Peer-to-Peer Systems and Applications

Lecture 10: Selected Topics II

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0. Lecture Overview

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   3. Routing Table Construction
   4. Peer Selection Policy
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1. Kademlia

Routing Concept, Protocol, Routing Table Construction,
Peer Selection Policy, Enhancements

1.0 Kademlia

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- Use α parallel iterative lookup to locate data
  - Retrieve data faster
  - Overcome faulty nodes
  - Usually α = 3
- DHT-based overlay network using the XOR distance metric
  - Simple operation
  - Symmetrical routing paths (A → B == B → A)
    - due to $d_{XOR}(A,B) == d_{XOR}(B,A)$
- Store data with key X on k nodes closest to X according to XOR metric
  - “build in” replication ensuring data availability
  - Usually k = 20
- Use lookup messages to maintain the overlay network
  - Learn useful routing information from received lookup requests

XOR Distance Calculation:

ID Node A: 110101
ID Node B: 010001

$d_{XOR}(A,B) = d(110101,010001)$

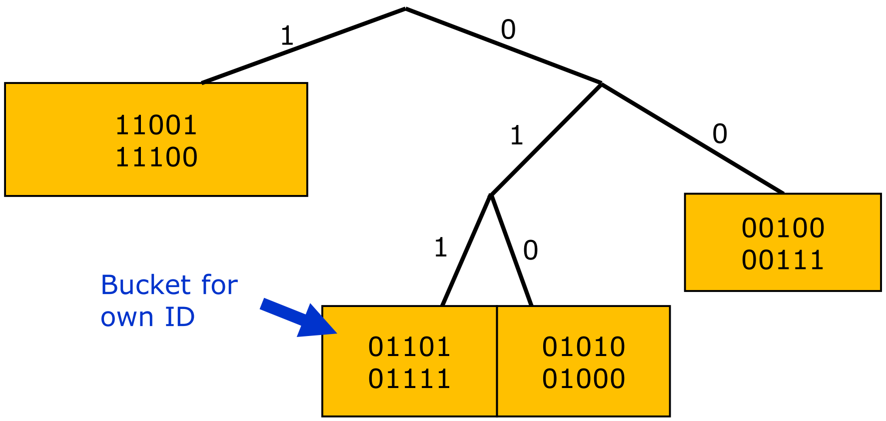
1 1 0 1 0 1
XOR
0 1 0 0 0 1
↓
1 0 0 1 0 0

$d_{XOR}(A,B) = 100100_2 = 36_{10}$

1.1. Concept of the Kademlia Routing Process

- Structure of routing table
  - Every node maintains a binary tree like routing table
  - Tree branches along the local node ID
  - Every leave is a bucket with k entries

Example routing table for node 01110 with bucket factor k = 2



Lookup procedure for a key X

Step 1: Traverse routing table tree and pick bucket with node IDs closest to key X

Step 2: Put node IDs in a node list

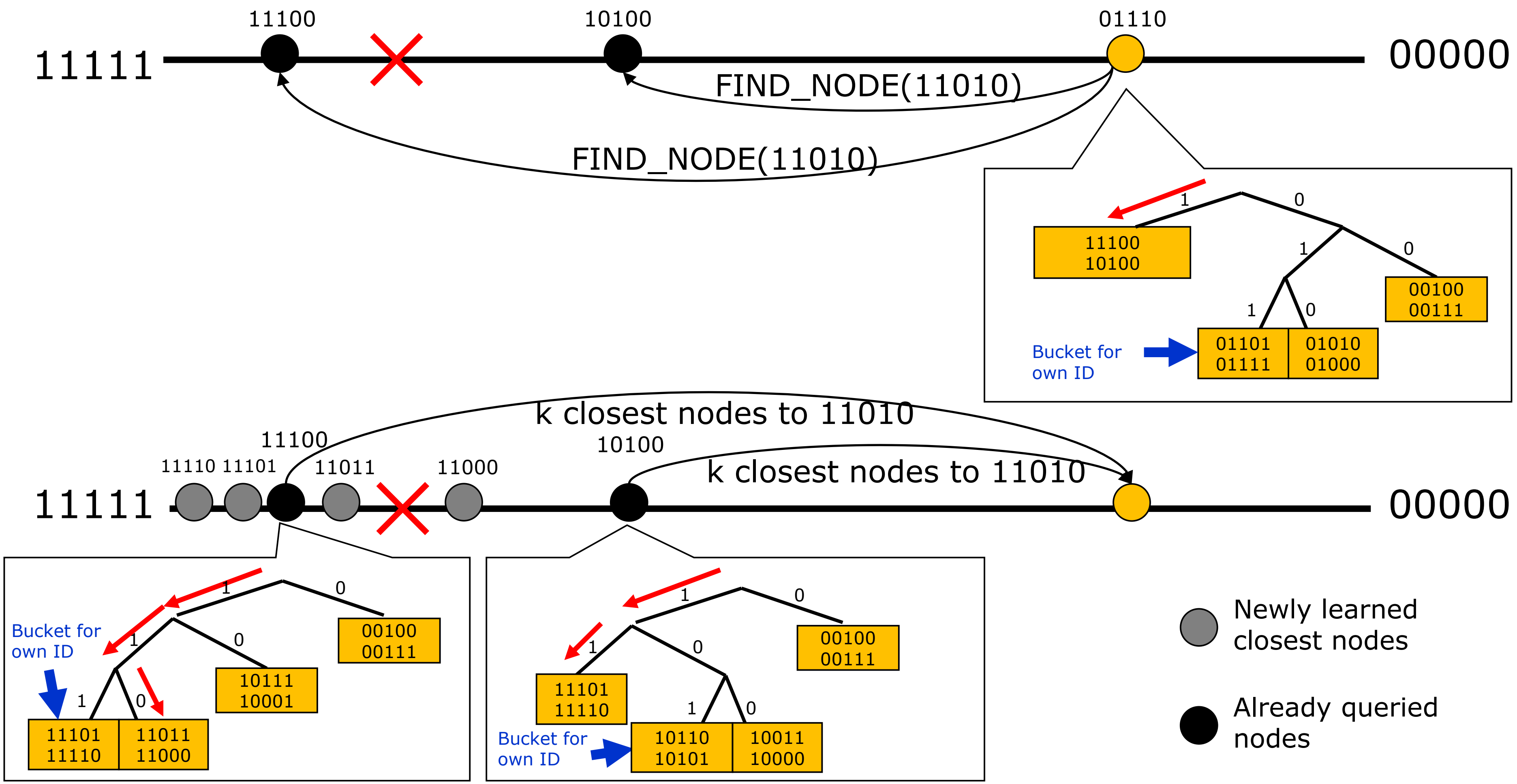
Step 3: Send a closest nodes request to nodes in the list closest to X

Step 4: Put received node IDs in node list

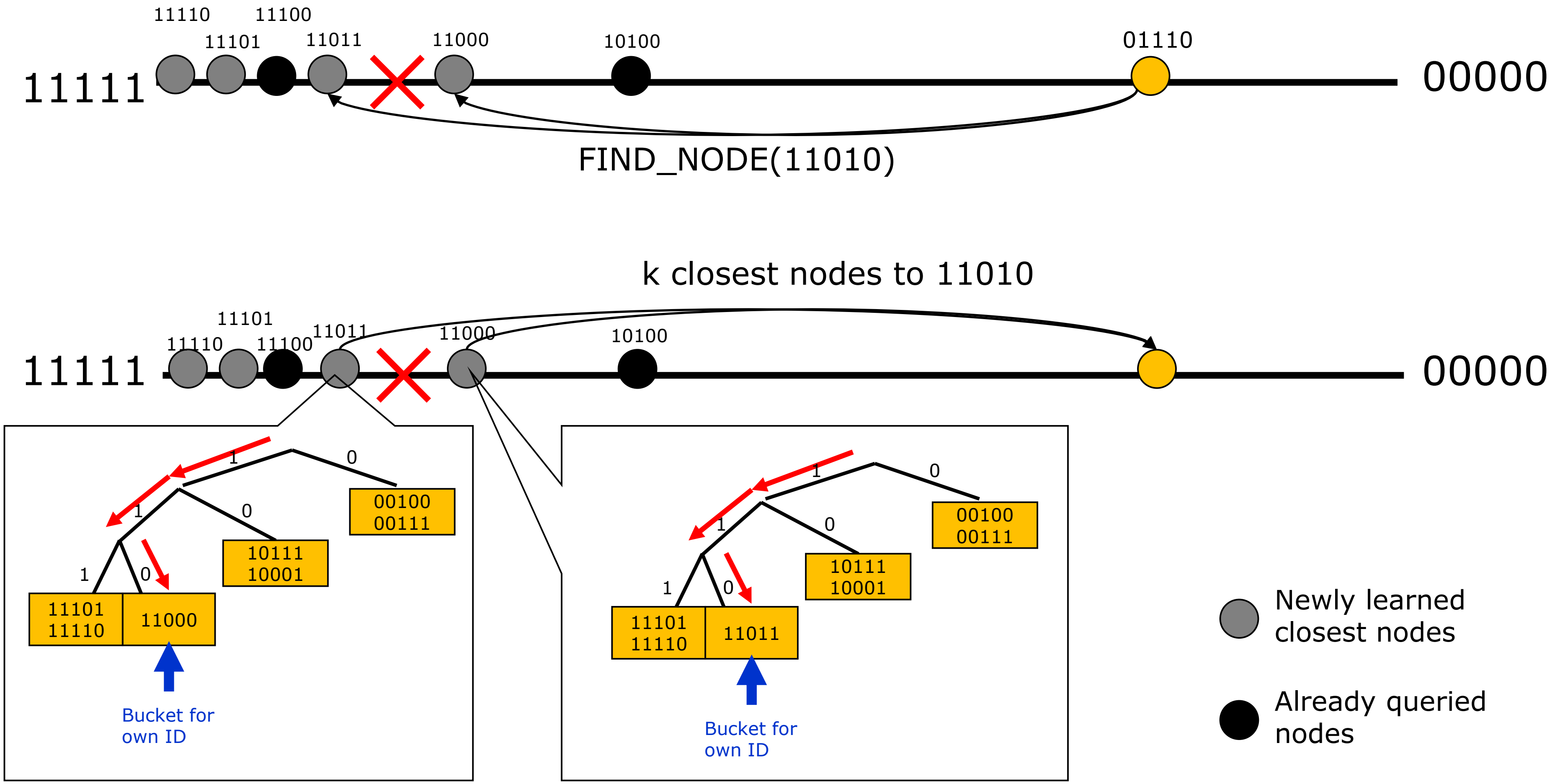
Step 5: Repeat until Step 3 and 4 until set of k closest node to not change anymore

