Introduction to Distributed Hash Tables

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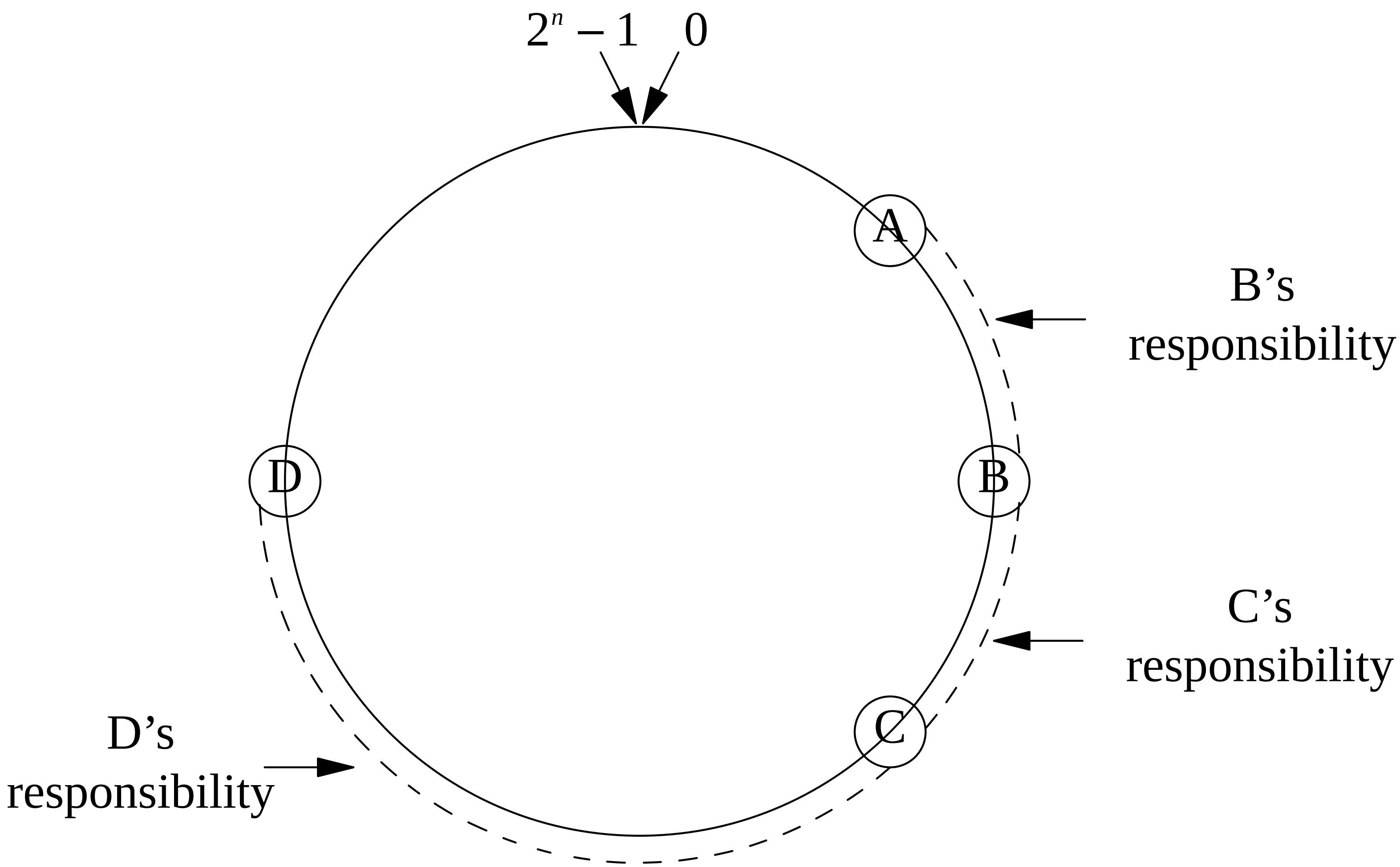
Overall Concept

