# Distributed Systems

## 7: Peer-to-Peer-Networks

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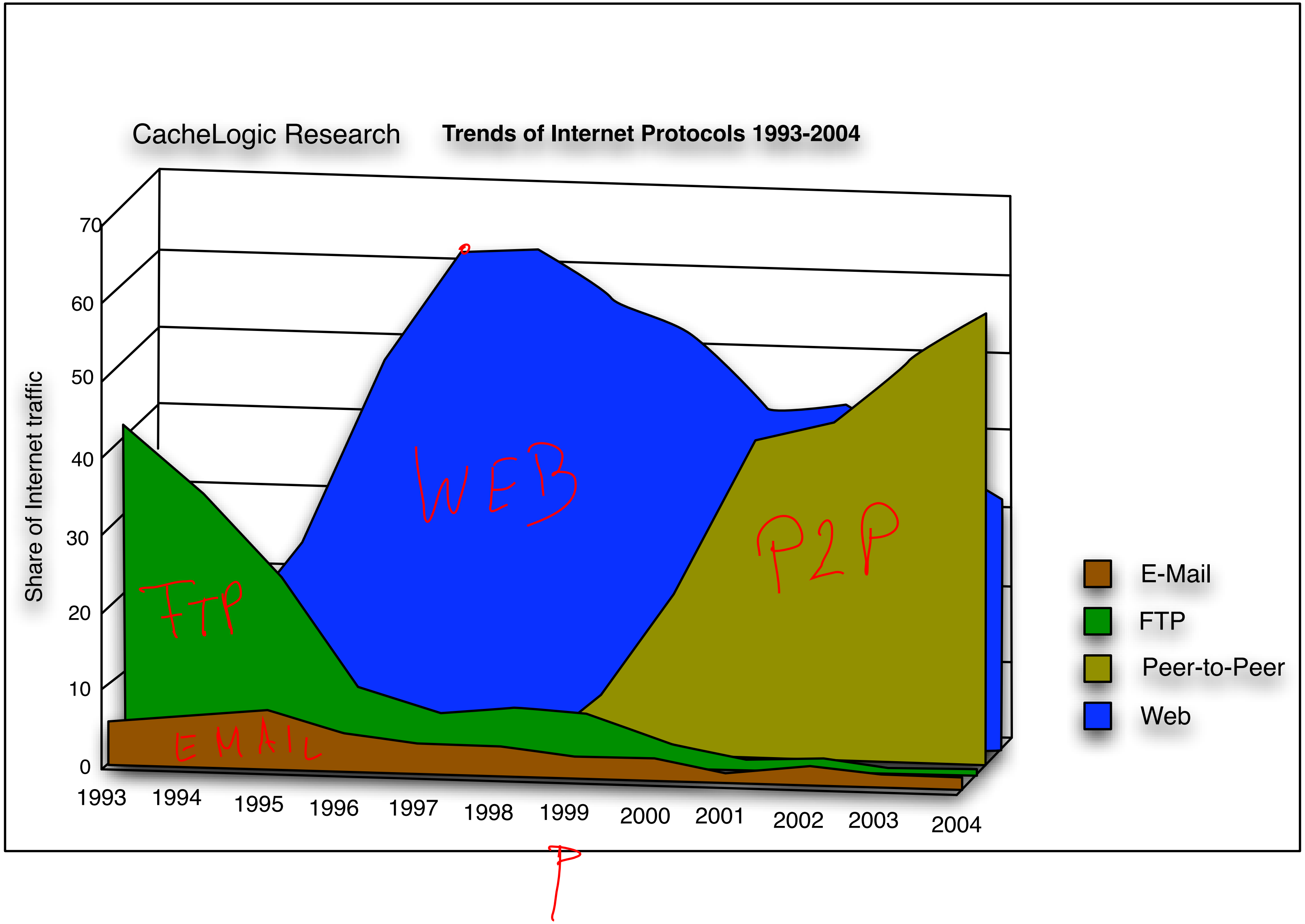
# What is a P2P Network?

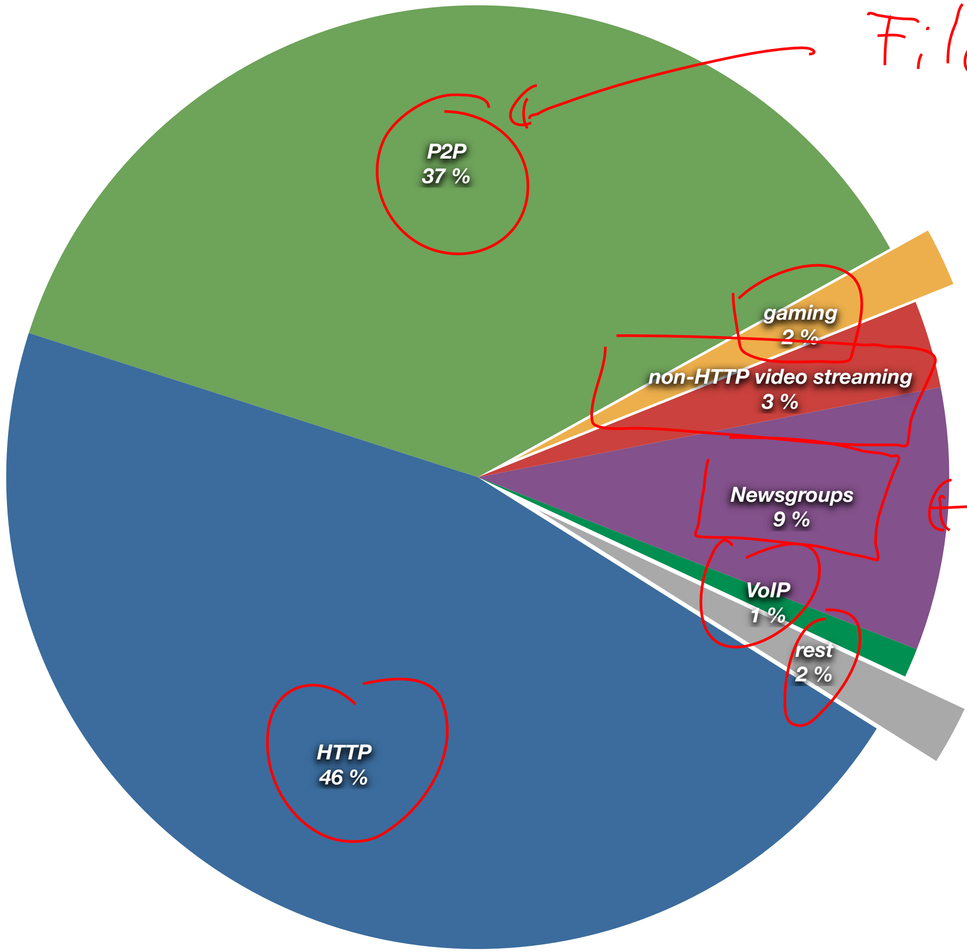
- What is P2P NOT?
  - a peer-to-peer network is not a client-server network
- Etymology: peer
  - from latin par = equal
  - one that is of equal standing with another
  - P2P, Peer-to-Peer: a relationship between equal partners
- Definition
  - a Peer-to-Peer Network is a communication network between computers in the Internet
    - without central control
    - and without reliable partners
- Observation
  - the Internet can be seen as a large P2P network