Step 6: Pick k-closest nodes from node list and send store or get data request to them

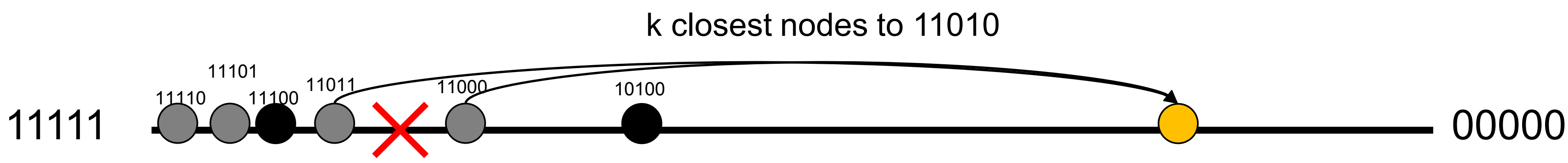
1.1. Routing from 01110 to 11010, α = 2, k = 2



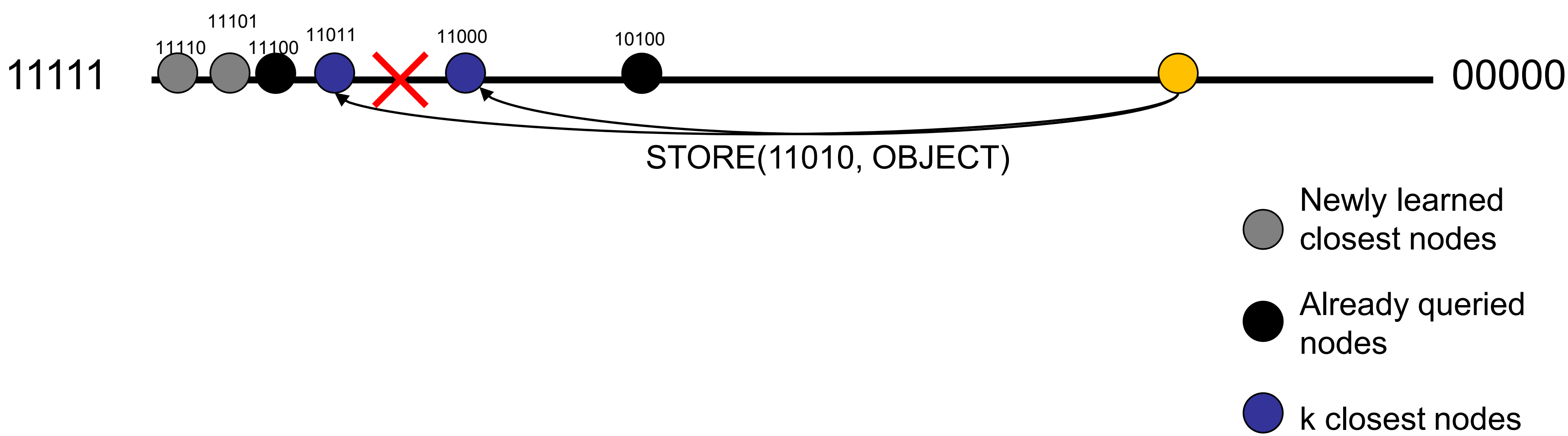
1.1. Routing from 01110 to 11010, α = 2, k = 2



1.1. Routing from 01110 to 11010, α = 2, k = 2



No new nodes discovered → stop lookup process



1.2. Kademlia Protocol

- The Kademlia protocol consists of 4 RPCs:
  - FIND_NODE(KEY):
    - Recipient returns <IP Address, UDP Port, Node ID> triples for k closest nodes he knows about
  - FIND_VALUE(KEY):
    - Like FIND_NODE
    - With exception:
      - If recipient already stores the value, the value is returned instead of k closest nodes
  - PING(IP ADDRESS)
    - Probes a node to see if it is online
  - STORE(KEY, VALUE)
    - Instructs a node to store a <key,value> pair

1.3. Construction of Routing Table

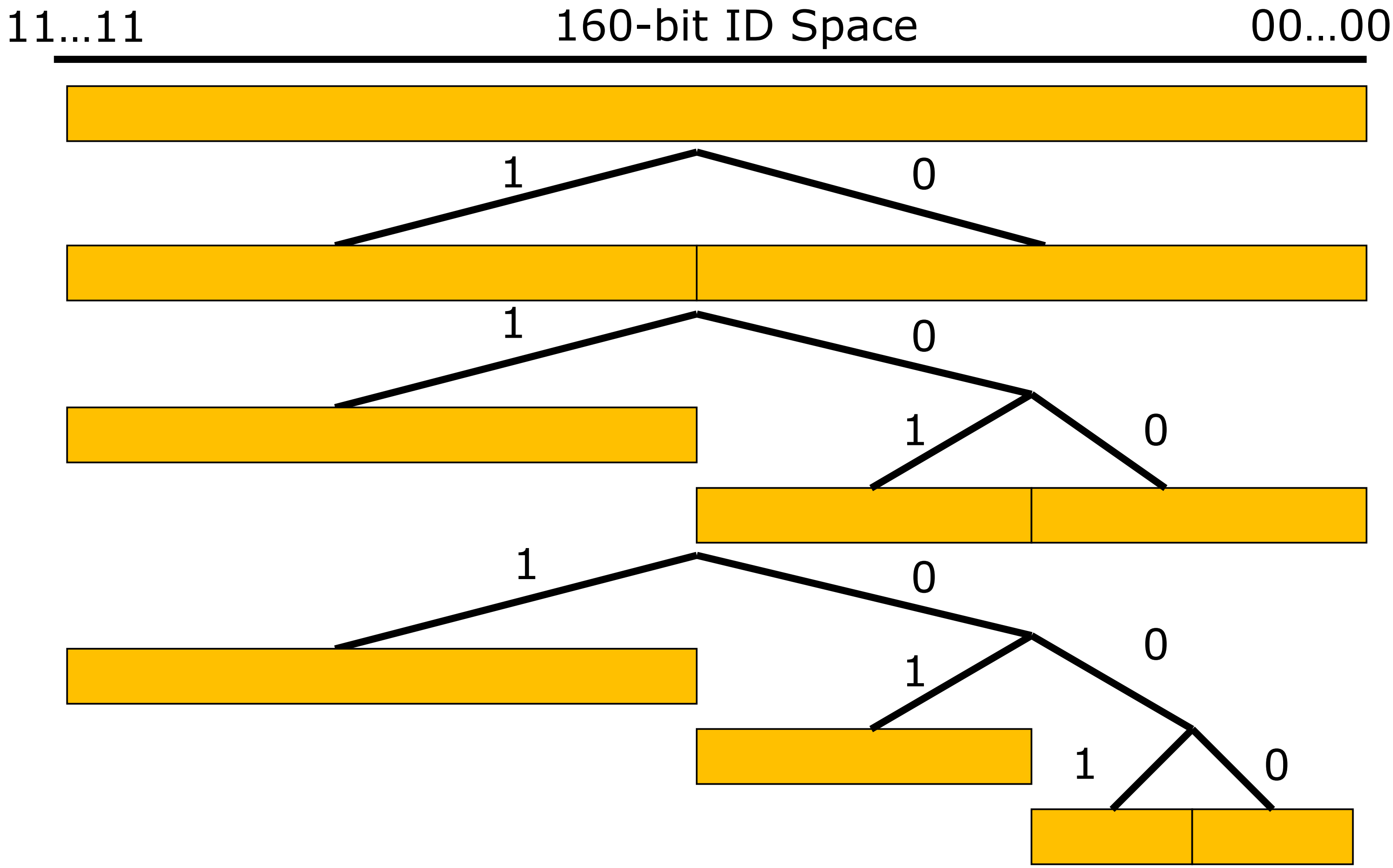
- Each node maintains routing table (k buckets)
  - Routing tables of different peers may be different

- For each 0 <= i < 160 every node
  - keeps a list of <IP Address, UDP Port, Node ID> triples
  - for k nodes within range [2 ^i ; 2 ^(i+1)[
  - in total k * 160 contacts

- Nodes learn from
  - messages they receive or
  - using the FIND_NODE method

- Preference towards old contacts
  - Study has shown that the longer a node has been up,
    the more likely it is to remain up another hour
  - Resistance against DoS attacks by flooding the network with new nodes

1.3. Evolution of the k Buckets



1.3. Example for Node ID 01110, k=2

11111 5-bit ID Space 00000

New node 11001:

11001

New node 01101:

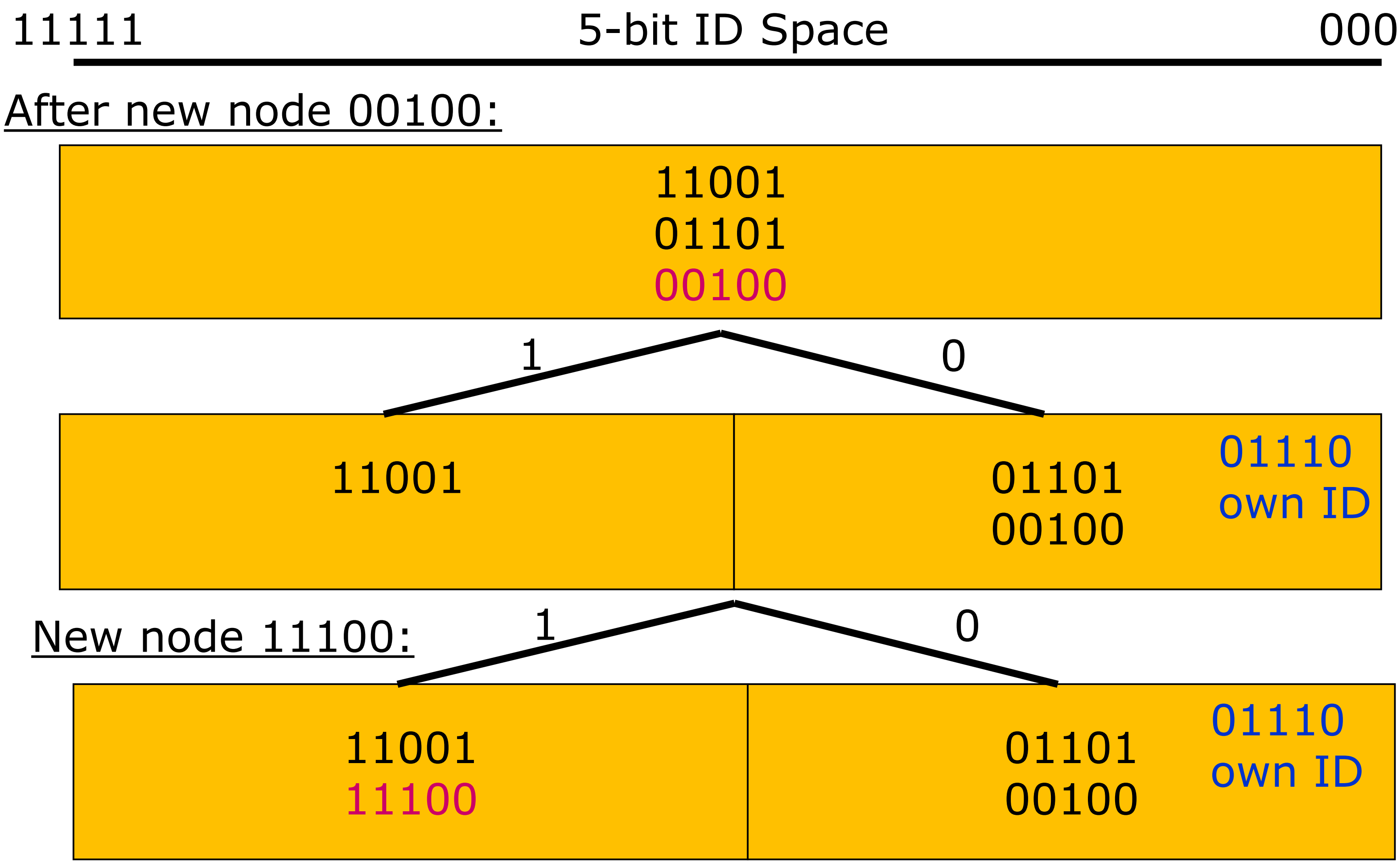
11001
01101

New node 00100:

11001
01101
00100 but … no because 3rd, and k=2 is max.

k bucket is full → split necessary

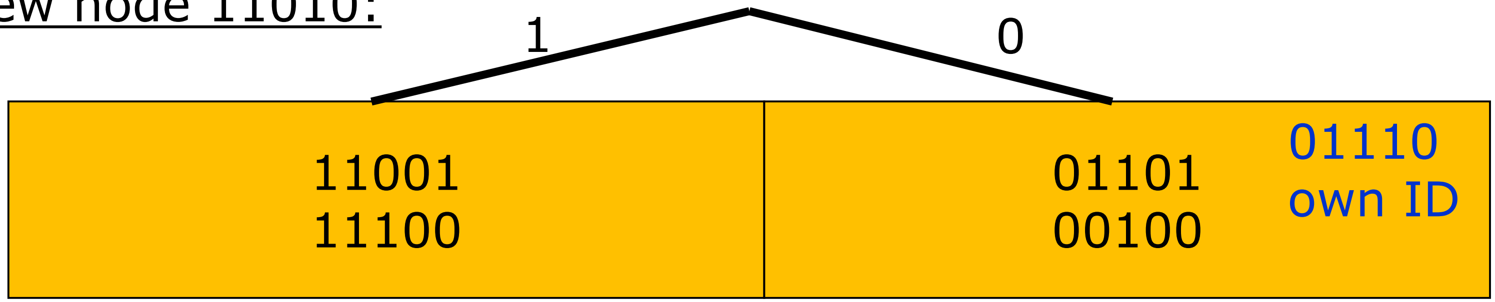
1.3. Example for Node ID 01110, k=2



1.3. Example for Node ID 01110, k=2

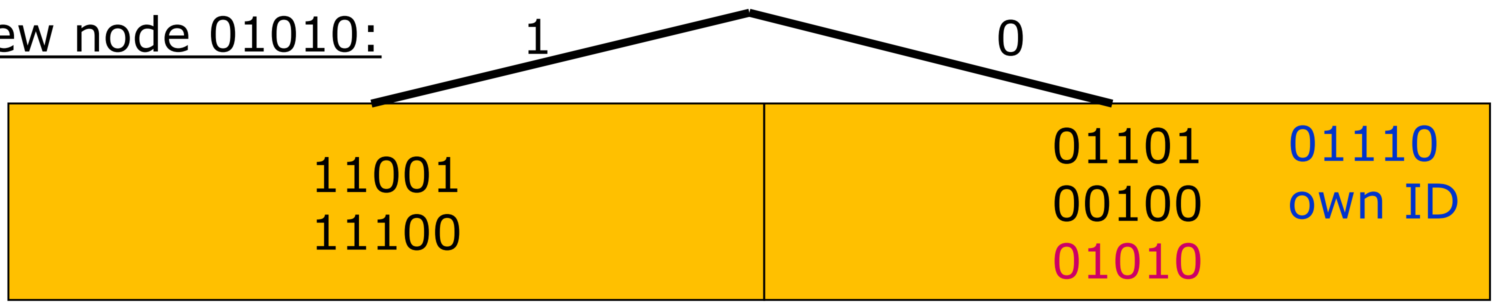
11111 5-bit ID Space 00000

New node 11010:



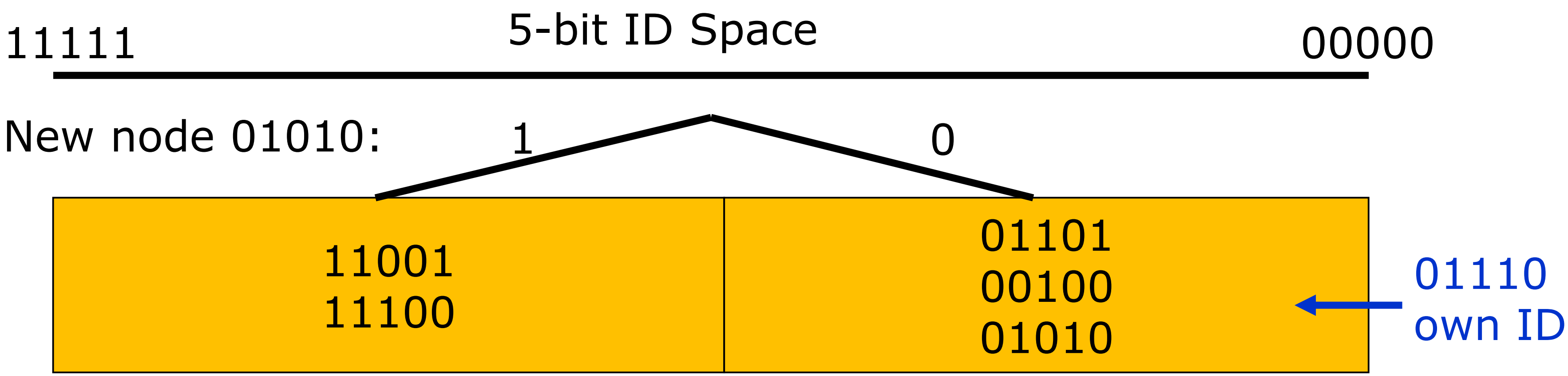
Left k bucket full and 11010 NOT in k-bucket-range of 01110 → node is dropped

New node 01010:

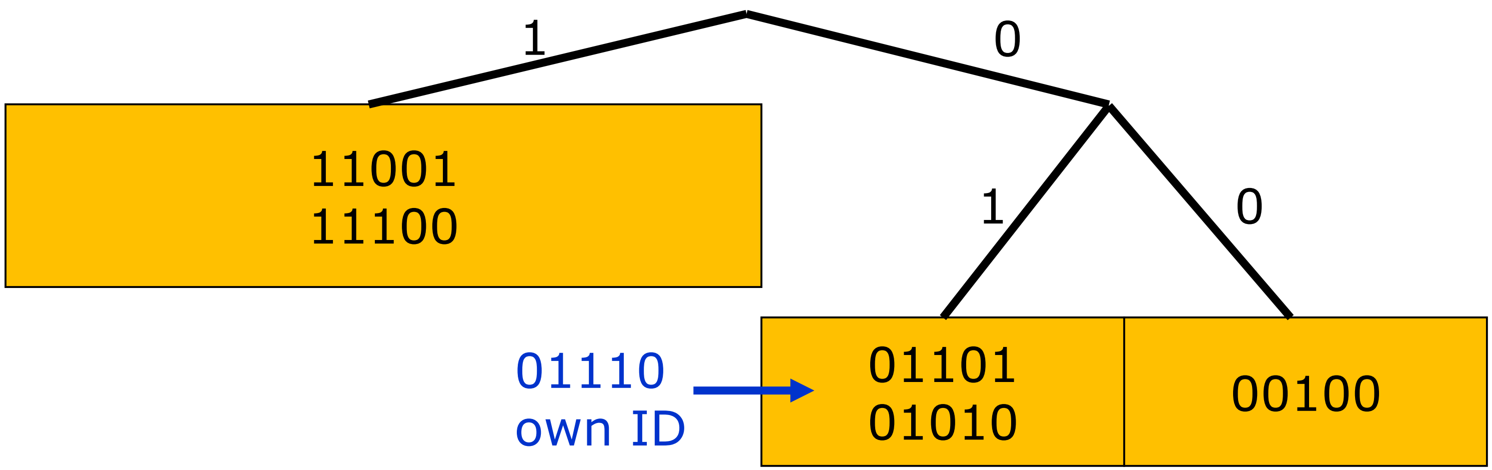


Right k bucket full and 01010 in k-bucket-range of 01110 → split necessary

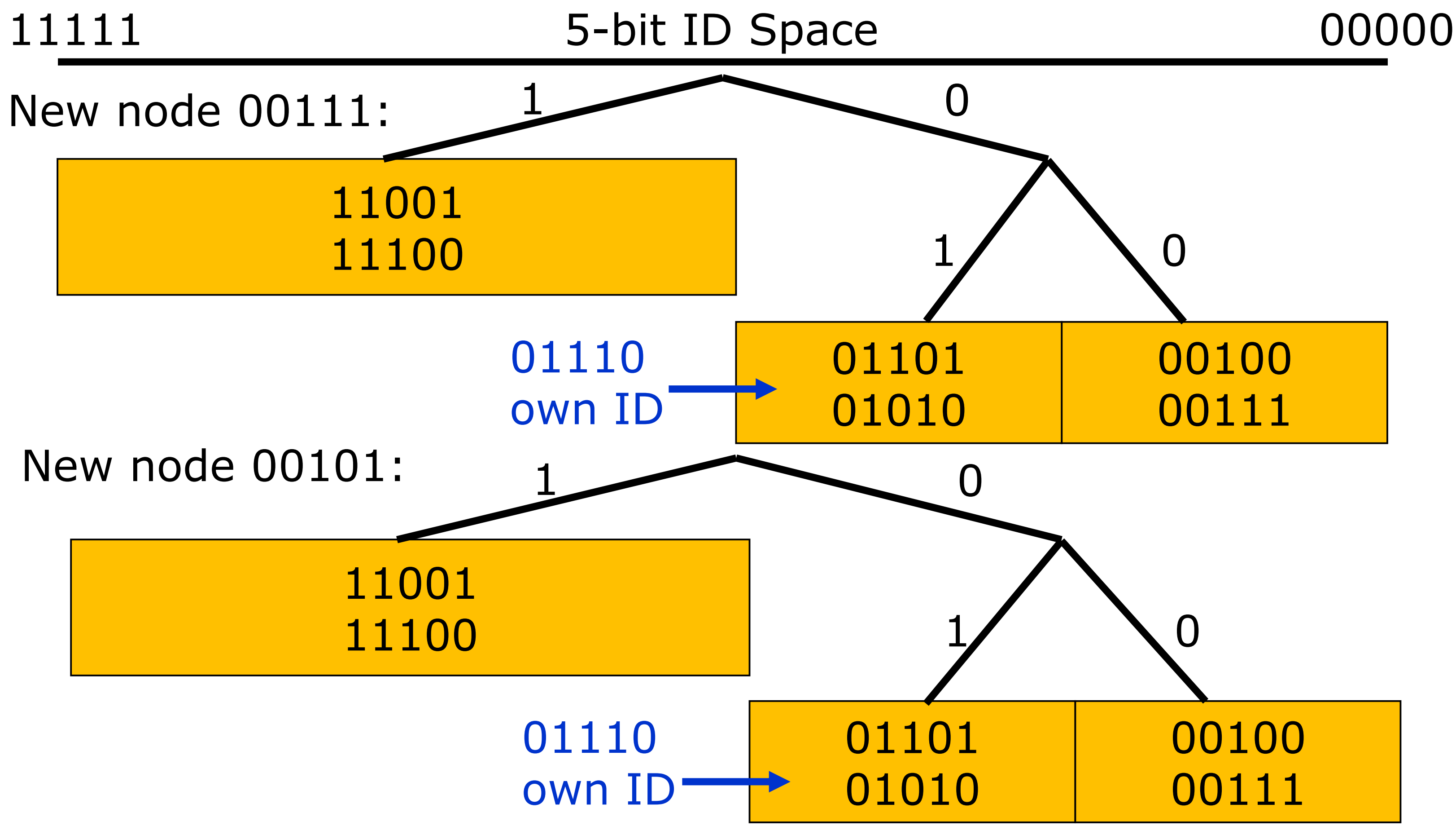
1.3. Example for Node ID 01110, k=2



Right K bucket full and 01010 in k-bucket-range of 00110 → split necessary



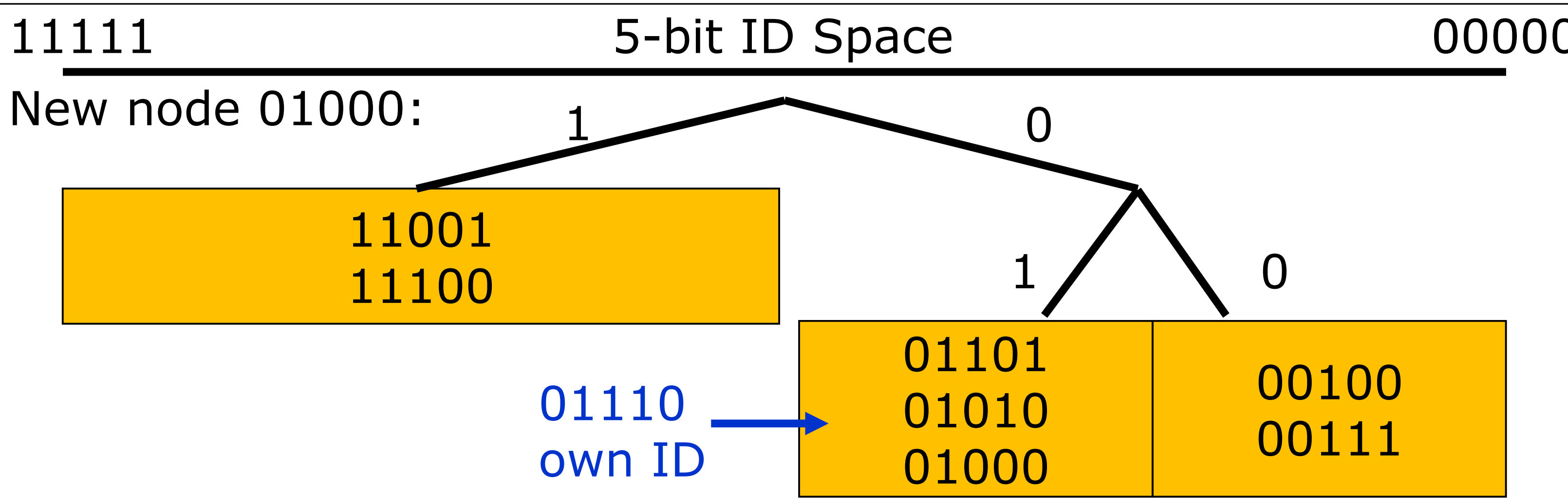
1.3. Example for Node ID 01110, k=2



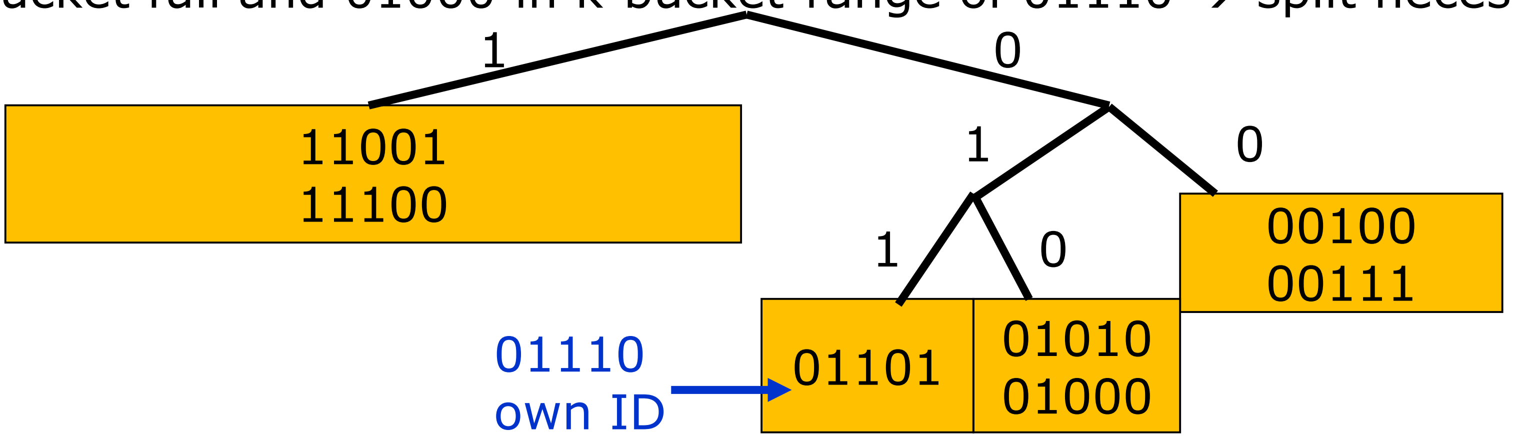
Left K bucket full and 00101 NOT in k-bucket-range of 01110 → node is dropped

1.3. Example for Node ID 01110, k=2

New node 01000:



K bucket full and 01000 in k-bucket-range of 01110 → split necessary



1.4. k Buckets: Peer Selection Policy

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- If node u receives a message from node v then it adds node v to its k-bucket according to the following rules:

  - IF v is already in a k-bucket
    THEN move v to the tail of the bucket

  - IF v is not in the k-bucket and the bucket has fewer than k entries
    THEN insert recipient to the tail of list

  - IF the appropriate k bucket is full AND least recently seen node is alive
    THEN move least recently seen node to tail of bucket and discard node v

  - IF the appropriate k bucket is full AND least recently seen node is <u>not</u> alive
    THEN remove least recently seen node from bucket and add node v at the tail

- Note: approx. k = 20 in the real world

1.5. Kademlia: Enhancements

- Parallel queries
  - For one query, α (alpha) concurrent lookups are sent
  - More traffic load, but lower response times

- Network maintenance
  - In Chord: active fixing of fingers
  - In Kademlia: learning for bypassing queries
  - Check if peer IDs fit better in routing table

- Large routing tables
  - In Chord: 1 finger per distance 2^i to 2^(i+1)
  - In Kademlia: k contacts per distance 2^i to 2^(i+1)
  - Increased robustness

2. Network Coding

Motivation, Theory, Example, Application

2.1. Network Coding Motivation

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- P2P problem area: distribute large data packets to many clients
  - Solution 1: exchange piece/chunk bitmap
    - Request contains the pieces we are looking for, recipient replies with piece or that pieces are not here
    - Peer may also collect piece/chunk bitmaps first
  - Solution 2: use network coding
    - Simple request, when there is nothing new, don't request.

