S/Kademlia:

A Practicable Approach Towards Secure Key-Based Routing

Ingmar Baumgart, Sebastian Mies

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Universität Karlsruhe (TH), Institute of Telematics
Prof. Dr. M. Zitterbart

Motivation

- Kademlia is a widely used Peer-to-Peer protocol
  - Azureus and eMule/eDonkey has over 1 million users
  - Proven to be scalable in “reality”
- But: No security considerations
  - Vulnerable to attacks → corrupted files, lookups fail
  - What about applications besides file-sharing?
- Our contribution:
  - Enhance Kademlia with security features

Kademlia Protocol

- Symmetric and unidirectional XOR metric
  - Lookups to converge to the same path
  - Allows reactive routing table maintenance
- Converging iterative parallel lookup
  - Iterative lookup → faster learning about new nodes
  - Asking nodes in parallel → Detection of failed nodes
- Simple: Only two RPCs needed for KBR
  - FIND_NODE and PING

Taxonomy of Attacks

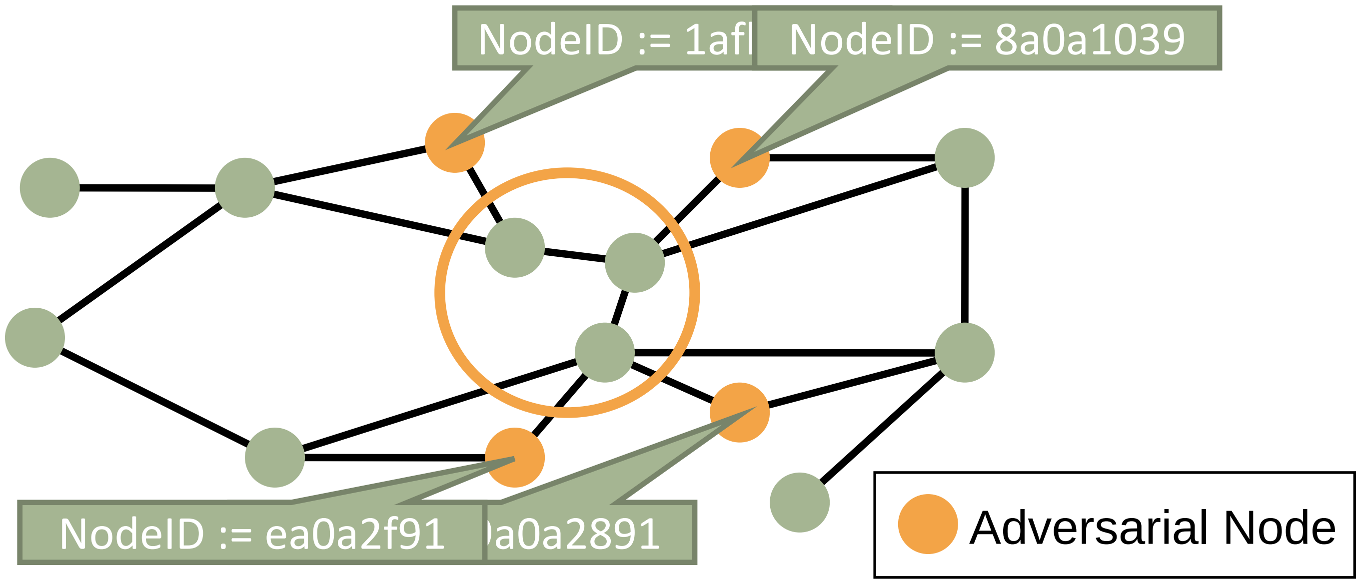
- Underlay network
  - Spoofing, Eavesdropping, Packet modifications
- Overlay routing
  - Eclipse attack
  - Sybil attack
  - Adversarial routing
- Other attacks
  - Denial-of-Service
  - Data Storage

Underlay Network Attacks

- No protection against
  - Spoofing, eavesdropping, modifications
  - → Overlay must provide end-to-end security
- Simple solution: Use NodeID := H(IP + Port)
  - No authentication, problems with NAT
  - IP spoofing still possible
- Better solution: Cryptographic NodeID
  - NodeID := H(public-key)
  - Allows authentication, key exchange, signing messages