# Global Internet Traffic Shares 1993-2004



# Global Internet Traffic 2007

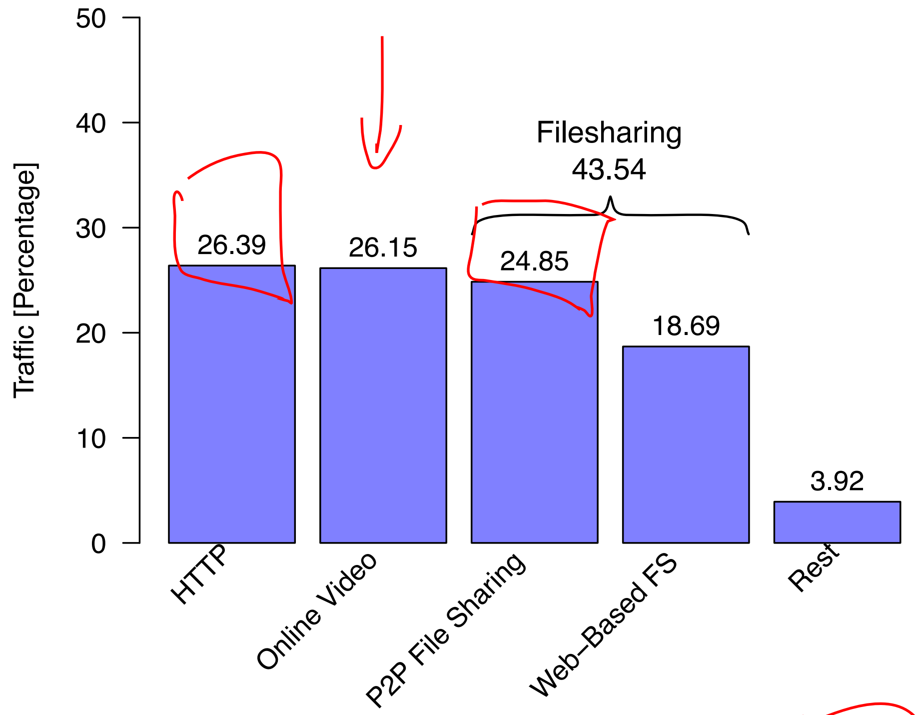
- Ellacoya report (June 2007)
  - worldwide HTTP traffic volume overtakes P2P after four years continues record
- Main reason: Youtube.com



# Internet Traffic 2010

- Cisco Visual Networking Index Usage
- contains data of 20 anonymous service providers

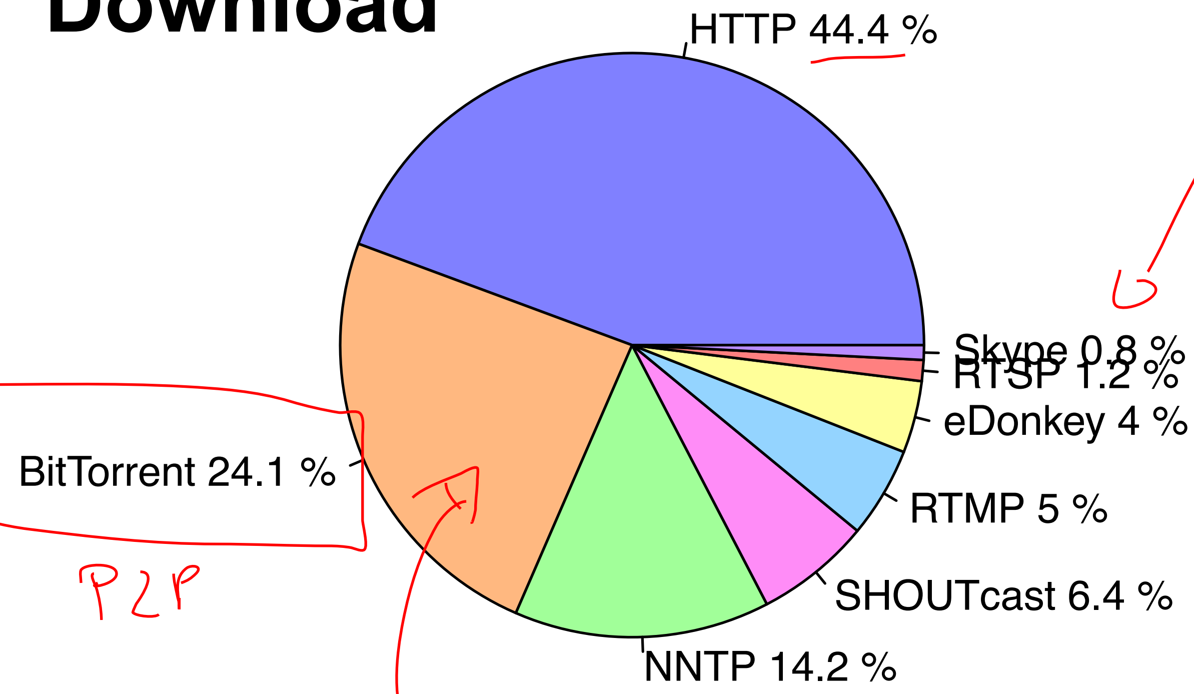
## Traffic Study



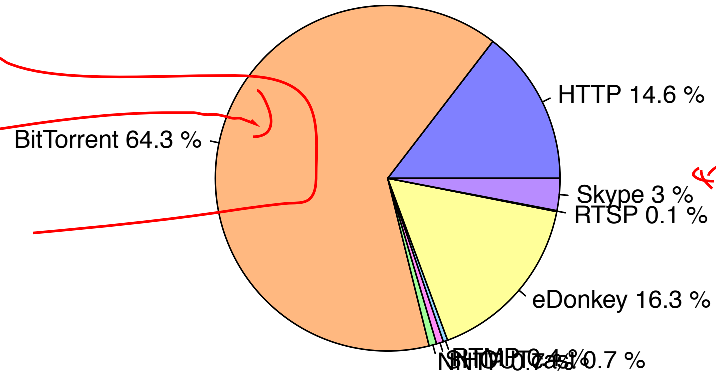

["Cisco Visual Networking Index: Usage", White Paper, 2010]