- Distributed Hash Table (DHT)
- Distribute data over a large P2P network
  - Quickly find any given item
  - Can also distribute responsibility for data storage
- What's stored is key/value pairs
  - The key value controls which node(s) stores the value
  - Each node is responsible for some section of the space
- Basic operations
  - $Store(key, val)$
  - $val = Retrieve(key)$

The standard example: Chord [SMK+01]

- Each node chooses a n-bit ID
  - Intention is that they be random
  - Though probably a hash of some fixed info
  - IDs are arranged in a ring
- Each lookup key is also a n-bit ID
  - I.e., the hash of the real lookup key
  - Node IDs and keys occupy the same space!
- Each node is responsible for storing keys "near" its ID
  - Traditionally between it and the previous node
    - Item is stored at "successor"
    - Can be replicated at multiple successors

The Chord Ring



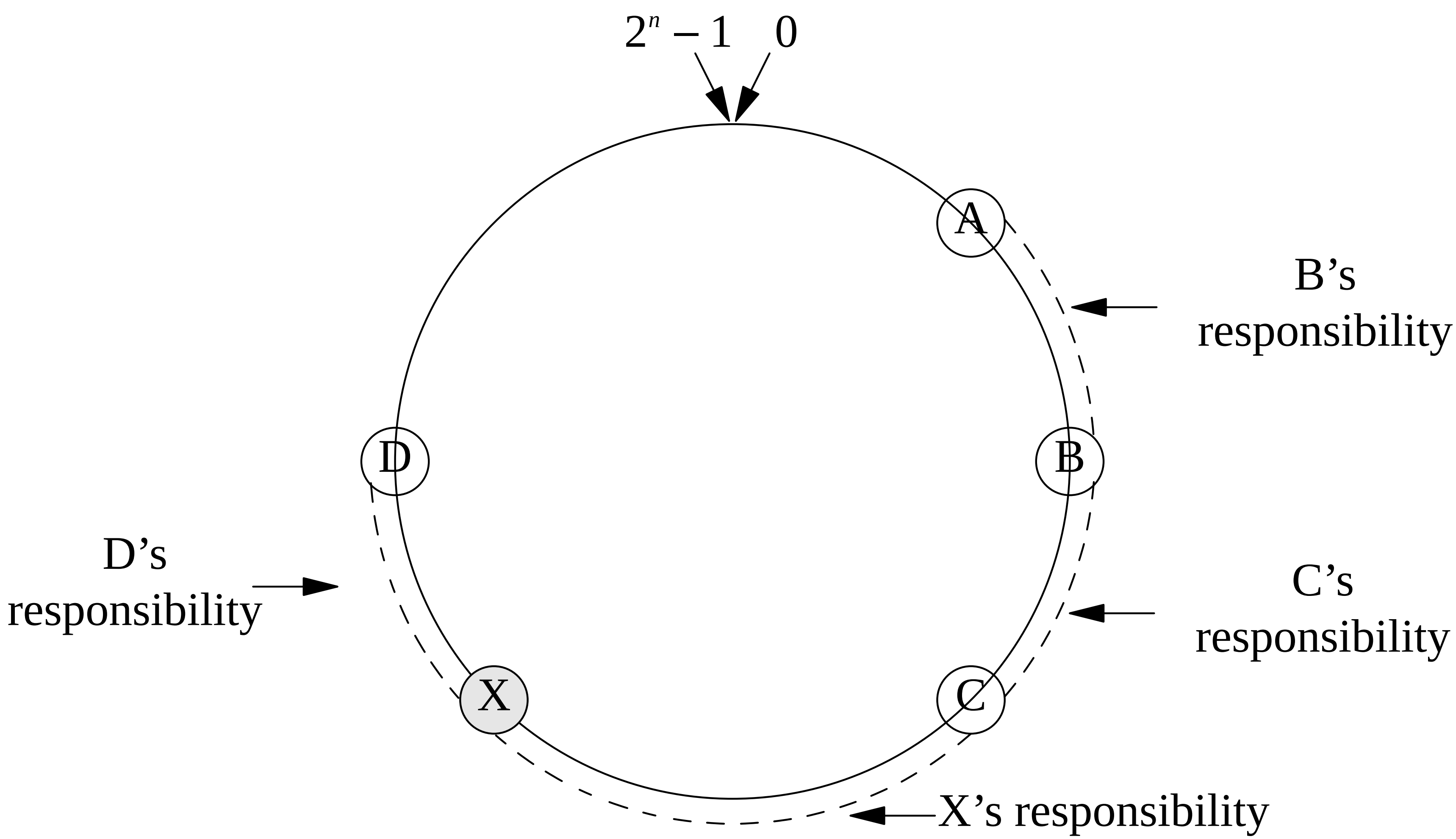
Routing

- Naive routing algorithm
  - Each node knows its neighbors
    - * Send message to nearest neighbor
    - * Hop-by-hop from there
  - Obviously this is $O(n)$
    - * So no good
- Better algorithm: “finger table”
  - Memorize locations of other nodes in the ring
    - * a, $a+2$, $a+4$, $a+8$, $a+16$, ... $a+2^n-1$
  - Send message to closest node to destination
    - * Hop-by-hop again
    - * This is $log(n)$