Eclipse Attack

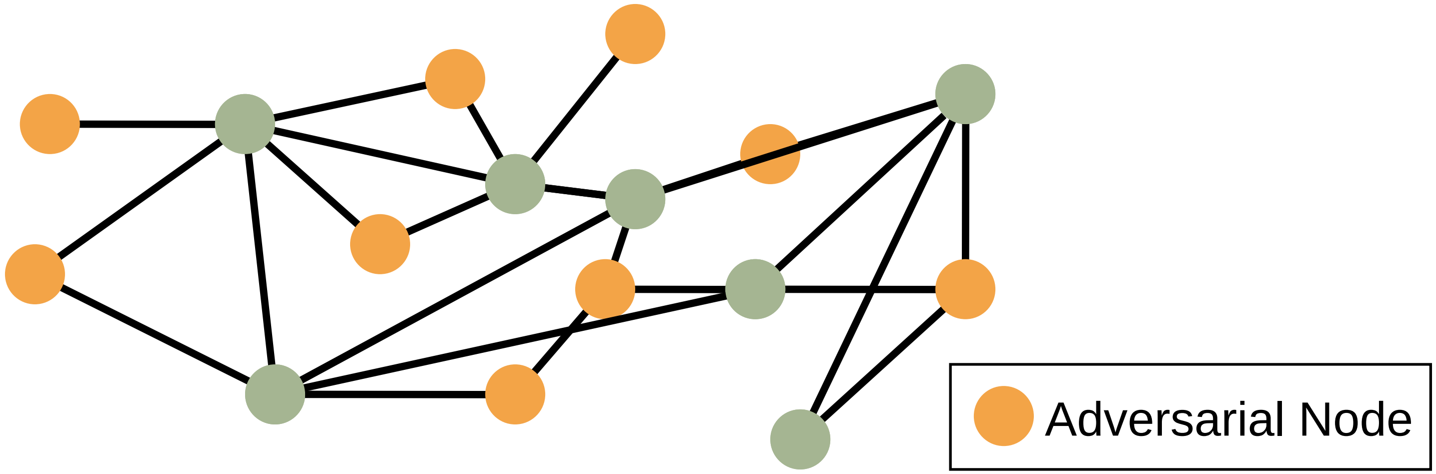
- Attacker: Cuts off a part of the network
  → Lookups fail, data corruption, partitioning



→Countermeasure:
Prevent a node from choosing its ID freely

Sybilattack

- Attacker: Adds huge number of nodes
  - →Network under control



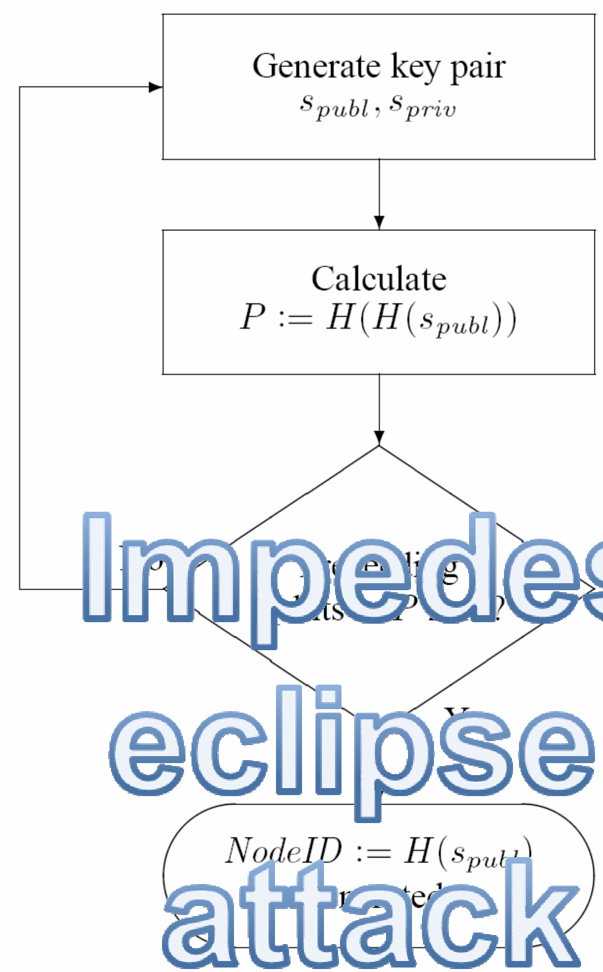
→Countermeasure:

Prevent joining with a huge quantity of nodes

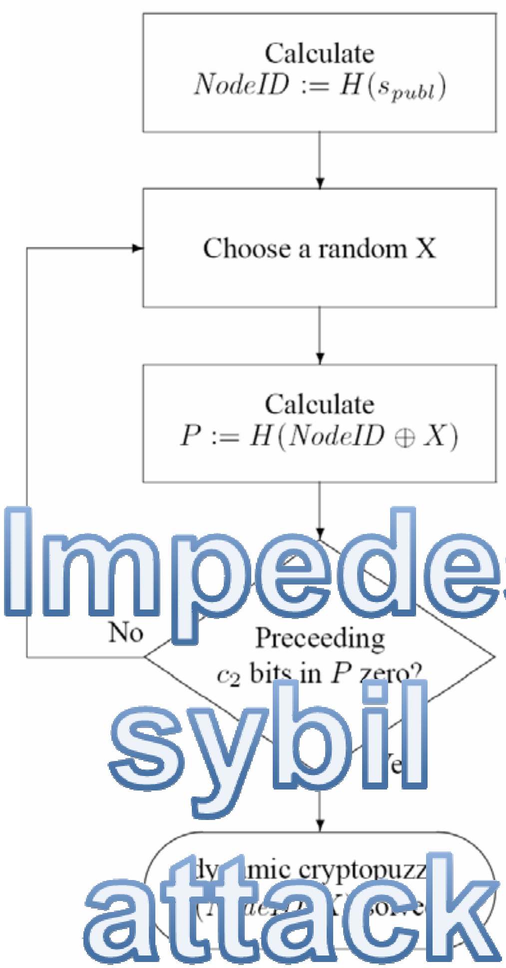
S/Kademlia: Secure NodeID Assignment

- NodeID := H(public-key)
  - Allows secure communication between two nodes
  - Duplicate NodeIDs improbable
- Signatures
  - Weak: Signature(timestamp, IP, port)
    - Used for PING or FIND_NODE messages
  - Strong: Signature(message)
    - Used for DHT storage messages
- Certificates
  - Certificate of a well-known trusted CA
    - CA prevents sybil- and eclipse attack
  - Decentralized with crypto-puzzles

S/Kademlia: NodeID Crypto-Puzzles



Impedes eclipse attack



Impedes sybil attack

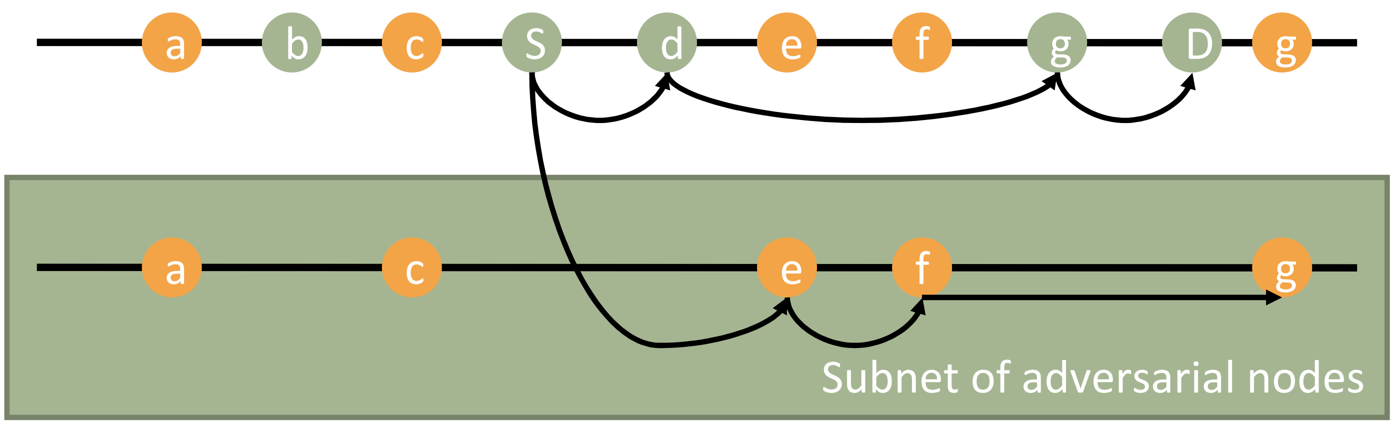
S/Kademlia: NodeID Summary

- Cryptographic NodeIDs for E2E security
- Crypto-puzzles
  - make it diffcult to generate
    - a large quantity of NodeIDs (Sybilattack)
    - non-random NodeIDs (Eclipse attack)

    →Adversarial nodes uniformly distributed
  - adapt when computational resources become cheaper

Adversarial Overlay Routing

- Attacker: Reroutes packets into own subnet
  →Lookup finds the closest adversarial node