- Random network coding: send linear combination of all received chunks

→ no need to exchange piece/chunk information

2.2. Network Coding Theory

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- `M1, …, Mn` → original packets / `g1, …, gn` → random coefficients

- Encoding: $X = \sum_{i=1}^{n} g_i M^i$
  - Encoding vector `g`, information vector `X`
  - Send `X,g`

- Re-encoding, `h1, …, hm` → random coefficients:

$$X' = \sum_{j=1}^{m} h_j X^j$$

$$g_i' = \sum_{j=1}^{m} h_j g_i^j$$

  - Encoding vector `h` → `g'`
  - Information vector `X'`
  - Send `X',g'`

2.3. Network Coding Example

- Peer 1 chooses coefficients (encoding vector), calculates linear combination, sends two to Peer 2 and one to Peer 3

Coefficient (randomly chosen or try not to be linear dependant)

Peer 1

Peer 1	M1=17	1,3,2
	M2=8	2,1,3
	M3=9	2,3,1

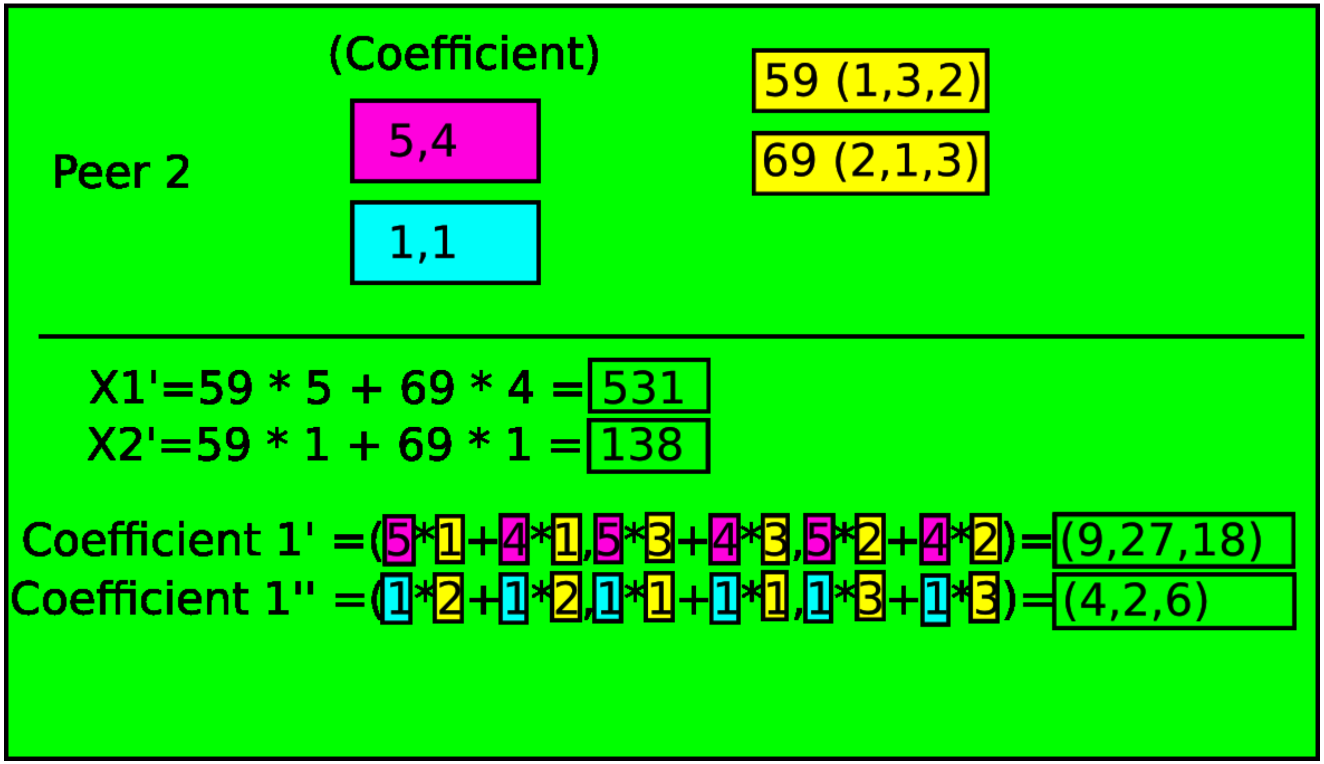
X1= 1 * 17 + 3 * 8 + 2 * 9 = 59 (1,3,2)

X2= 2 * 17 + 1 * 8 + 3 * 9 = 69 (2,1,3)

X3= 2 * 17 + 3 * 8 + 1 * 9 = 67 (2,3,1)

2.3. Network Coding Example

- Peer 2 also has random coefficients, gets two linear comb. from Peer 1, creates new linear comb. (adapt coeff.), send to Peer 3



2.3. Network Coding Example

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- Peer 3 gets all 3 linear comb. with coding vector, does Gauss elimination (linear system with 3 equations & 3 unknowns) [1]

Peer 3

67 (2,3,1)
531 (9,27,18)
138 (4,2,6)

$$
\begin{aligned}
9M1 + 27M2 + 18M3 &= 531\\
4M1 + 2M2 + 6M3 &= 138\\
2M1 + 3M2 + 1M3 &= 67\\
\hline
0M1 - 10M2 - 2M3 &= -98\\
0M1 - 3M2 - 3M3 &= -51\\
\hline
0M1 + 0M2 + 1M3 &= 9
\end{aligned}
$$

M1=17

M2=8

M3=9

[1] http://www.gregthatcher.com/Mathematics/GaussJordan.aspx

2.3. Network Coding Example

- Peer 3 gets other linear comb. with coding vector, does Gauss elimination (linear system with 3 equations & 3 unknowns) [1]

X1 = 1 * 17 + 3 * 8 + 4 * 9 = 77 (1,3,4)

Peer 3

531 (9,27,18)

138 (4,2,6)

$$
\begin{aligned}
9M1 + 27M2 + 18M3 &= 531 \\
4M1 + 2M2 + 6M3 &= 138 \\
1M1 + 3M2 + 4M3 &= 77 \\
\hline
0M1 - 10M2 - 2M3 &= -98 \\
0M1 - 0M2 - 2M3 &= 18 \\
\hline
0M1 + 0M2 + 1M3 &= 9
\end{aligned}
$$

M1=17

M2=8

M3=9

[1] http://www.gregthatcher.com/Mathematics/GaussJordan.aspx

2.4. Network Coding Application

- Send packets as long as linear independant
  - No exchange of bitmap
- Random coefficients: low probability of collision
- Overhead of transmitting the encoding vectors is small, size of block is Kbytes
  - CPU overhead $O(n^3)$, (n = number of blocks)
- Avalanche: File Swarming with Network Coding [1]
  - Network Coding improves robustness and throughput

[1] http://research.microsoft.com/en-us/projects/avalanche/

3. WebRTC

Introduction, Architecture, Example, Outlook

3.1. WebRTC – Introduction (1)

- WebRTC for browser to browser communication
  - P2P, no server involved (~mostly)
- Google bought in 2010 GIPS and open sourced WebRTC
- Protocol standardized by IETF (codec requirements, media protocol), JavaScript API by W3C
- Supported by Chrome, Firefox (and others)
- Compatibility [1]
  - WebRTC support since Chrome 26+, Firefox 23+
  - SCTP: supported by Firefox, Chrome 31+
  - Binary data: supported by Firefox, Chrome 31+

[1] http://peerjs.com/status

3.1. WebRTC – Introduction (2)

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- Filling gap in the Web-Experience

  - Video Chat → Google Hangouts Plugin, Flash, Java
  - Multimedia / Confernces → Expensive, proprietary 3rd party apps
  - Customer Service → Chat only, 3rd party plugins/apps
  - Online Games → Flash
  - Real-time Feeds → Proprietary software
  - File Sharing → Requires Server / BitTorrent

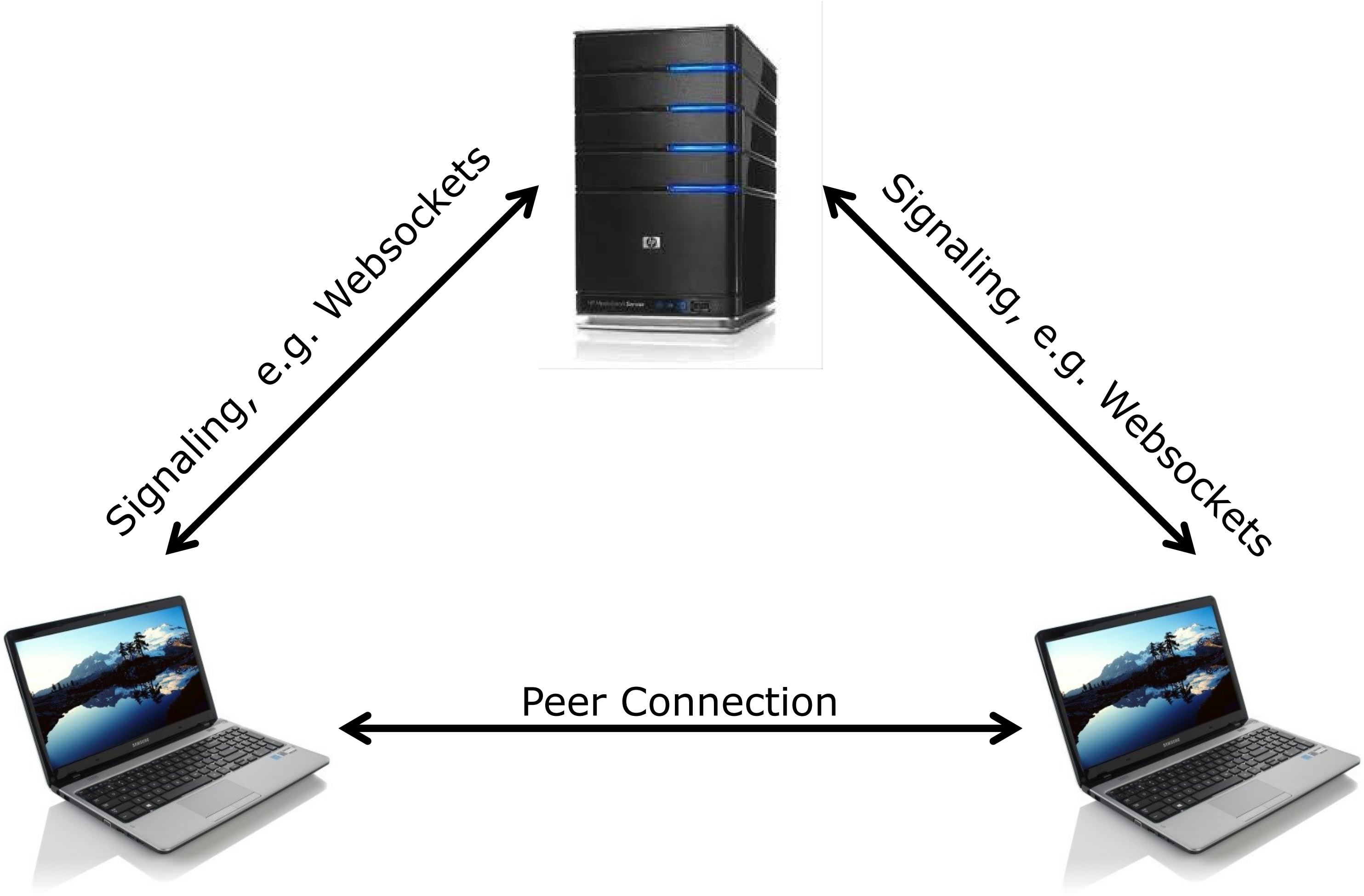
- WebRTC widely deployed, no client necessary!