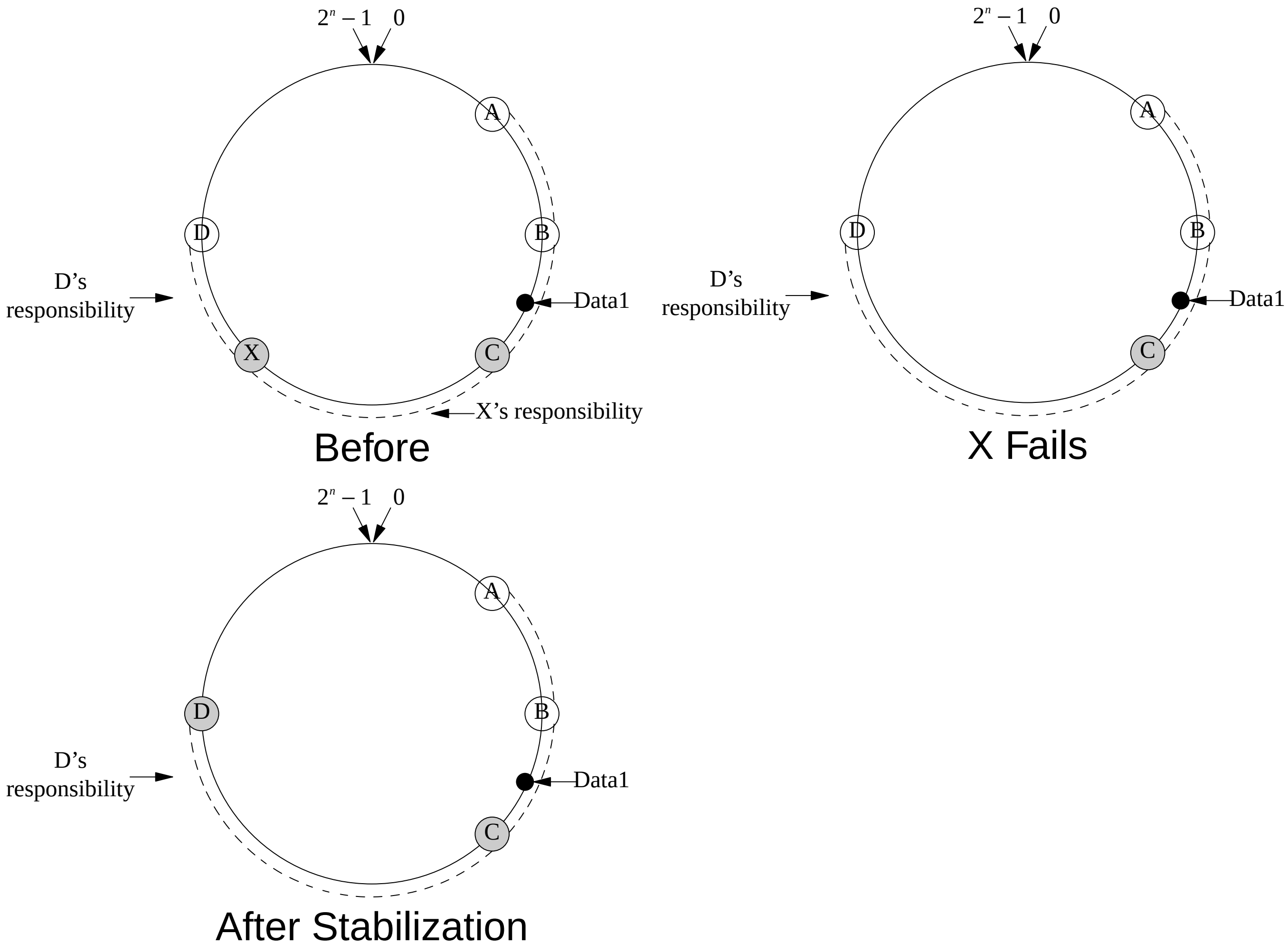
Joining

- Select a node-ID
- Contact the node that immediately follows you
  - Note that this is the same node with responsibility for your node-ID
  - Copy his state
- Data is now split up between you and the previous successor node
- Note: this requires knowing some "bootstrap node" a priori

Adding a node



Node Failure



Data must be replicated to survive node failure.

Other Structured P2P Systems

- CAN [RFH+01]
- Pastry [RD01]
- Tapestry [ZHS+01]
- Kademlia [MM02]
- Bamboo [RGRK]
- ...
- Same concept but different structure, routing algorithms, and performance characteristics

What DHTs are good at

- Distributed storage of things with known names
- Highly scalable
  - Automatically distributes load to new nodes