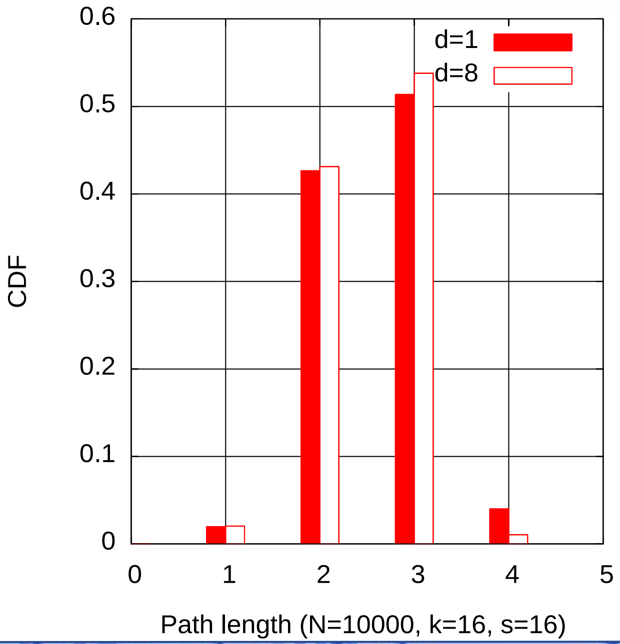


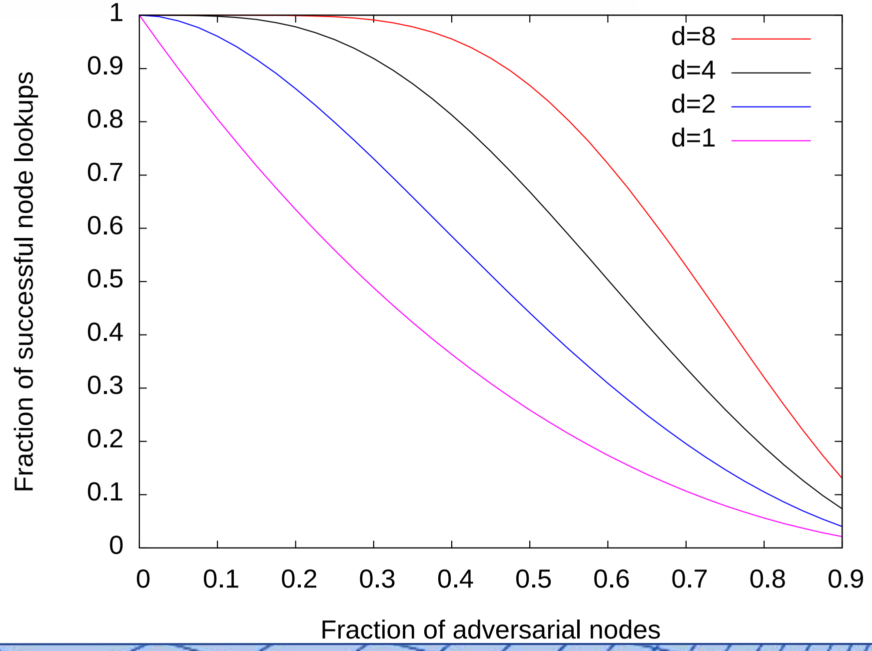
→Countermeasure:
Use parallel lookups over disjoint paths

Adversarial Overlay Routing - Analysis

- Let (h_x) be the CDF of path lengths *m* the density of adversarial nodes and *d* the number of disjoint paths then a lookup succeeds with probability

$$P_K := \sum_{i=1}^{|(h_x)|} \left(h_i \cdot \left(1 - \left(1 - (1-m)^i \right)^d \right) \right)$$



