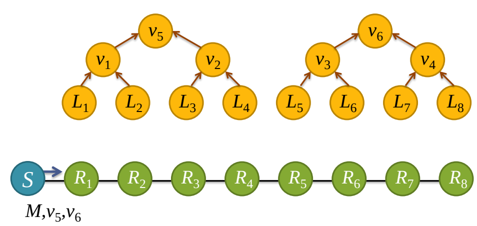
1.5n-Round Protocol



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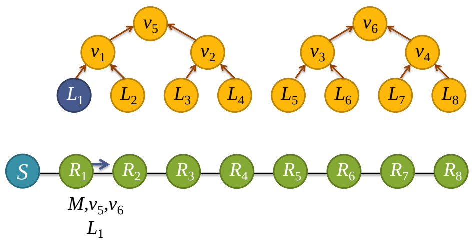

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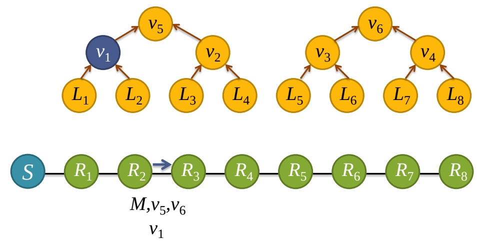

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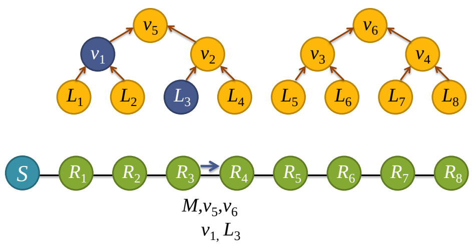

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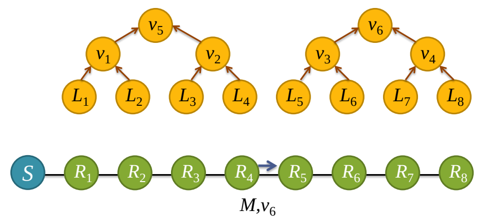

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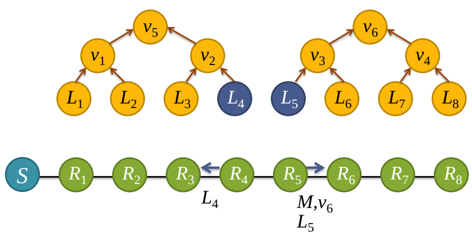

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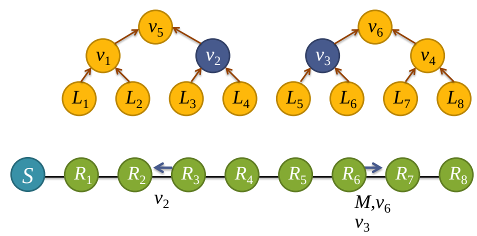

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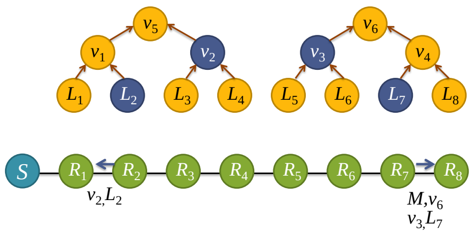

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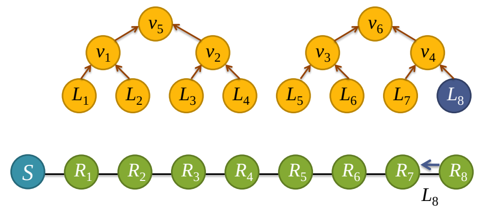

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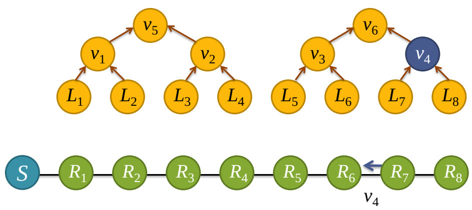

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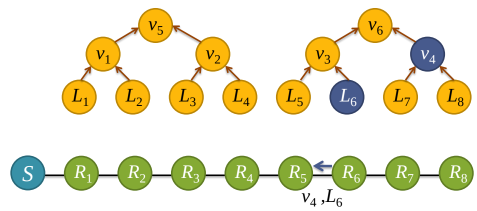

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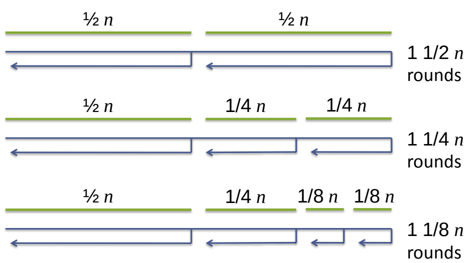
General Optimization



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n-Round Protocol

- Break the receiver set into log *n* groups
- Doubles communication overhead but halves the number of rounds
- No protocol can be faster than this

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Guy Fawkes on the Path Topology

- Optimization to reduce Guy Fawkes to $2n$ rounds
- Reduce that to n rounds using the same divide-and-conquer technique

Round Complexity Lower Bounds

- Any Signature-free Broadcast Authentication Protocol that completes in $(2-\rho)\log n$ rounds for $0<\rho\leq 1$ must have $\Omega(n^\rho)$ comm. overhead per node
- Proven using a reduction to a known result for multi-receiver MACs
- Protocols with polylog communication overhead must take 2 log n rounds or more

Tightness of the Bound

- Optimization of protocols for fully connected topologies
- Achieves $2\log n$ rounds with $O(\log^2 n)$ communication per node
- No protocol with polylog per node communication overhead can take fewer rounds

Lower Bounds for Trees

- Any Signature-free Broadcast Authentication Protocol that completes in $(2.44-\rho)\log n + O(1)$ rounds in a tree topology must have $\Omega(n^\rho)$ comm. overhead per node
- Strictly more than 2 passes are needed for trees
  - Known protocols are likely already optimal for trees

Thank You!

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