- Robust against node failure
  - ...except for bootstrap nodes
  - Data automatically migrated away from failed nodes
- Self organizing
  - No need for a central server

What DHTs are bad at

- Searching
  - Consequence of hash algorithm
  - "abc" and "abcd" are at totally different nodes
  - **Warning:** DHT people call lookup "search"
- Security problems
  - Hard to verify data integrity
  - Secure routing is an open problem

Example Application: Fully Distributed Name Service

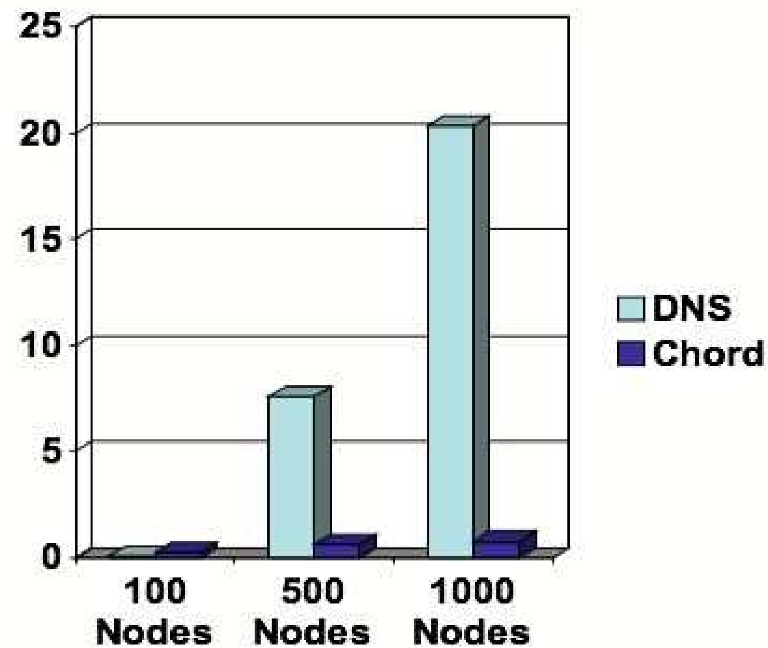
- DNS is distributed but hierarchical
  - Dependency on the roots
  - Potential single point of failure
  - No real load balancing
    - Arguable whether this is desirable (economics)
- Can we use a DHT here?