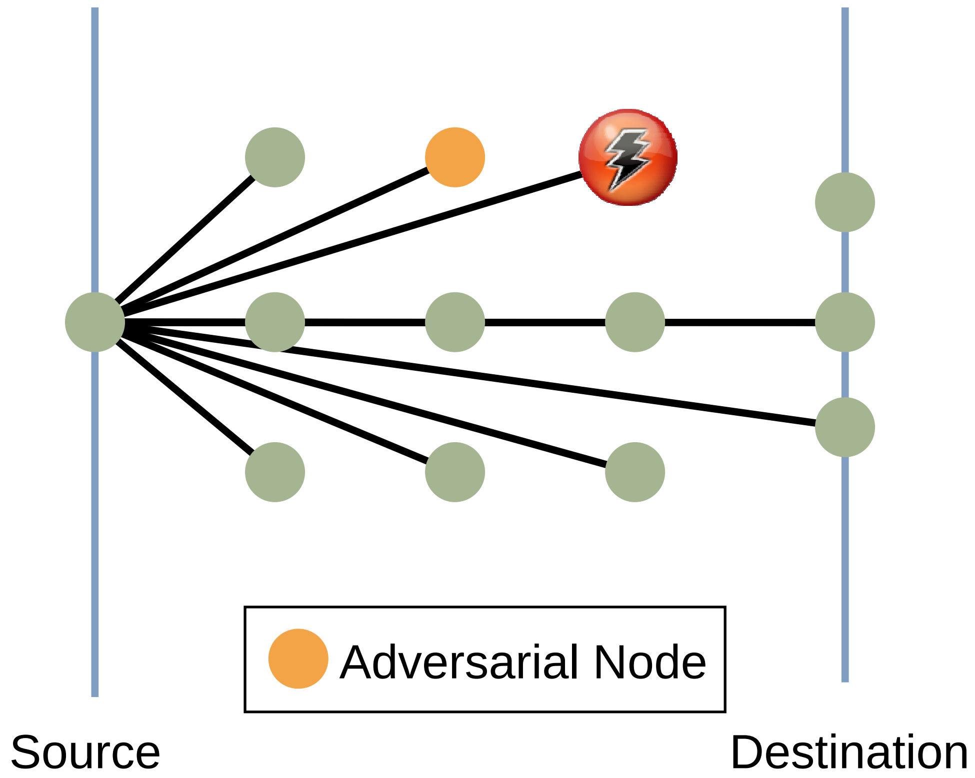


S/Kademlia: Lookup over disjoint paths

- Iterative lookup
  - allows to ensure lookup on disjoint paths
  - needs enhancement

- Lookup procedure (simplified)
  1. Lookup k closest nodes in own routing table
  2. Distribute them over d path lookups
  3. Do parallel path lookups
     - Check if a node already visited/result used

S/Kademlia: Lookup over disjoint paths



S/Kademlia: Reliable Sibling Broadcast

- Motivation
  - Lookup probabilities analyzed for node lookups only
  - DHT operations need siblings for replication

  →A reliable sibling lookup is important

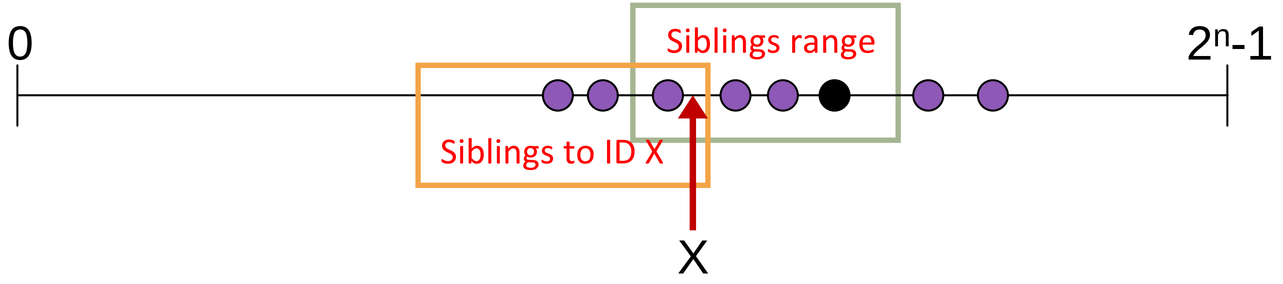
- Each node needs to know s closest nodes (siblings) to an identifier if it falls inside its sibling range

  → Not part of the original Kademlia design

S/Kademlia: Reliable Sibling Broadcast

- A special sorted sibling list is introduced in S/Kademlia
  - If s is the number of siblings then a sibling list of size >5s is needed at least to ensure that the node knows at least s siblings to an identifier in its siblings range w.h.p (see proof in the paper)

→Special splitting of smallest sub-tree can be omitted



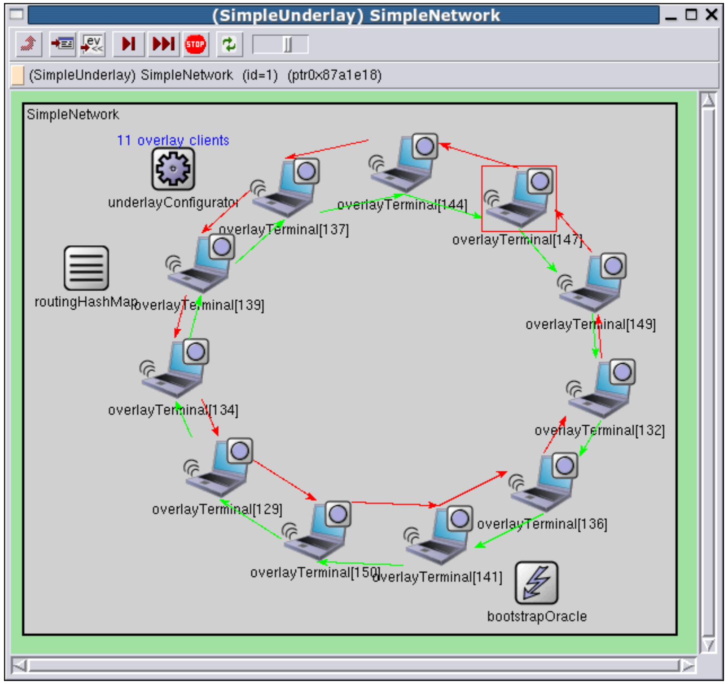
S/Kademlia: Routing-Table Maintenance

- Network join: lookup own NodeID
- Bucket Refresh
  - Bucket has not been used for a long time
    → Lookup a random NodeID from the bucket
- Filling Routingtable with NodeIDs
  - Add nodes, if they are actively known
    (by a response to a RPC)
  - Add nodes, if they are passively known
    (by a RPC request) only if the prefix of X bits does not match the nodes NodeID