# Internet Traffic of a German ISP August 2009

## Download




## Upload

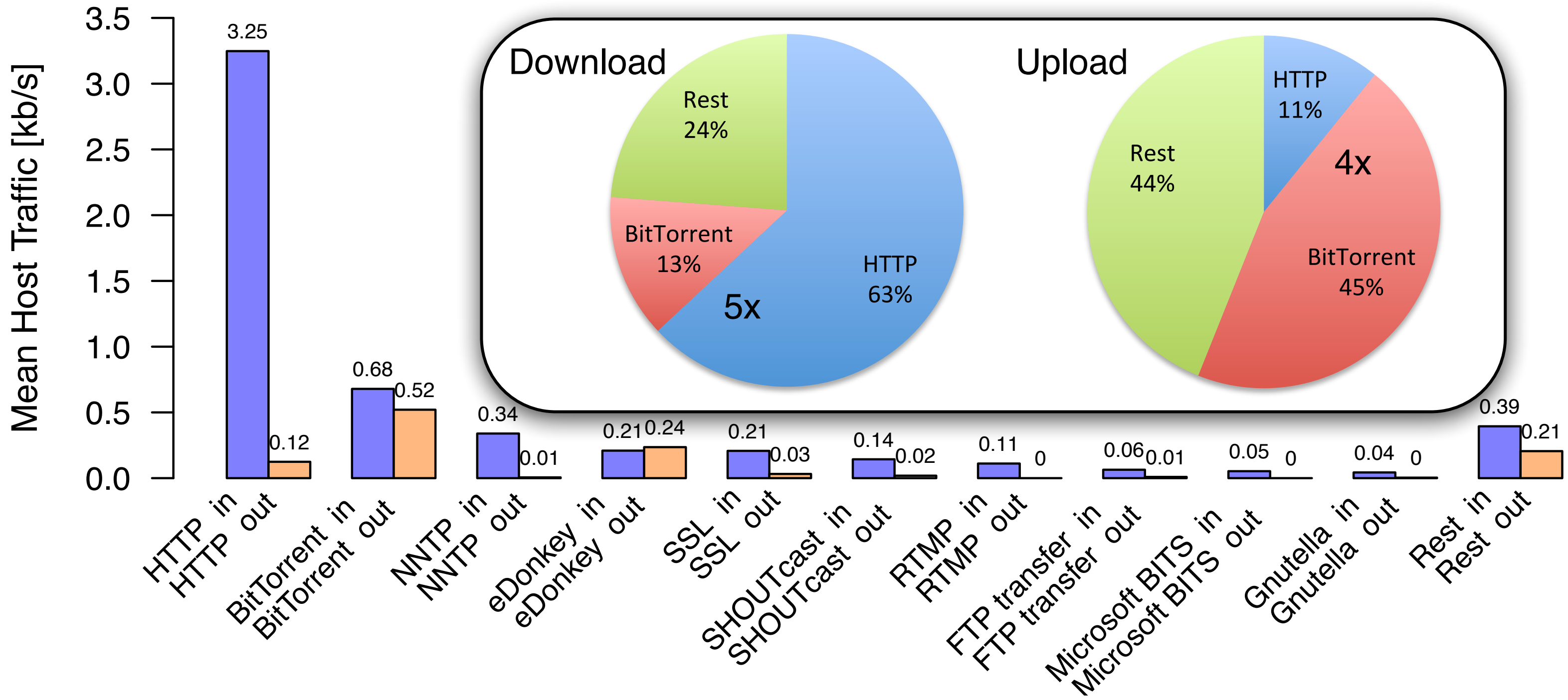



Source: Alsbih, Janson, S. Analysis of Peer-to-Peer Traffic and User Behaviour ITA 2011

# Internet Traffic of a German ISP August 2009

- HTTP most traffic
- BitTorrent most upload

## Top ten services of the average user




Source: Alsbih, Janson, S. Analysis of Peer-to-Peer Traffic and User Behaviour ITA 2011

# Milestones P2P Systems

- Napster (1st version: 1999-2000)
- Gnutella (2000), Gnutella-2 (2002) P2P
- Edonkey (2000)
  - later: Overnet usese Kademlia
- FreeNet (2000)
  - Anonymized download
- JXTA (2001) SUN
  - Open source P2P network platform
- FastTrack (2001)
  - known from KaZaa, Morpheus, Grokster
- Bittorrent (2001)
  - only download, no search
- Skype (2003)
  - VoIP (voice over IP), Chat, Video

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# Milestones Theory

- Distributed Hash-Tables (DHT) (1997)
  - introduced for load balancing between web-servers
- CAN (2001)
  - efficient distributed DHT data structure for P2P networks
- Chord (2001)
  - efficient distributed P2P network with logarithmic search time
- Pastry/Tapestry (2001)
  - efficient distributed P2P network using Plaxton routing
- Kademlia (2002)
  - P2P-Lookup based on XOr-Metrik
- Many more exciting approaches
  - Viceroy, Distance-Halving, Koorde, Skip-Net, P-Grid, ...
- Recent developments
  - Network Coding for P2P
  - Game theory in P2P
  - Anonymity, Security

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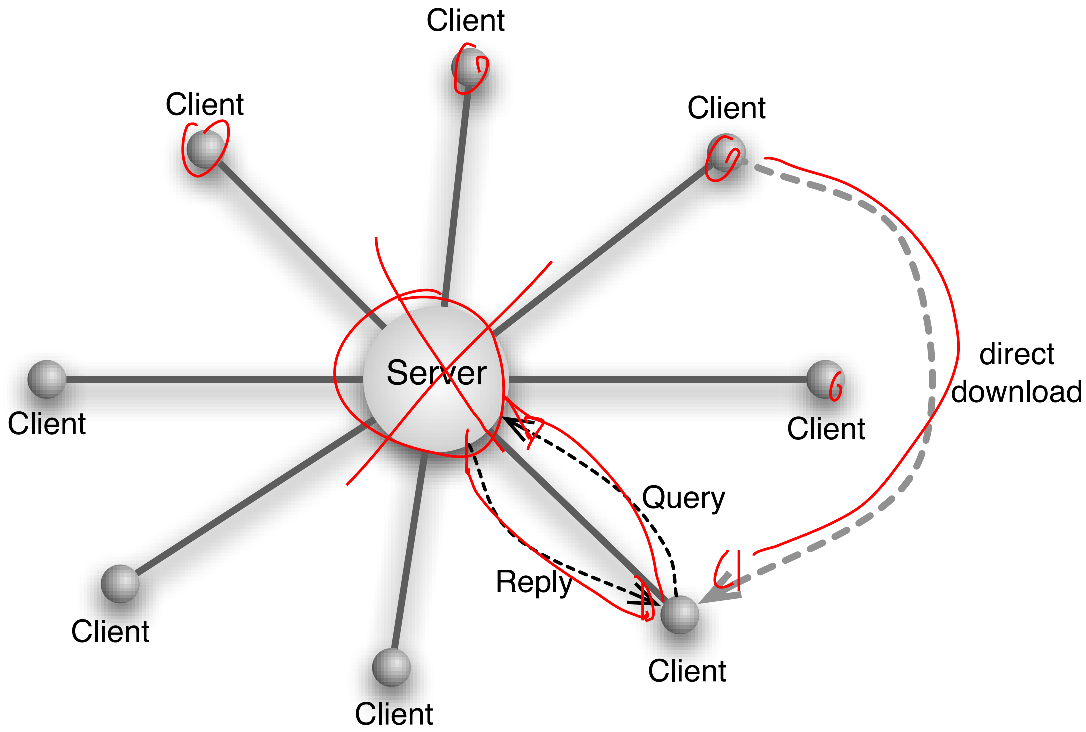
# Napster

- Shawn (Napster) Fanning
  - published 1999 his beta version of the now legendary Napster P2P network
  - File-sharing-System
  - Used as mp3 distribution system
  - In autumn 1999 Napster has been called download of the year
- Copyright infringement lawsuit of the music industry in June 2000
- End of 2000: cooperation deal
  - between Fanning and Bertelsmann Ecommerce
- Since then Napster is a commercial file-sharing platform

# How Did Napster Work?

- Client-Server
- Server stores
  - Index with meta-data
    - file name, date, etc
  - table of connections of participating clients
  - table of all files of participants
- Query
  - client queries file name
  - server looks up corresponding clients
  - server replies the owner of the file
  - querying client downloads the file from the file owning client