DDNS [CMM02] and CoDoNS [RS04]

- Obvious approach: Each DNS name becomes a DHT entry
  - e.g., `www.example.com:A` $\rightarrow$ `192.0.2.7`
    - (Just a conceptual example)
- DDNS
  - Based on Chord
  - Inferior performance to DNS ($log(N)$ lookup cost)
- CoDoNS
  - Based on Beehive
  - $O(1)$ performance due to aggressive replication
    - Probably unrealistic memory requirements on each node
- Both use DNSSEC for security

Performance Under Attack

- DNS
  - Attack on root nodes
- Chord
  - Attack on a continuous subspace

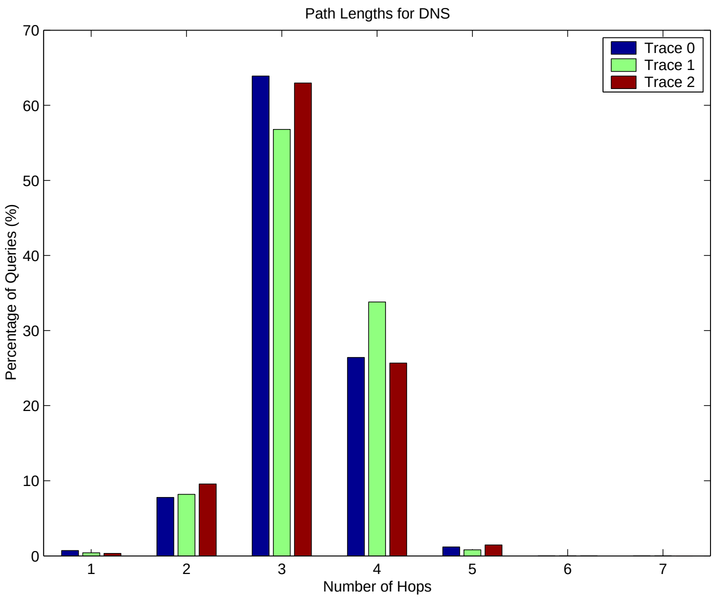


Percent failed queries

Data/Figure from Pappas et al. [PMTZ06]

Performance: Path Length

DNS



Chord

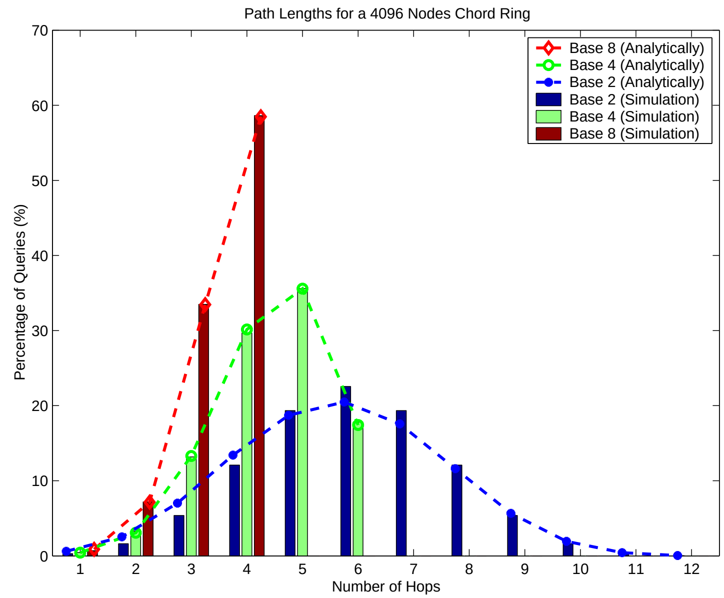


Figure from Pappas et al. [PMTZ06]