→Makes it difficult for an attacker to actively modify routing-table

Evaluation: Simulator & Parameters

- Simulations have been done with OverSim
  - Provides a framework for overlays in OMNet++
  - Common KBRs already implemented
  - Open for contribution
  - Released under GPL
  - Visit http://www.oversim.org



- Simulation Parameters
  - SimpleUnderlay was used
  - No churn was simulated

Evaluation: Assumptions & Procedure

- Assumptions
  - Lookup fails if adversarial node is on lookup path
  - Lookup origin and destination not adversarial

- Simulation Procedure

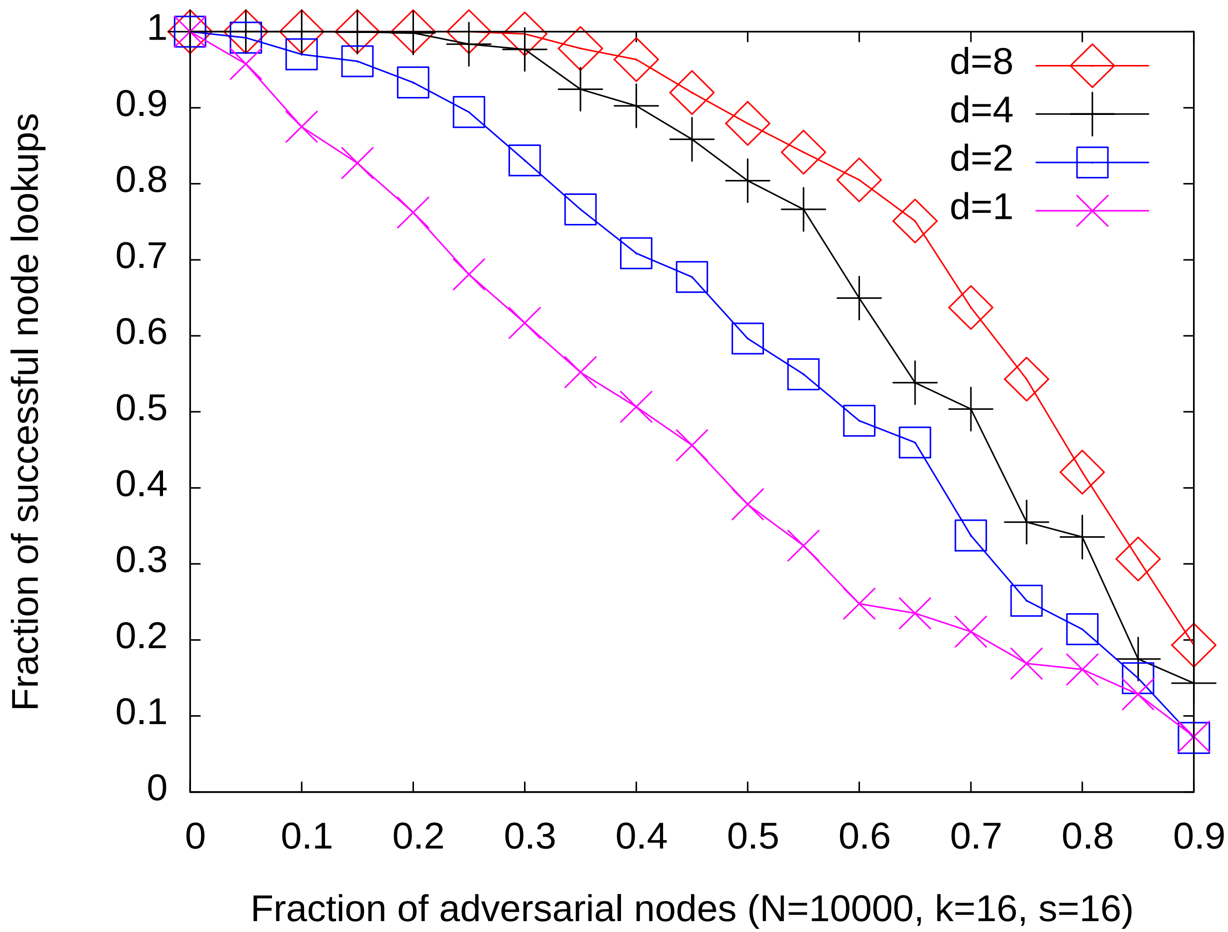
  1.) Creation of a stable Overlay of with N Nodes