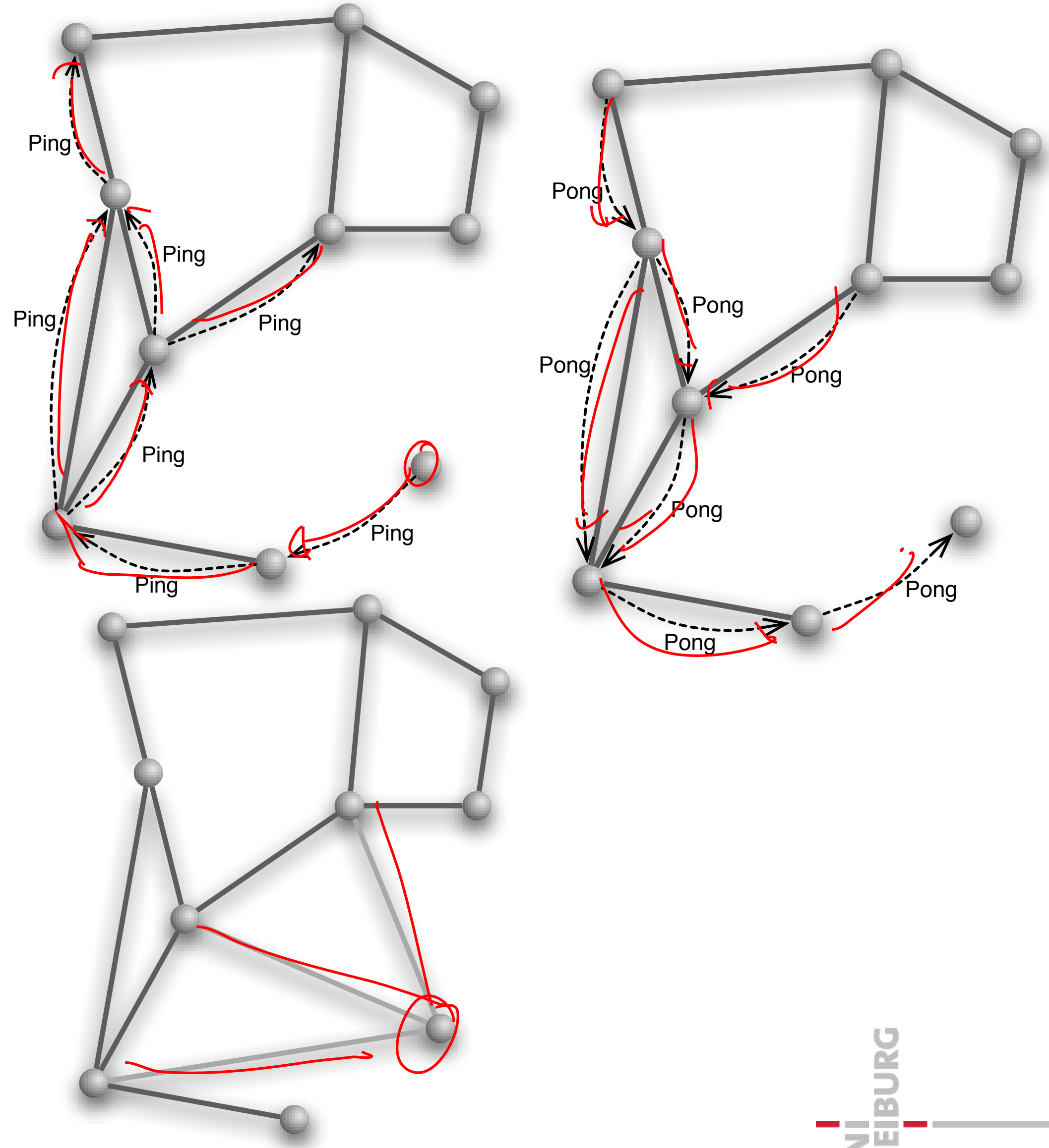


# History of Gnutella

- Gnutella
  - was released in March 2000 by Justin Frankel and Tom Pepper from Nullsoft
  - Since 1999 Nullsoft is owned by AOL
- File-Sharing system
  - Same goal as Napster
  - But without any central structures

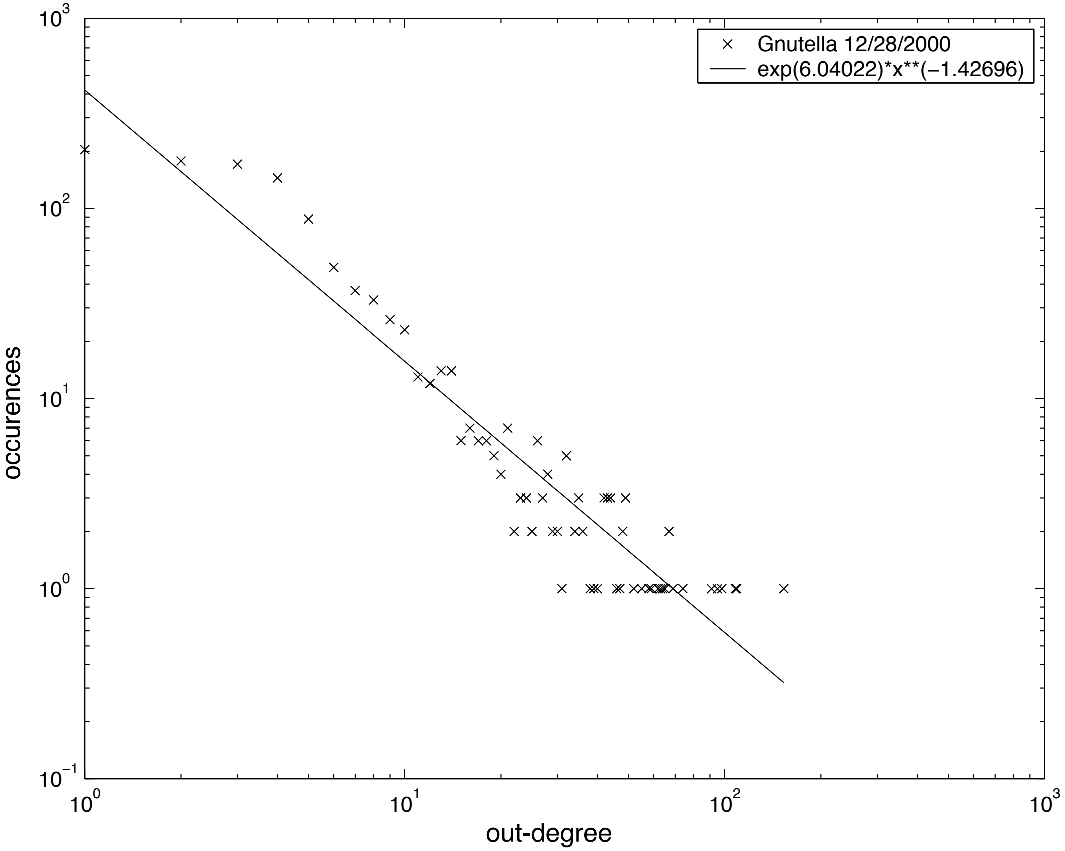
# Gnutella — Connecting

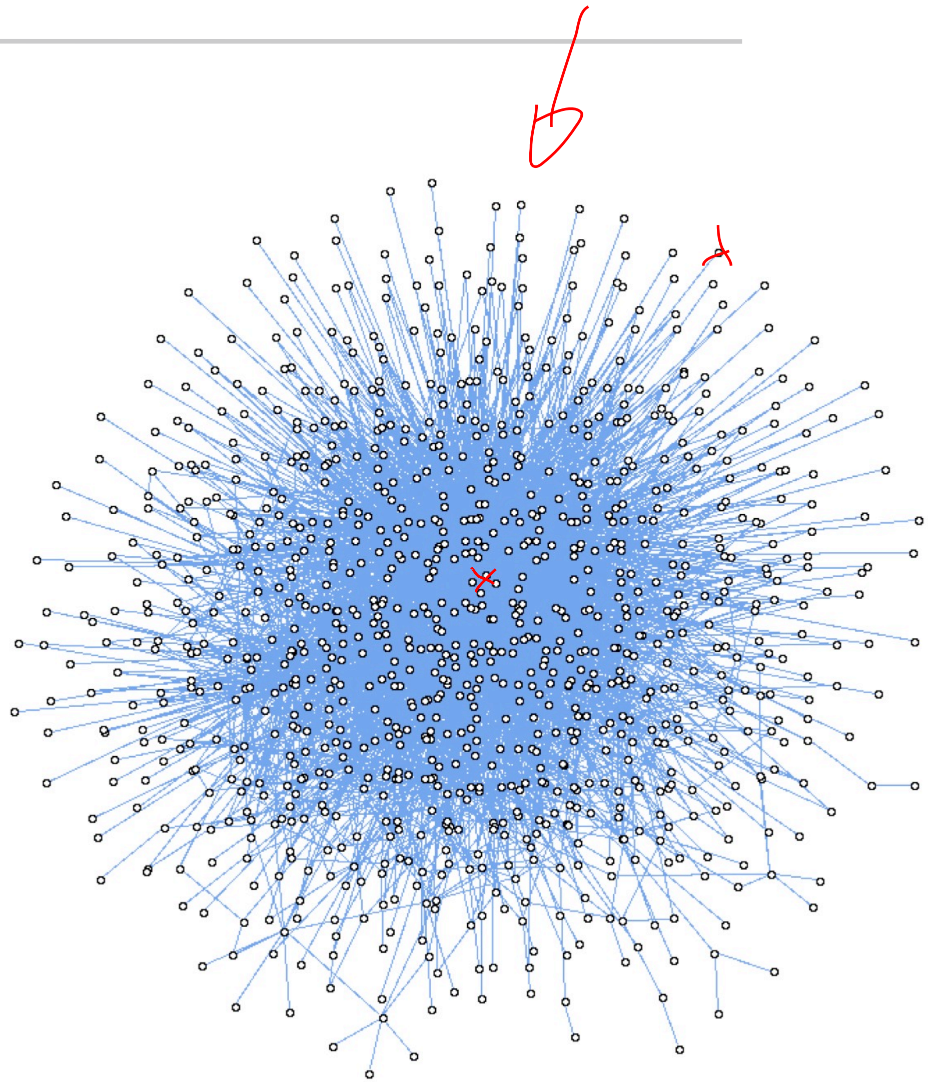
- Neighbor lists
  - Gnutella connects directly with other clients
  - the client software includes a list of usually online clients
  - the clients checks these clients until an active node has been found
  - an active client publishes its neighbor list
  - the query (ping) is forwarded to other nodes
  - the answer (pong) is sent back
  - neighbor lists are extended and stored
  - the number of the forwarding is limited (typically: five)