Example Application: Peer-to-Peer VoIP

- Skype Envy
- Reduce network operational costs
- Avoid having (paying) a service provider
- VoIP when there's no Internet connectivity
- Scalability
- Anonymous Calling

What's the problem?

- SIP is *already* mostly P2P
- SIP UAs can already connect directly to each other
  - But in practice they go through a centralized server
  - Modulo firewall and NAT traversal issues
- The problem is locating the right peer to connect to
  - Currently this is done with DNS
    - Works fine with stable centralized servers
  - But how do you lookup the location of unstable peers?
  - What about dynamic DNS?
    - Concerns about performance
    - What if you're disconnected from the Internet?

draft-bryan-sipping-p2p-02 [BLJ06]

- Uses a DHT for location
  - Specified for Chord
  - ... but could be anything
- `REGISTER` by storing your location in DHT
  - Under your URL
- Calling node looks up your URL in the DHT
  - ... and connects
- This is a strawman design
  - Not even a WG yet (BOF yesterday, ad hoc tomorrow)
  - Known security problem

Overview of Security Issues

- Data correctness
- Correctness of routing
- Fairness and detecting defection
- DoS

Data Correctness

- Storing nodes have no relationship to data owner
- What stops me from overwriting data?
  - Nothing!
- And how do I know it's right when I get it?
- General approach: make sure data is verifiable
  - Self-certifying (e.g., $k = SHA1(data)$)
  - Externally signed

A simple attack: chosen Node-ID

- Assume you want to impersonate a specific value k
  - Generate a node between k and $successor(k)$
  - You're now $successor(k)$
- General fix: make it hard for people to choose their own Node-Id freely
  - Chord uses $SHA1(IPaddress)$
  - This isn't perfect
    - An attacker who controls a big IP address space can generate a lot of IDs until it finds one it likes
    - IPv6 makes this situation much worse

Node impersonation

- Why bother with choosing your Node-Id
  - Just impersonate the current $successor(k)$
  - This requires subverting Internet routing
- One natural defense: public key cryptography
  - $NodeId = SHA1(PublicKey)$
  - Easy for peers to verify
  - But this makes it easy to generate chosen NodeIDs by trial and error
  - Can use a CGA variant here: $H(IP)||H(PublicKey)$

Sybil Attacks

- What if you had a lot of bad nodes
  - Just register with the DHT a lot of times
  - Interfere with most or all routing
  - For any lookup key
- Potential defenses
  - Proof-of-work for registration
    - Usual concerns about variance in machine performance
  - Reverse Turing Tests – but who would administer them
  - Certified Node-IDs
    - Requires a central authority

Routing Attacks and Defenses

- General concept: get all stored replicas with high probability
- Current state of the art [CDG+02]
  - Failure test
    - Detect density if replica set
    - Compare to own neighbor set density
    - Fake replica sets should be less dense
  - Redundant routing
    - Only used when routing failure detected
    - Expensive but high probability of success
- Assumes secure NodeID assignment
- Even more comnplicated with topology-based routing [CKS+06]

Fairness

- File storing costs resources
- How do you make sure people do their fair share?
- Basically an unsolved problem
  - Auditing
  - Cheating detection?