3.1. WebRTC – Introduction (2)

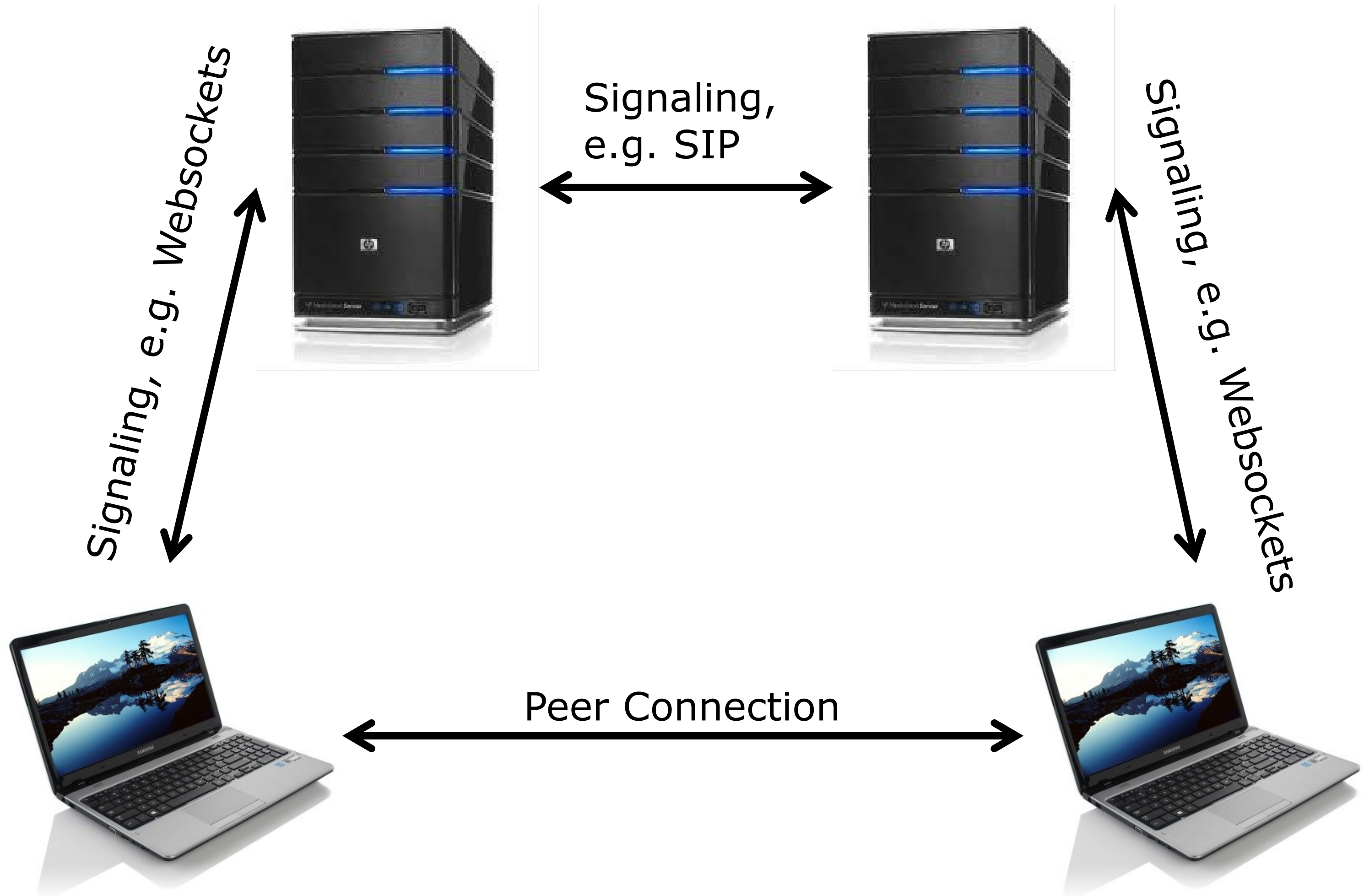
- Developer does not need to care about NAT
  - Abstraction, using STUN, ICE, TURN
  - STUN: session traversal utilities for NAT (detect which kind of NAT)
  - TURN: traversal using relays around NAT (relay)
  - ICE: interactive connectivity establishment , uses STUN and TURN
  - UPnP / NAT-PMP setup by the browser optional? [1]
    - Bugzilla@Mozilla – Bug 860045 [2]
- Once connection is established – easy API
  - `sendChannel.send("hallo")`
  - `sendChannel.onmessage = function …`
- Mandatory AES encryption
  - SRTP for Media, DTLS for Data, HTTPS for Signalling

[1] http://tools.ietf.org/html/draft-kaplan-rtcweb-api-reqs-00
[2] https://bugzilla.mozilla.org/show_bug.cgi?id=860045

3.2. WebRTC Architecture - Triangle



3.2. WebRTC Architecture - Trapezoid



3.3. WebRTC Architecture - Example

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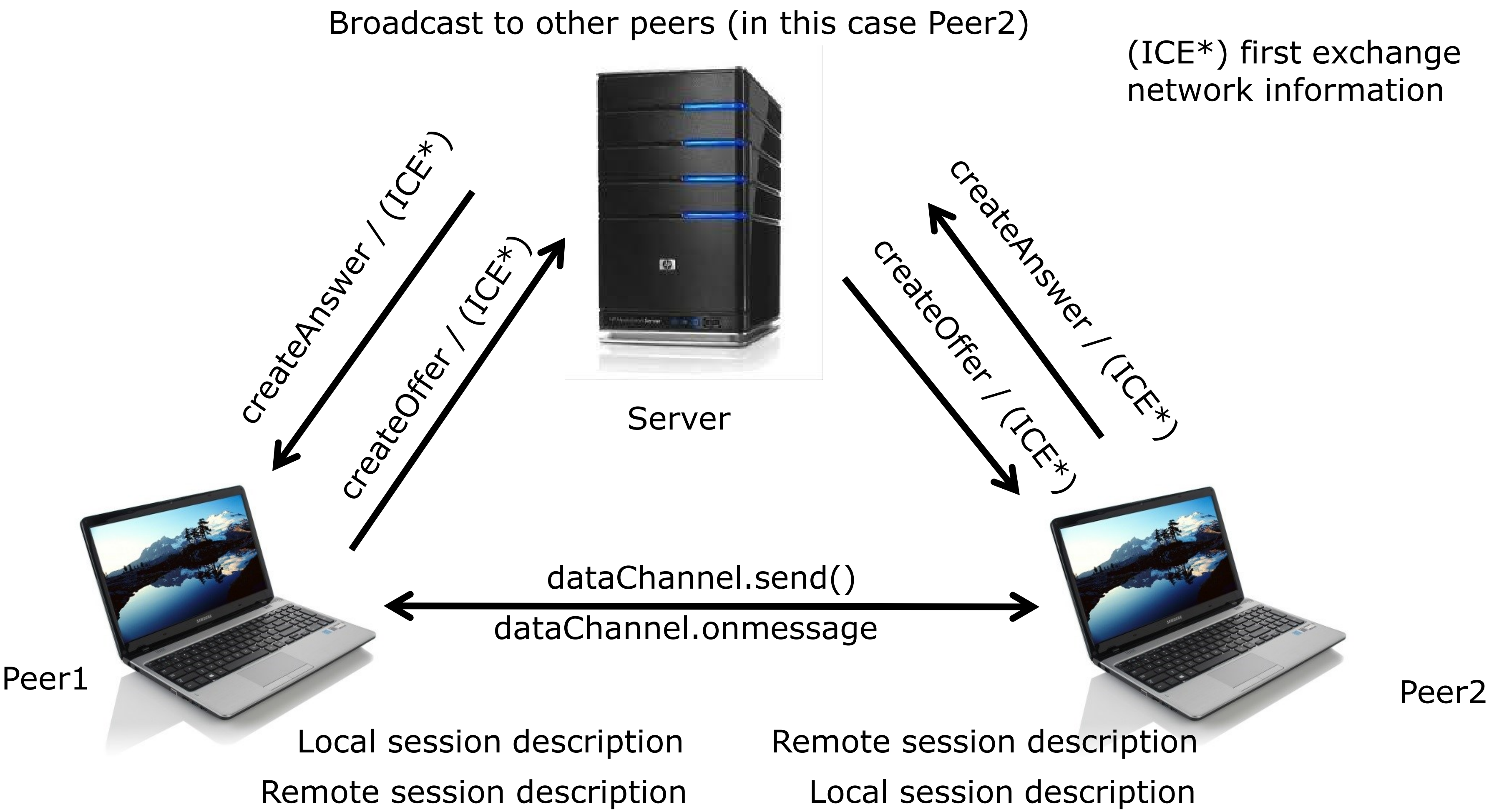


3.4. WebRTC - Outlook

- Examples:
  - WebRTC Plugin-free Screen Sharing [1], RTCPeerConnection Simple Demo [2]
- Strong focus on VoIP
  - Skype competitor?
  - Microsoft / IE and WebRTC?
  - SDP / signaling overhead if using with raw P2P data
- Fewer plugins (flash, java), fewer registrations
- Mandatory Codecs? [3]
  - Video codec in JavaScript [4]
- Web-based P2P frameworks
  - http://peerjs.com - make the API simpler
- New types of applications – Conferencing, gaming, P2P file sharing
  - PeerCDN [5], serve static content from browsers of other visitors

[1] https://www.webrtc-experiment.com/Pluginfree-Screen-Sharing/#CA134CZY-1FQD7VI
[2] https://www.webrtc-experiment.com/demos/client-side.html

[3] http://gigaom.com/2013/10/30/google-sticks-with-vp8-opposes-ciscos-push-for-h-264/
[4] https://brendaneich.com/2013/05/today-i-saw-the-future/