# Gnutella — Graph Structure

- Graph structure
  - constructed by random process
  - underlies power law
  - without control



Gnutella snapshot in 2000

# Pastry

- Peer-to-Peer Networks

# Pastry

- Peter Druschel
  - Rice University, Houston, Texas
  - now head of Max-Planck-Institute for Computer Science, Saarbrücken/Kaiserslautern
- Antony Rowstron
  - Microsoft Research, Cambridge, GB
- Developed in Cambridge (Microsoft Research)
- Pastry
  - Scalable, decentralized object location and routing for large scale peer-to-peer-network
- PAST
  - A large-scale, persistent peer-to-peer storage utility
- Two names one P2P network
  - PAST is an application for Pastry enabling the full P2P data storage functionality
  - First, we concentrate on Pastry

# Pastry Overview

- Each peer has a 128-bit ID: nodeID
  - unique and uniformly distributed
  - e.g. use cryptographic function applied to IP-address
- Routing
  - Keys are matched to $\{0,1\}^{128}$
  - According to a metric messages are distributed to the neighbor next to the target
- Routing table has
  $O(2^b(\log n)/b) + \ell$ entries
  - n: number of peers
  - $\ell$: configuration parameter
  - b: word length
    - typical: b= 4 (base 16),
      $\ell = 16$
    - message delivery is guaranteed as long as less than $\ell/2$ neighbored peers fail
- Inserting a peer and finding a key needs $O((\log n)/b)$ messages

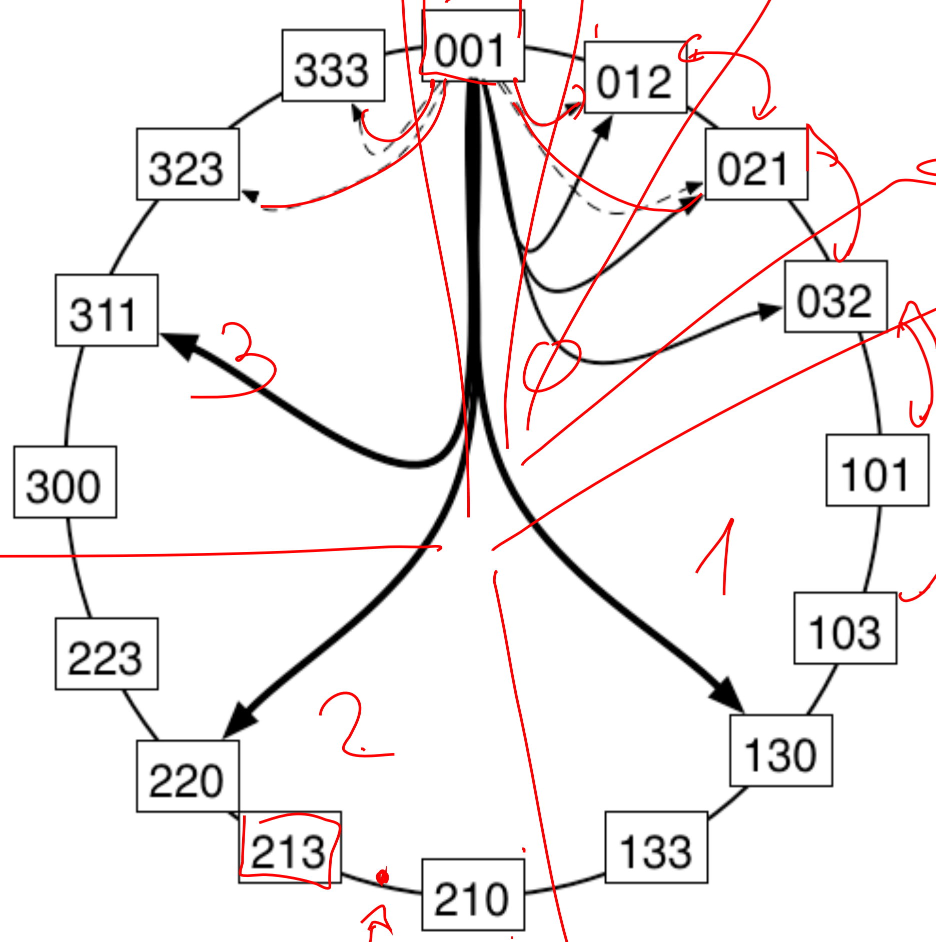
# Routing Table

- NodeId presented in base $2^b$
  - e.g. NodeID: 65A0BA13
- For each prefix p and letter $x \in \{0,..,2^b-1\}$ add an peer of form px* to the routing table of NodeID, e.g.
  - $b=4$, $2^b=16$
  - 15 entries for 0*,1*, .. F*
  - 15 entries for 60*, 61*,... 6F*
  - ...
  - if no peer of the form exists, then the entry remains empty
- Choose next neighbor according to a distance metric
  - metric results from the RTT (round trip time)
- In addition choose $\ell$ neighors
  - $\ell/2$ with next higher ID
  - $\ell/2$ with next lower ID

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0x | 1x | 2x | 3x | 4x | 5x | | 7x | 8x | 9x | ax | bx | cx | dx | ex | fx |
| 60x | 61x | 62x | 63x | 64x | | 66x | 67x | 68x | 69x | 6ax | 6bx | 6cx | 6dx | 6ex | 6fx |
| 650x | 651x | 652x | 653x | 654x | 655x | 656x | 657x | 658x | 659x | | 65bx | 65cx | 65dx | 65ex | 65fx |
| 65a0x | | 65a2x | 65a3x | 65a4x | 65a5x | 65a6x | 65a7x | 65a8x | 65a9x | 65aax | 65abx | 65acx | 65adx | 65aex | 65afx |