DoS

- Not much work done here
- Often possible to force system into pathological thrashing-type behavior
- Even worse if you compromise or attack a bootstrap node
- How do you do cost containment?
  - Make other people store a lot of data for you
- Force expensive secure routing algorithms

Summary

- A technically sweet technology
- Some obvious applications
- Still under very active research
- Some unsolved security problems
- Need to make sure capabilities match applications

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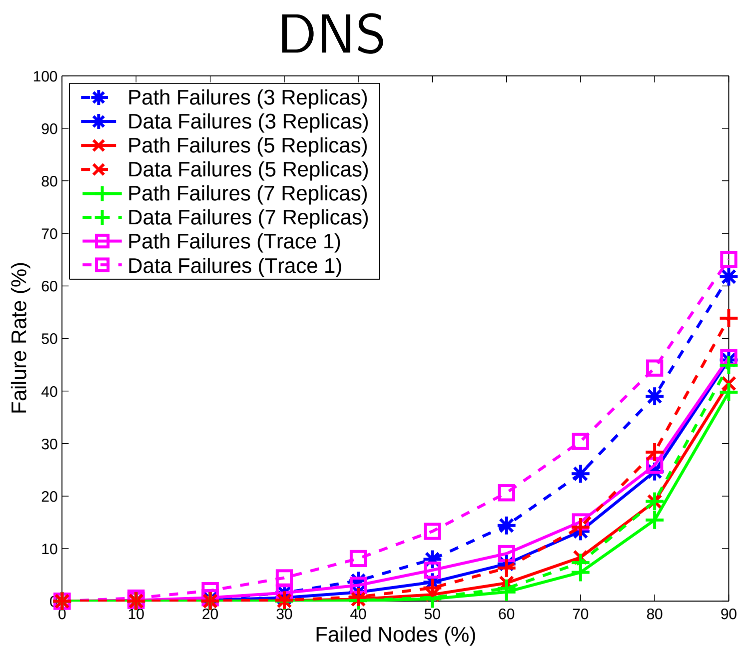
BACKUP SLIDES

Ring Stabilization

- Need to propagate joins and leaves
- Periodically ask your successor who his predecessor is
  - If it's after you then it's your successor
  - Notify it and update yourself
  - rinse, repeat
- Ring works even if not completely consistent
  - Performance just isn't as good

Availability - Random Failures



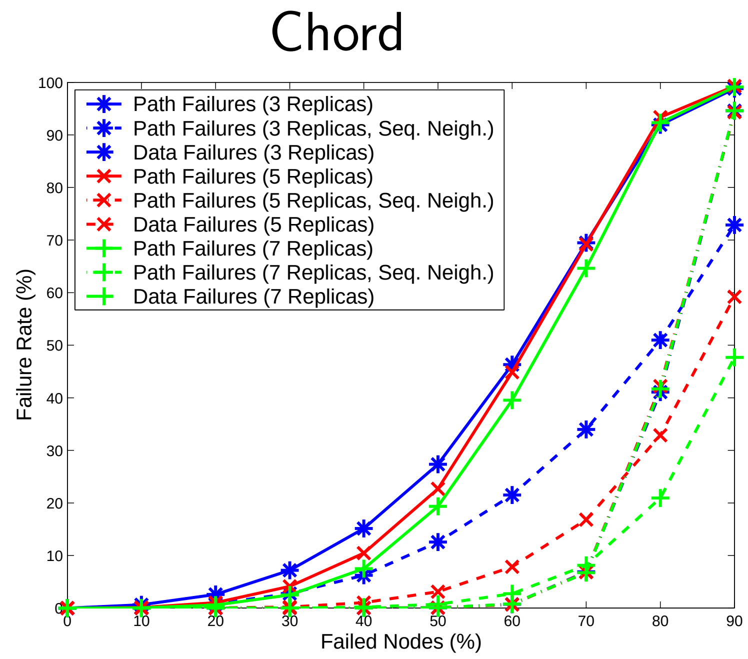


Figure from Pappas et al. [PMTZ06]

Example Application: Distributed File Storage

- Why a distributed file system?
  - Anywhere access to information
  - File sharing
    - Especially multimedia files
- Naive design
  - Store each file at node(s) corresponding to its name
  - Bad load balancing
    - Some files are more popular than others
    - Unlucky servers get hammered
  - Name collisions
    - Who has the right to store "Crossroads"?
      - And which version is it?