[5] http://peercdn.com/

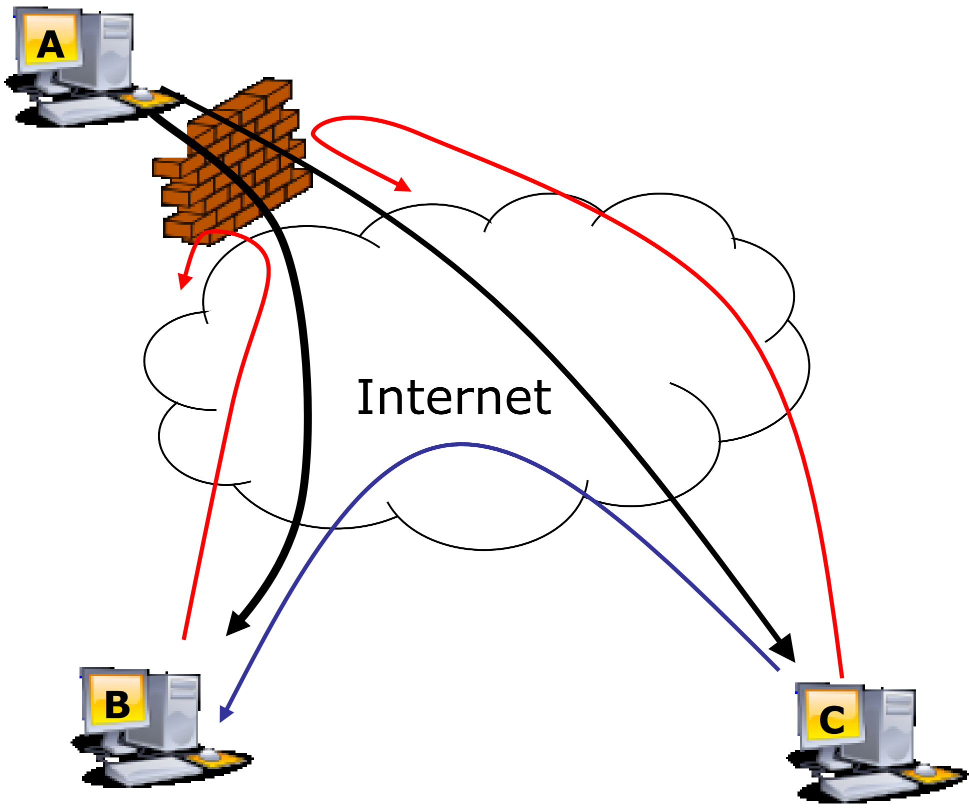
4. NAT Traversal

Background, Relaying, Hole Punching

4.0. NAT Traversal

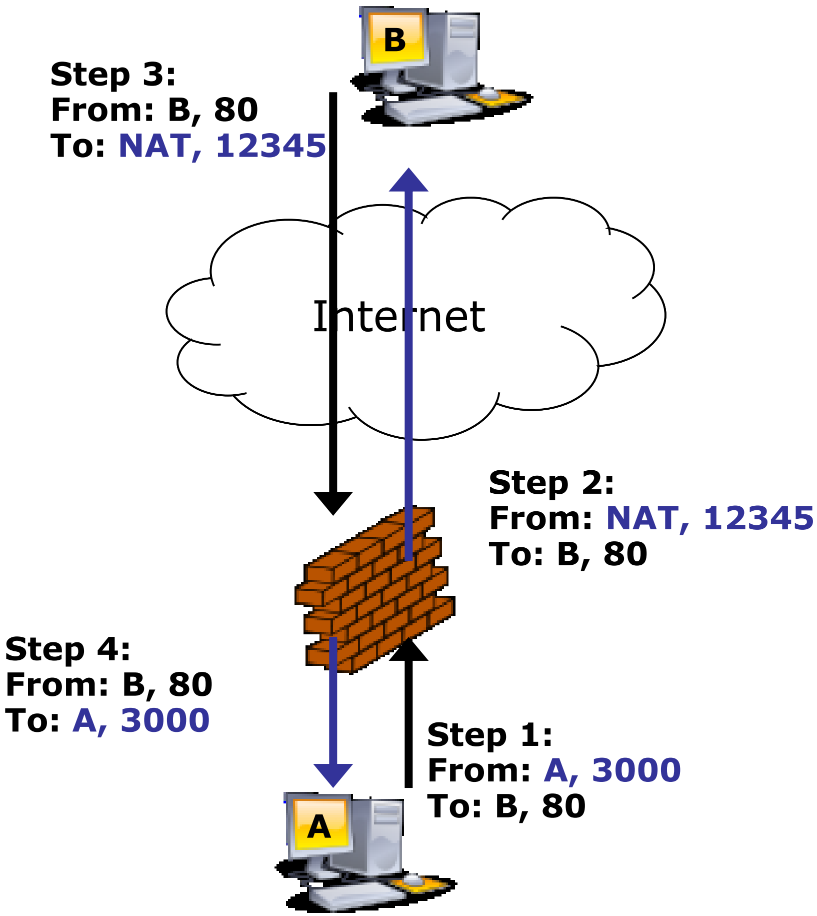
- Nodes must be able to contact each other
- Does not work for peers hidden behind NAT boxes and firewalls
  - Peers cannot be contacted arbitrary
- In real systems often 60-80% of peers are hidden
  - Less available resources
  - Smaller user base

→ P2P applications have to deal with NAT issues, but often this is done only later, as low priority, cf. Skype



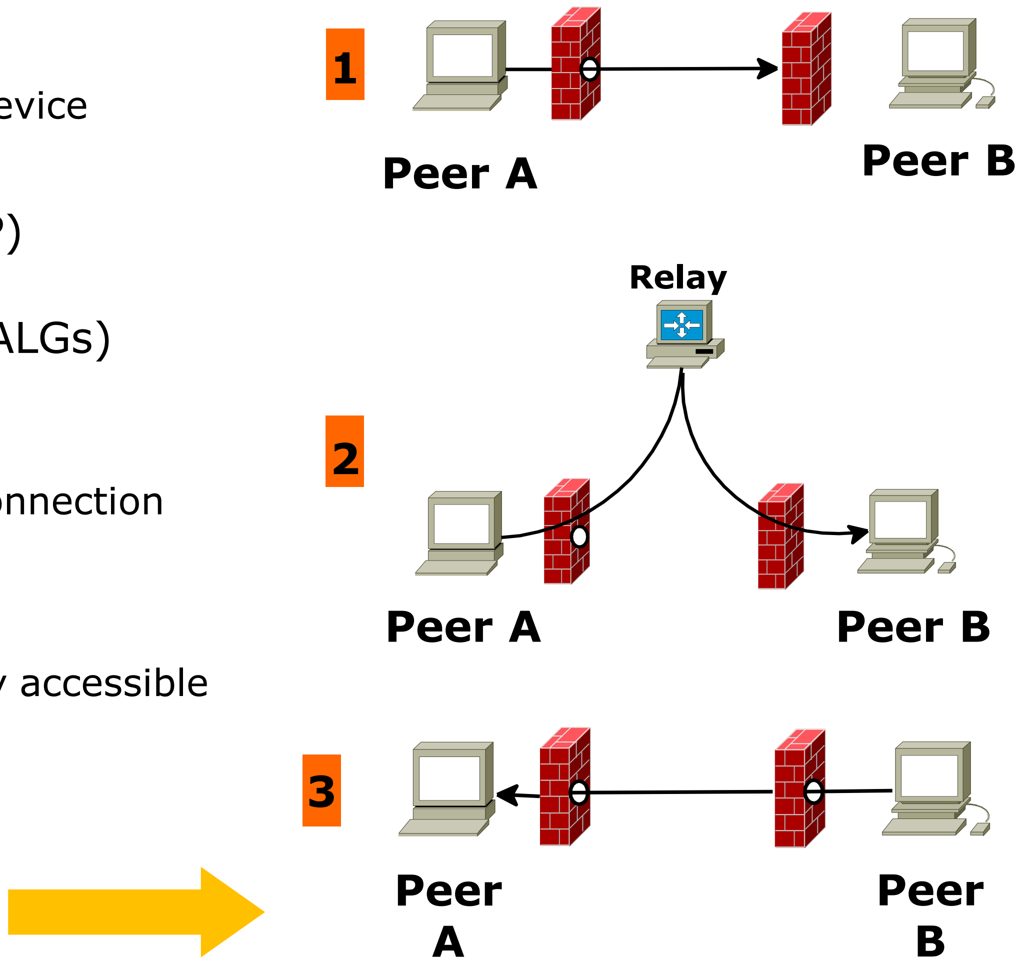
4.1. Background: NAT

- Reuse one IP address for many hosts
  - Solution for sparse IPv4 address space
  - Security features
- Functionality
  - Address rewriting in IP header
  - Works only if hidden host initiates the communication!
    - Applies for Client-Server
    - Not for P2P!