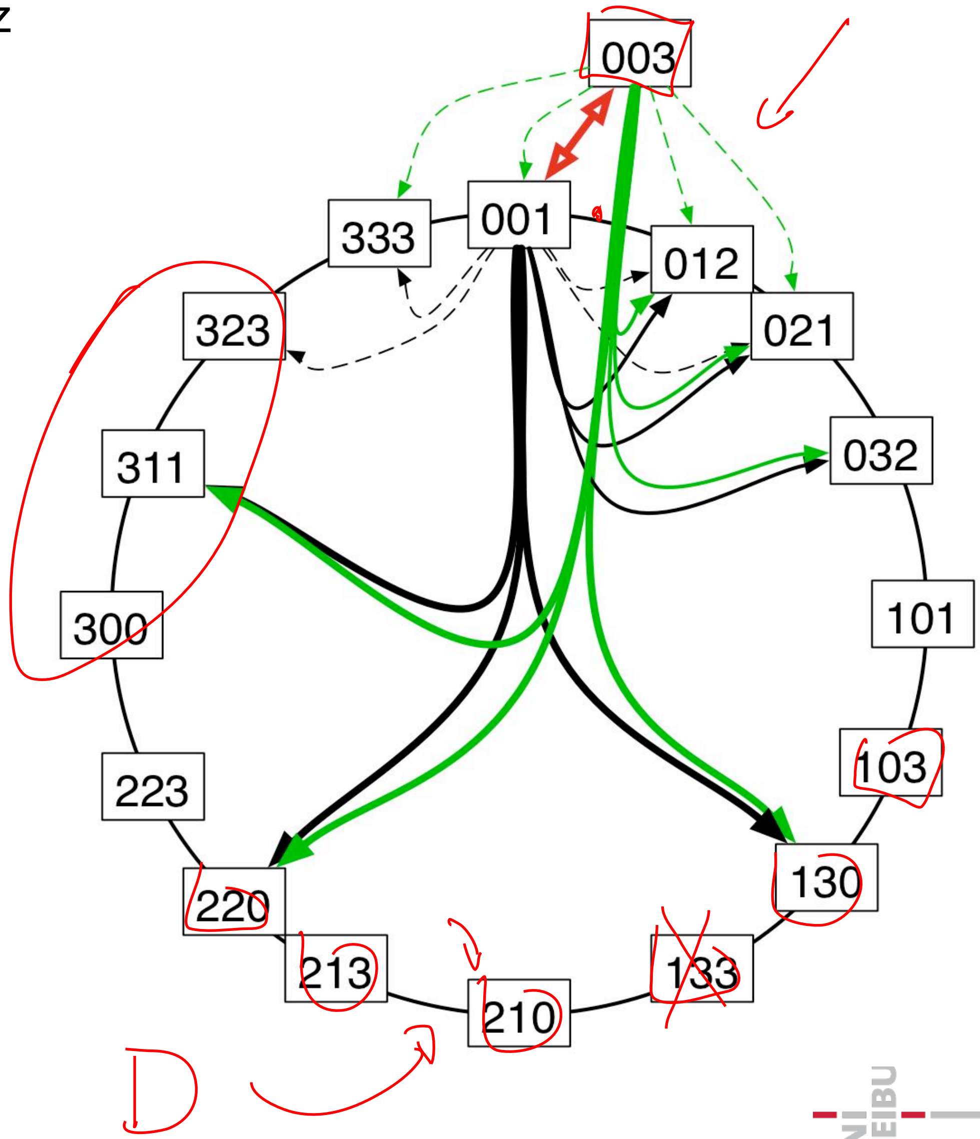
# Routing Table

- Example b=2
- Routing Table
  - For each prefix p and letter x ∈ form px* to the routing table of
- In addition choose ℓ neighbors
  - ℓ/2 with next higher ID
  - ℓ/2 with next lower ID
- Observation
  - The leaf-set alone can be used
- Theorem
  - With high probability there are entries in each routing table



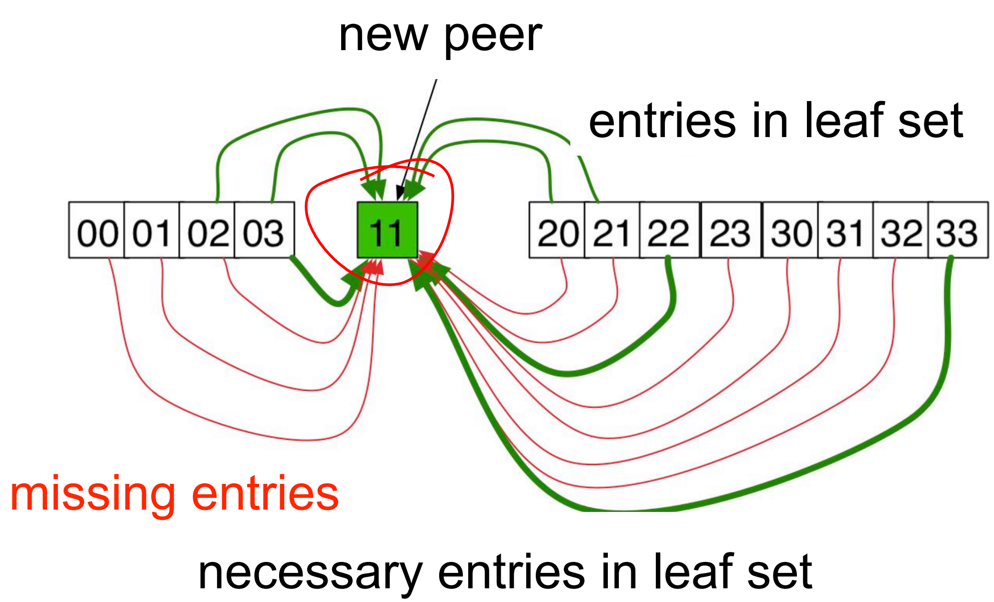
# A Peer Enters

- New node x sends message to the node z with the longest common prefix p
- x receives
  - routing table of z
  - leaf set of z
- z updates leaf-set
- x informs $\ell$-leaf set
- x informs peers in routing table
  - with same prefix p (if $\ell/2 < 2^b$)
- Numbor of messages for adding a peer
  - $\ell$ messages to the leaf-set
  - expected $(2^b - \ell/2)$ messages to nodes with common prefix
  - one message to z with answer



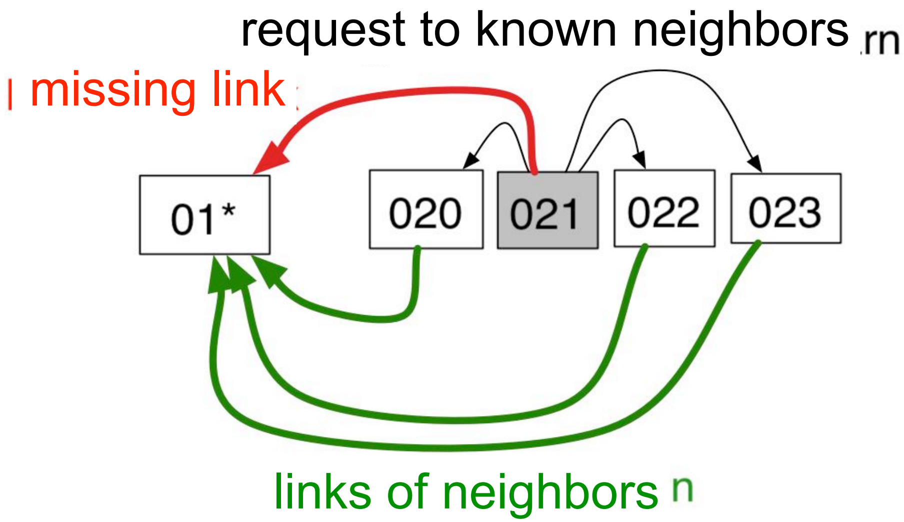
# When the Entry-Operation Errs

- Inheriting the next neighbor routing table does not allows work perfectly
- Example
  - If no peer with 1* exists then all other peers have to point to the new node
  - Inserting 11
  - 03 knows from its routing table
    - 22,33
    - 00,01,02
  - 02 knows from the leaf-set
    - 01,02,20,21
- 11 cannot add all necessary links to the routing tables