  2.) Lookup of N random nodes

  3.) Increase of adversarial nodes by 5%, repeat lookups

  4.) 90% of the nodes adversarial? → Stop

Evaluation: Results



→ Even with 25% adversarial nodes 99% lookups succeed

Conclusions and Future Work

- Our design makes it difficult for an attacker to
  - launch large-scale sybil- or eclipse attacks and
  - enhances lookup success significantly in the presence of adversarial nodes

  → Not limited to Kademlia
- S/Kademlia has a sibling list
  - Lookup probability same as it is for the node lookup
  - Allows DHTs to reliably store replicas
- Future Work:
  - Evaluate security features under churn
  - Enhance S/Kademlia with a secure DHT

Thank you for listening! … Questions?

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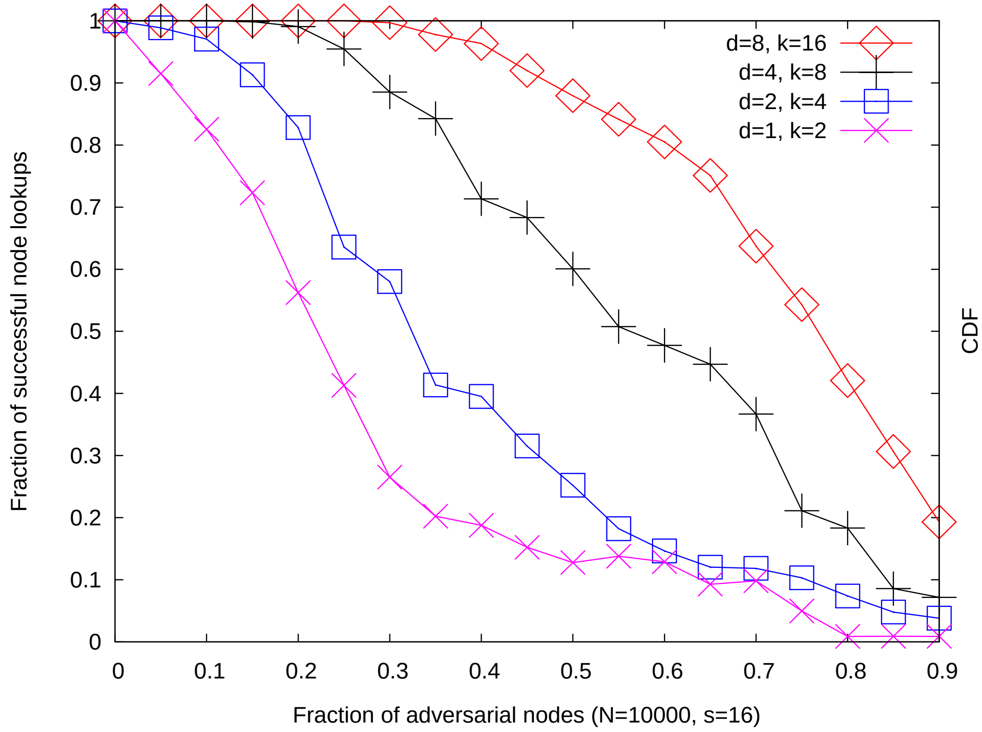