Solving the name collision problem

- Don't use user-friendly names
  - We've just established that they're overloaded anyway
- Use Hash(file) as lookup key
  - This guarantees uniqueness
    - At least statistically
  - Plus you can verify correctness
    - Just recompute the hash and compare to lookup key

Cooperative File System [DKK$^+$01]

- Based on Chord and DHash
- Store blocks instead of files
  - Automatically provides load balancing
  - Any substantial file will be split across many servers
    - "Virtual servers" allow even better load balancing
  - Blocks are cached along their Chord lookup path
    - Provides offloading for popular files
- Each block stored under its hash value
  - "Root-block" contains pointers to file blocks
  - Root block is signed
    - Stored under $Hash(PublicKey)$
- Note: this does not solve the directory problem

Real P2P Systems Let You Search

- "Give me every song from Blonde on Blonde"
  - "Dylan, Bob" or "Bob Dylan"? How do you spell "Blonde"?
- SHA-1 of "Dylan, Bob", "Bob Dylan", and "Dylan" are all unrelated
  - And stored on totally different nodes. Try all variants????
  - And what about free text search?
- Successful P2P file sharing systems allow search
  - Centralized: Napster, Torrent trackers, etc.
  - Decentralized: flooding
- DHTs offer no leverage here
  - You could build an index on the DHT [BKKMS03]
  - But not particularly efficient [LHSH03]

Background: Skype

- P2P Voice Application
  - 241.5 Million Downloads
  - Millions online at once
  - 1.9B Minutes Served
- Advertised as p2p VoIP, but?
  - Supernodes
  - Centralized Login Server
  - Namespace ownership
  - Hands out certs signed by Skype
  - SIP-based PSTN Interconnect server
  - All encrypted and all proprietary

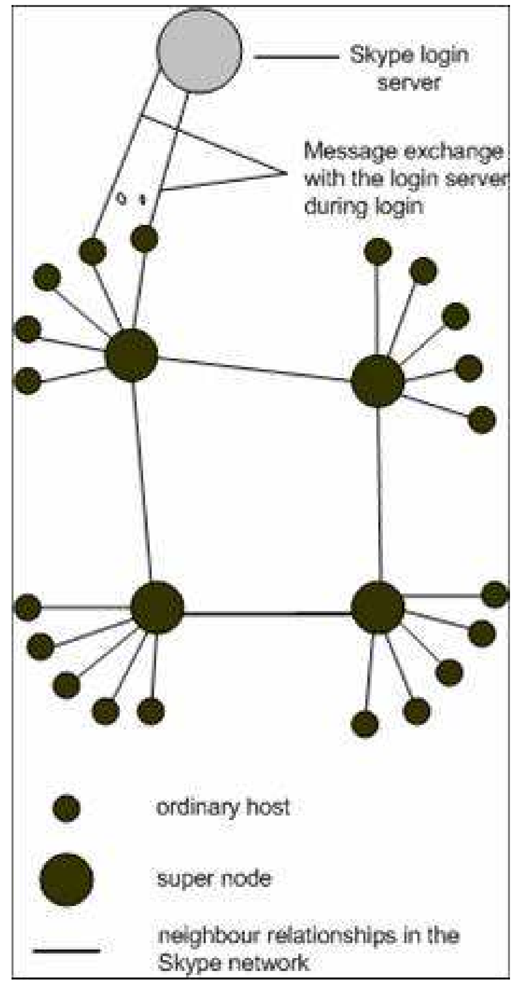


Diagram from Baset and Schulzrinne [BS04]