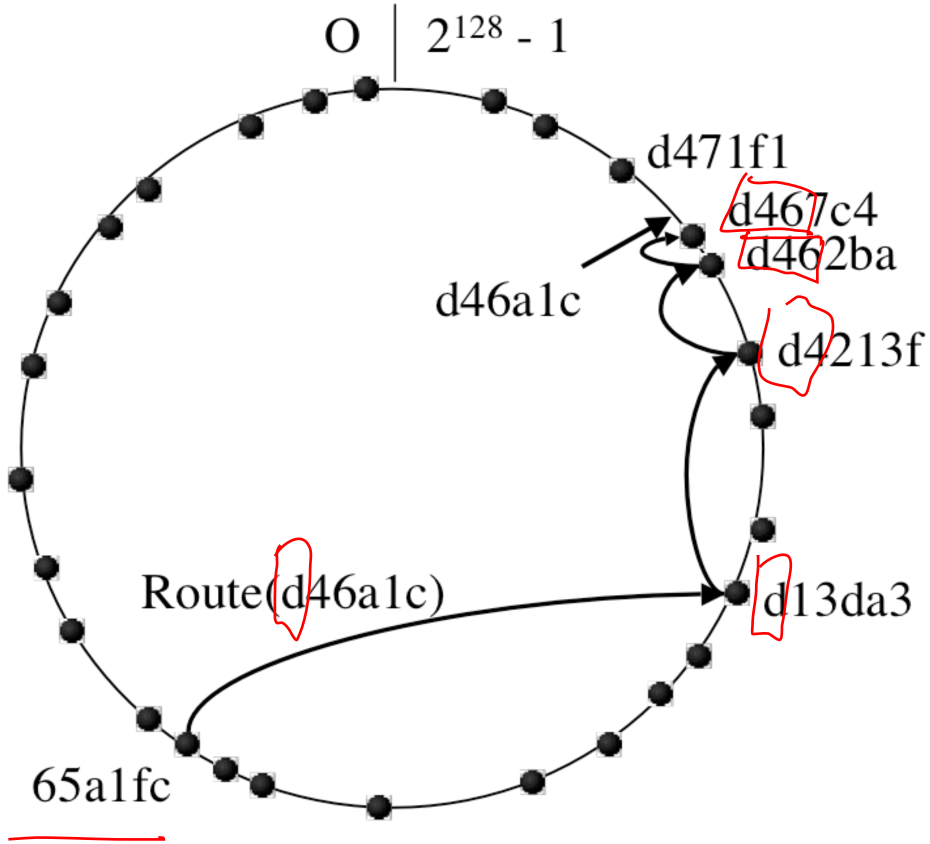
# Missing Entries in the Routing Table

- Assume the entry $R_i^j$ is missing at peer D
  - j-th row and i-th column of the routing table
- This is noticed if a message of a peer with such a prefix is received
- This may also happen if a peer leaves the network
- Contact peers in the same row
  - if they know a peer this address is copied
- If this fails then perform routing to the missing link



# Lookup

- Compute the target ID using the hash function
- If the address is within the $\ell$-leaf set
  - the message is sent directly
  - or it discovers that the target is missing
- Else use the address in the routing table to forward the mesage
- If this fails take best fit from all addresses

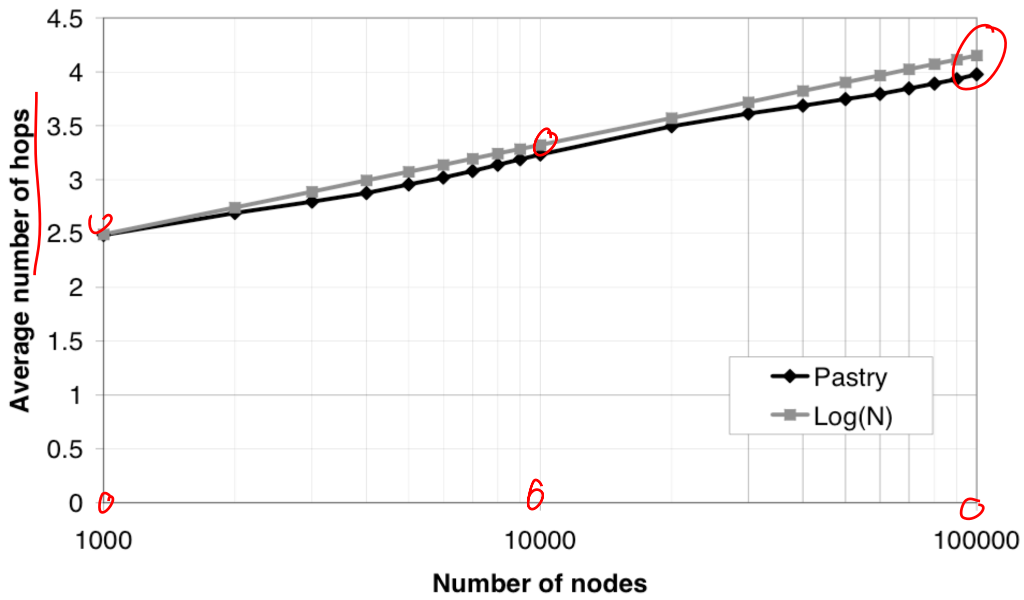


# Routing — Discussion

- If the Routing-Table is correct
  - routing needs O((log n)/b) messages
- As long as the leaf-set is correct
  - routing needs O(n/l) messages
  - unrealistic worst case since even damaged routing tables allow dramatic speedup
- Routing does not use the real distances
  - M is used only if errors in the routing table occur
  - using locality improvements are possible
- Thus, Pastry uses heuristics for improving the lookup time
  - these are applied to the last, most expensive, hops

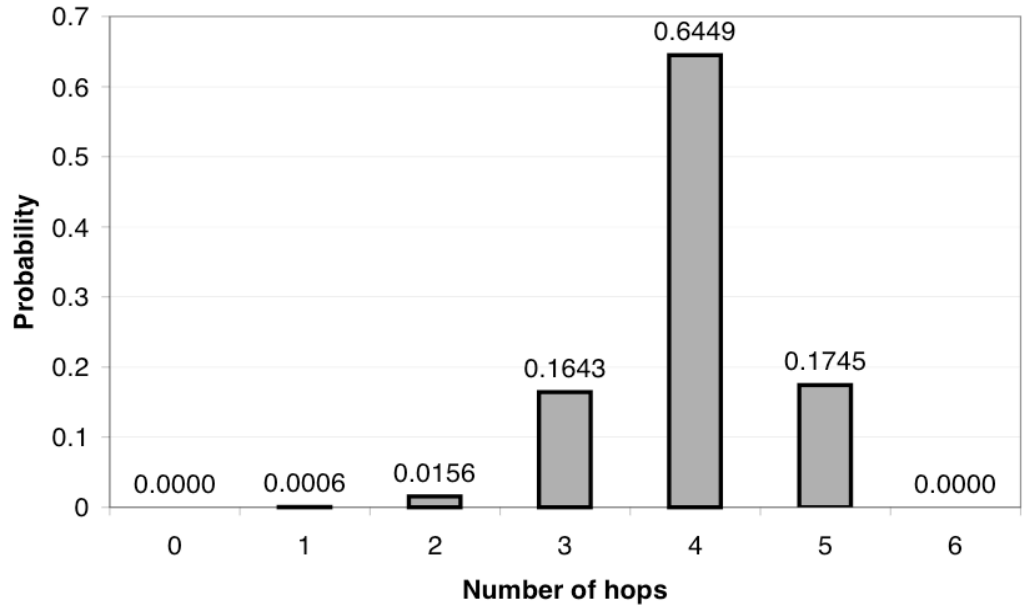
# Experimental Results — Scalability

- Parameter b=4, l=16, M=32
- In this experiment the hop distance grows logarithmically with the number of nodes
- The analysis predicts O(log n)
- Fits well