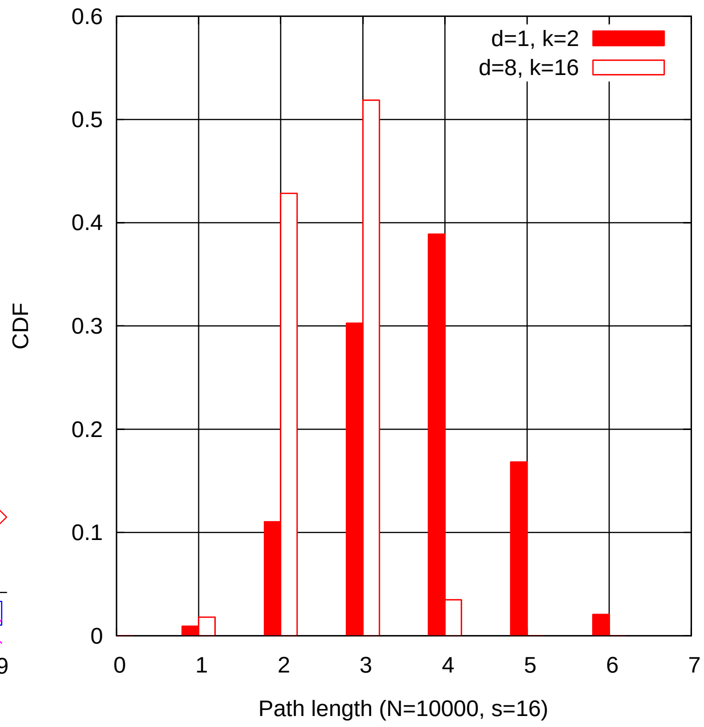
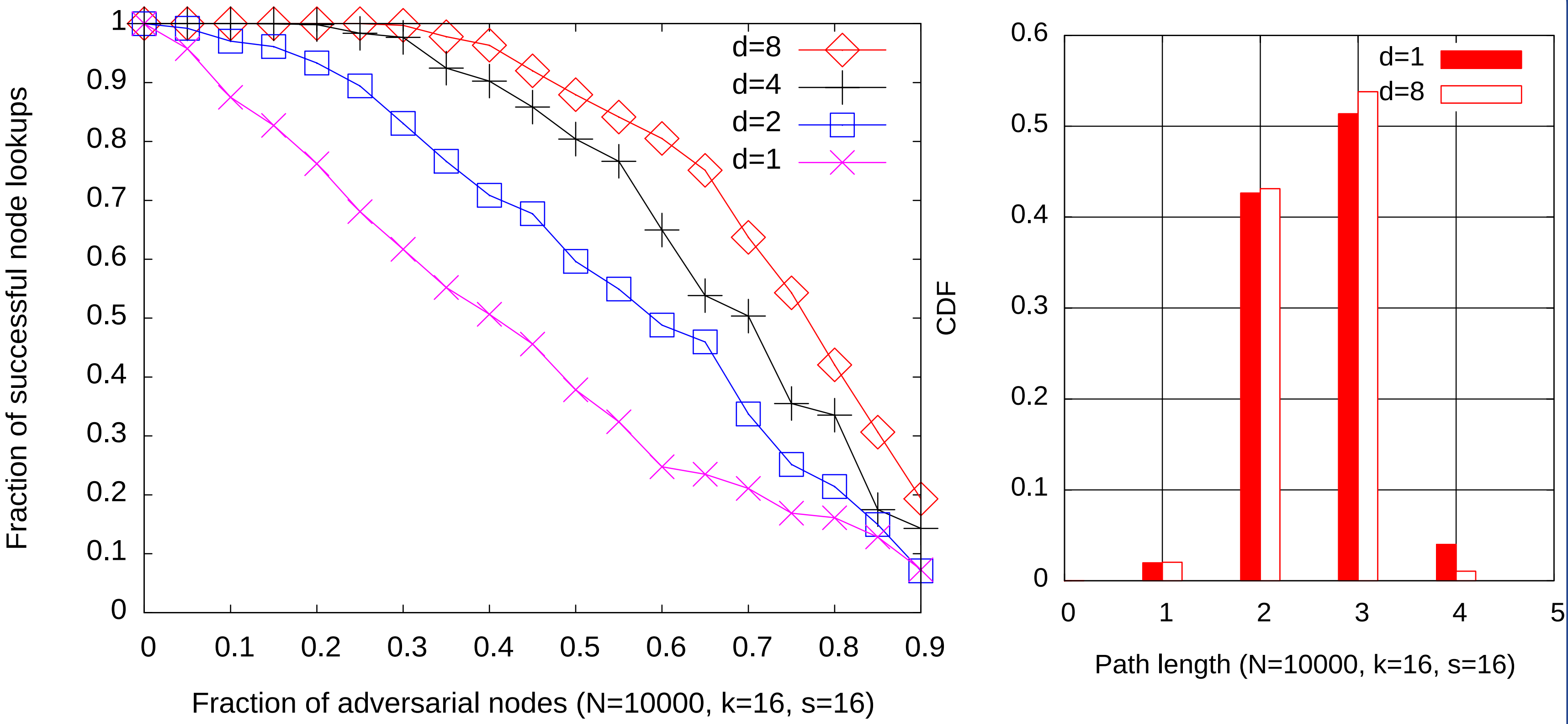
Backup Slides

Evaluation: N=10000, k=2d, d={1,2,4,8}





Evaluation: N=10000, k=16, d={1,2,4,8}



Introduction: Kademlia Routing Table

- Consists of n buckets of size k. The i-th bucket holds nodes of distance 2i <= d(X, a) < 2i+1
  → Each bucket covers a part of the identifier space
- Filling the routing table
  - First, only one bucket covering the whole identifier space exists
  - When a message from node X arrives and the Bucket which covers the identifier of X …
    - is not full: Add node X to bucket
    - is full: Split the bucket, if it covers the own NodeID and add the node
  - Special treatment of “close” nodes is needed

Introduction: A Kademlia Routing Table Example

- Routingtable with bucket size of k=2