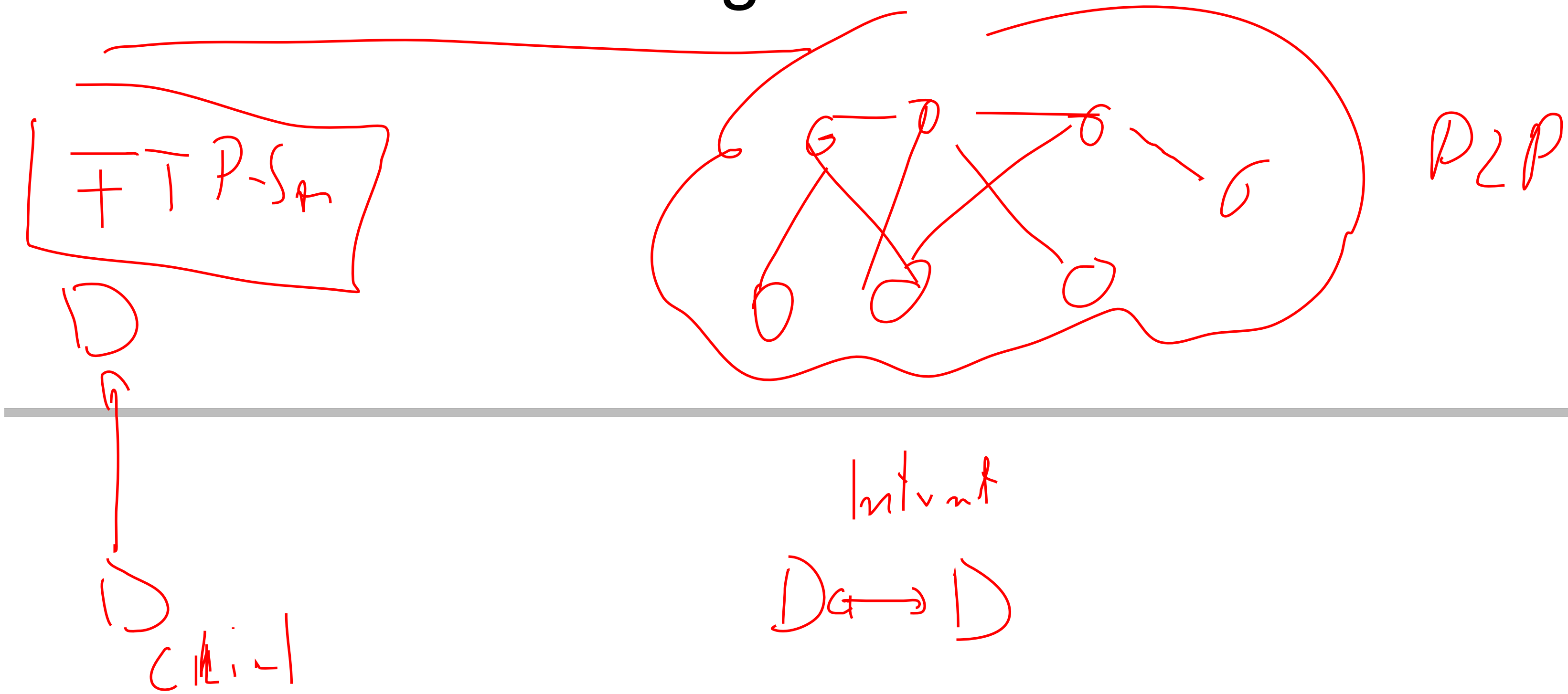
# Experimental Results
# Distribution of Hops

- Parameter b=4, l=16, M=32, n = 100,000
- Result
  - deviation from the expected hop distance is extremely small
- Analysis predicts difference with extremely small probability
  - fits well




# Past by Druschel, Rowstron 2001

- Distributed Storage



# PAST

- PAST: A large-scale, persistent peer-to-peer storage utility
  - by Peter Druschel (Rice University, Houston – now Max-Planck-Institut, Saarbrücken/Kaiserlautern)
  - and Antony Rowstron (Microsoft Research)
- Literature
  - A. Rowstron and P. Druschel, "Storage management and caching in PAST, a large-scale, persistent peer-to-peer storage utility", 18th ACM SOSP'01, 2001.
    - all pictures from this paper
  - P. Druschel and A. Rowstron, "PAST: A large-scale, persistent peer-to-peer storage utility", HotOS VIII,  May 2001.

# Goals of PAST

- Peer-to-Peer based Internet Storage
  - on top of Pastry
- Goals
  - File based storage
  - High availability of data
  - Persistent storage
  - Scalability
  - Efficient usage of resources

# Motivation

- Multiple, diverse nodes in the Internet can be used
  - safety by different locations
- No complicated backup
  - No additional backup devices
  - No mirroring
  - No RAID or SAN systems with special hardware
- Joint use of storage
  - for sharing files
  - for publishing documents
- Overcome local storage and data safety limitations

# Interface of PAST

- Create:
  `fileId = Insert(name, owner-credentials, k, file)`
  - stores a file at a user-specified number k of divers nodes within the PAST network
  - produces a 160 bit ID which identifies the file (via SHA-1)
- Lookup:
  `file = Lookup(fileId)`
  - reliably retrieves a copy of the file identified fileId
- Reclaim:
  `Reclaim(fileId, owner-credentials)`
  - reclaims the storage occupied by the k copies of the file identified by fileId

- Other operations do not exist:
  - No erase
    - to avoid complex agreement protocols
  - No write or rename
    - to avoid write conflicts
  - No group right management
    - to avoid user, group managements
  - No list files, file information, etc.
- Such operations must be provided by additional layer

# Relevant Parts of Pastry

- Leafset:
  - Neighbors on the ring
- Routing Table
  - Nodes for each prefix + 1 other letter
- Neighborhood set
  - set of nodes which have small TTL

**NodeId 10233102**

Leaf set

| SMALLER | | LARGER | |
|---|---|---|---|
| 10233033 | 10233021 | 10233120 | 10233122 |
| 10233001 | 10233000 | 10233230 | 10233232 |

Routing table

| | | | |
|---|---|---|---|
| -0-2212102 | 1 | -2-2301203 | -3-1203203 |
| 0 | 1-1-301233 | 1-2-230203 | 1-3-021022 |
| 10-0-31203 | 10-1-32102 | 2 | 10-3-23302 |
| 102-0-0230 | 102-1-1302 | 102-2-2302 | 3 |
| 1023-0-322 | 1023-1-000 | 1023-2-121 | 3 |
| 10233-0-01 | 1 | 10233-2-32 | |
| 0 | | 102331-2-0 | |
| | | 2 | |

Neighborhood set

| | | | |
|---|---|---|---|
| 13021022 | 10200230 | 11301233 | 31301233 |
| 02212102 | 22301203 | 31203203 | 33213321 |

# Interfaces of Pastry

- route(M, X):
  - route message M to node with nodeId numerically closest to X
- deliver(M):
  - deliver message M to application
- forwarding(M, X):
  - message M is being forwarded towards key X
- newLeaf(L):
  - report change in leaf set L to application

# Insert Request Operation

- Compute fileId by hashing
  - file name
  - public key of client
  - some random numbers, called salt
- Storage (k x filesize)
  - is debited against client‘s quota
- File certificate
  - is produced and signed with owner‘s private key
  - contains fileID, SHA-1 hash of file‘s content, replciation factor k, the random salt, creation date, etc.
- File and certificate are routed via Pastry
  - to node responsible for fileID
- When it arrives in one node of the k nodes close to the fileId
  - the node checks the validityof the file
  - it is duplicated to all other k-1 nodes numerically close to fileId
- When all k nodes have accepted a copy
  - Each nodes sends store receipt is send to the owner
- If something goes wrong an error message is sent back
  - and nothing stored

# Lookup

- Client sends message with requested fileId into the Pastry network
- The first node storing the file answers
  - no further routing
- The node sends back the file
- Locality property of Pastry helps to send a close-by copy of a file

# Reclaim

- Client‘s nodes sends reclaim certificate
  - allowing the storing nodes to check that the claim is authentificated
- Each node sends a reclaim receipt
- The client sends this recept to the retrieve the storage from the quota management

# Security

- Smartcard
  - for PAST users which want to store files
  - generates and verifies all certificates
  - maintain the storage quotas
  - ensure the integrity of nodeID and fileID assignment
- Users/nodes without smartcard
  - can read and serve as storage servers
- Randomized routing
  - prevents intersection of messages
- Malicious nodes only have local influence

# Storage Management

- Goals
  - Utilization of all storage
  - Storage balancing
  - Providing k file replicas
- Methods
  - Replica diversion
    - exception to storing replicas nodes in the leafset
  - File diversion
    - if the local nodes are full all replicas are stored at different locations

# Summary

- PAST provides a distributed storage system
  - which allows full storage usage and locality features
- Storage management
  - based ond Smartcard system
    - provides a hardware restriction
  - utilization moderately increases failure rates and time behavior

# Distributed Systems

## 7: Peer-to-Peer-Networks

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