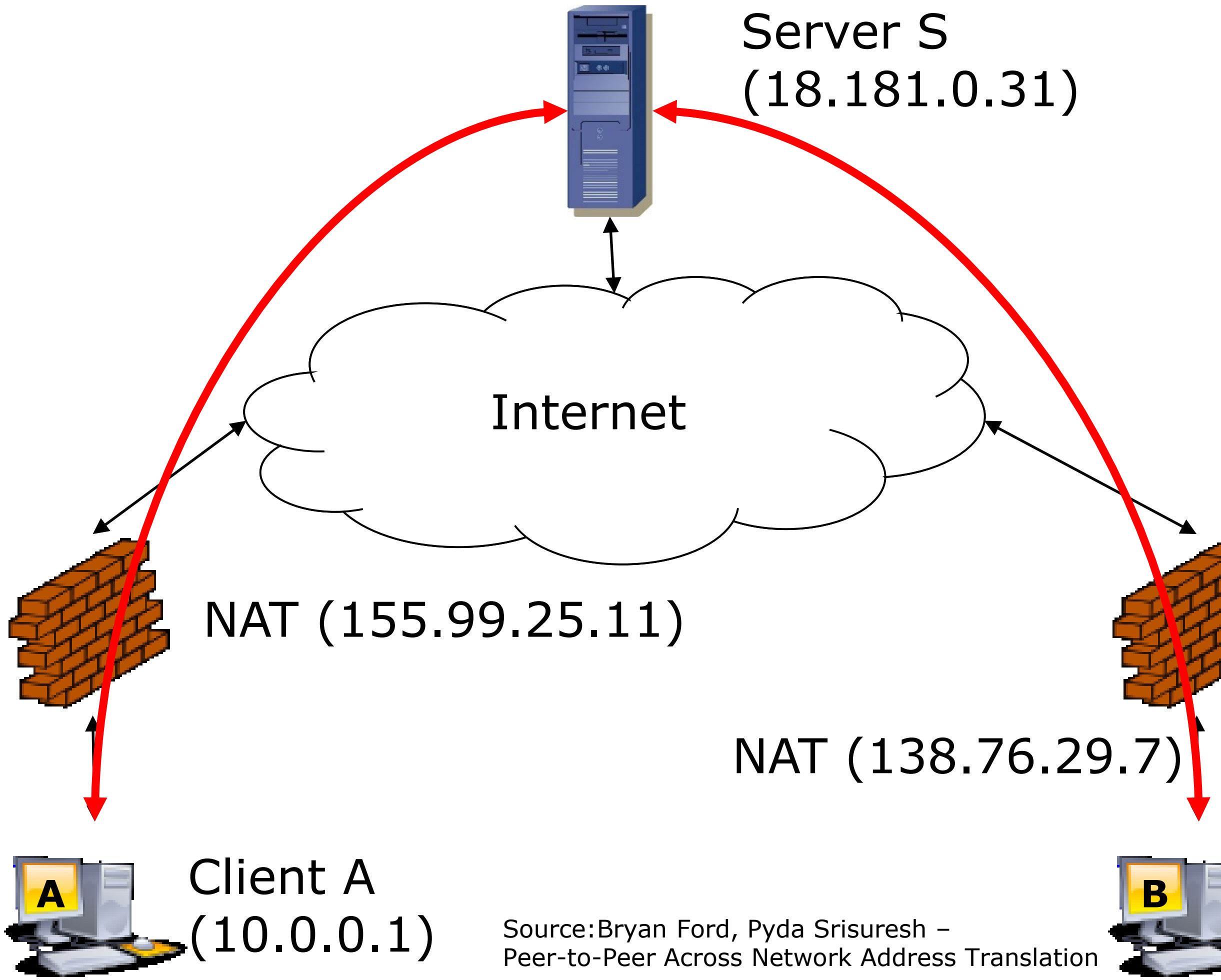


4.1. Background: NAT Traversal

- Port-Forwarding
  - Static mappings in the NAT device
- Universal Plug and Play (UPnP)
- Application Layer Gateways (ALGs)
- Connection Reversal
  - Let hidden host initiate the connection
- Relaying
  - Forward data through publicly accessible hosts
- Hole Punching
  - Exploit NAT functionality
  - Easy for UDP, hard for TCP …



4.2. Relaying



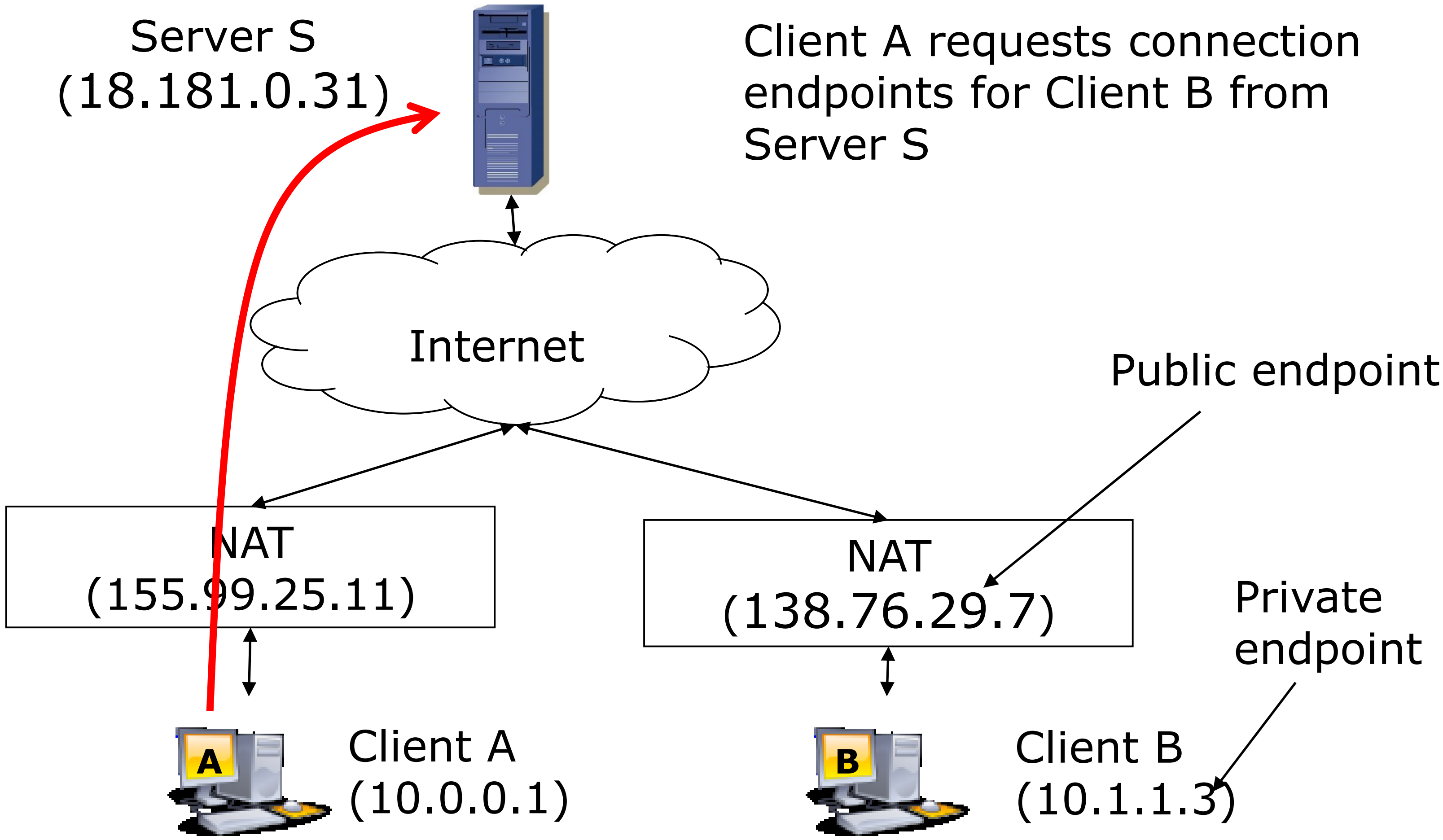
All data sent trough server

Reliable

Inefficient → processing power and bandwidth of server used

Source: Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

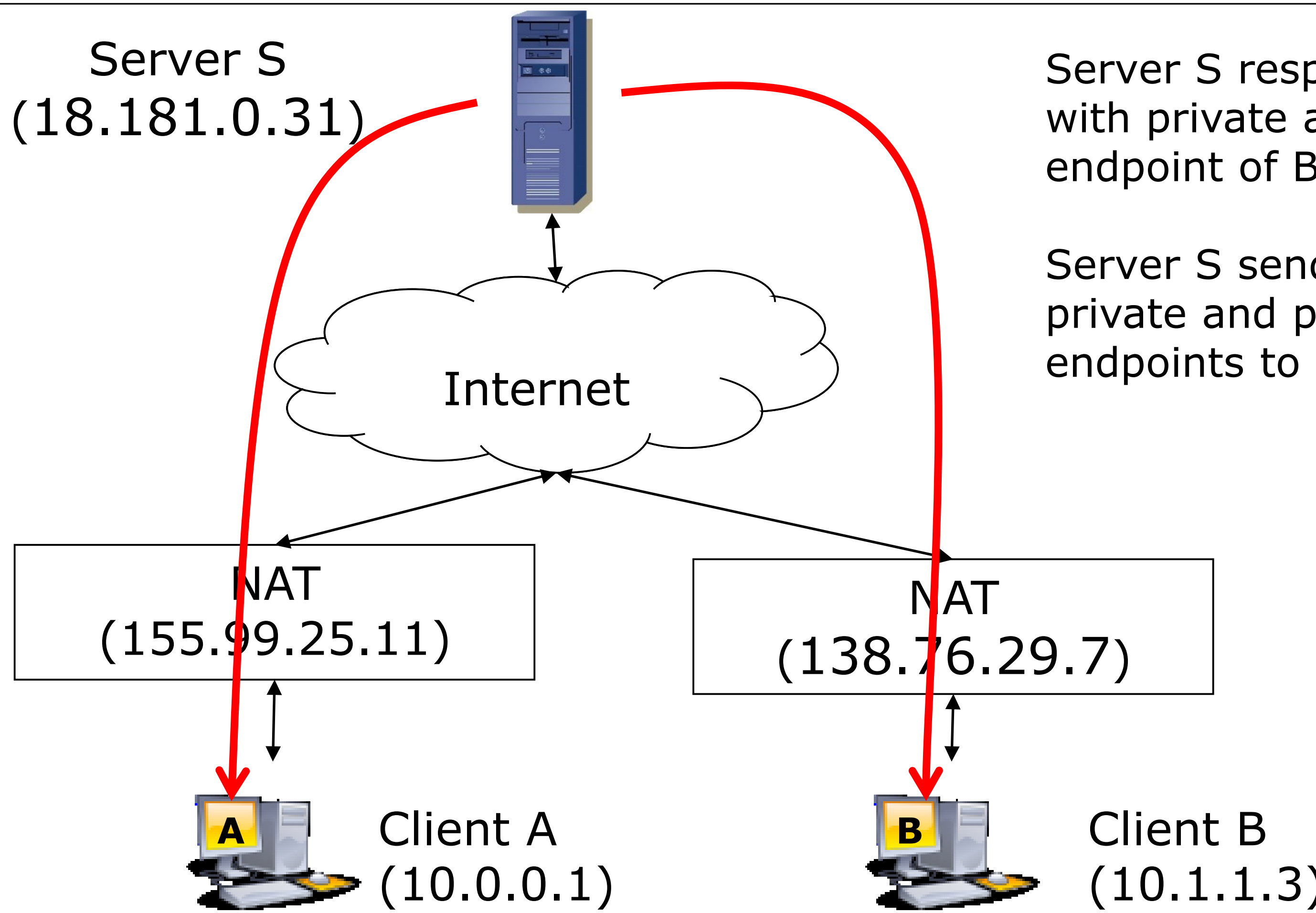
4.3. UDP Hole Punching – First Step



Client A requests connection endpoints for Client B from Server S

Source:Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

4.3. UDP Hole Punching – Second Step

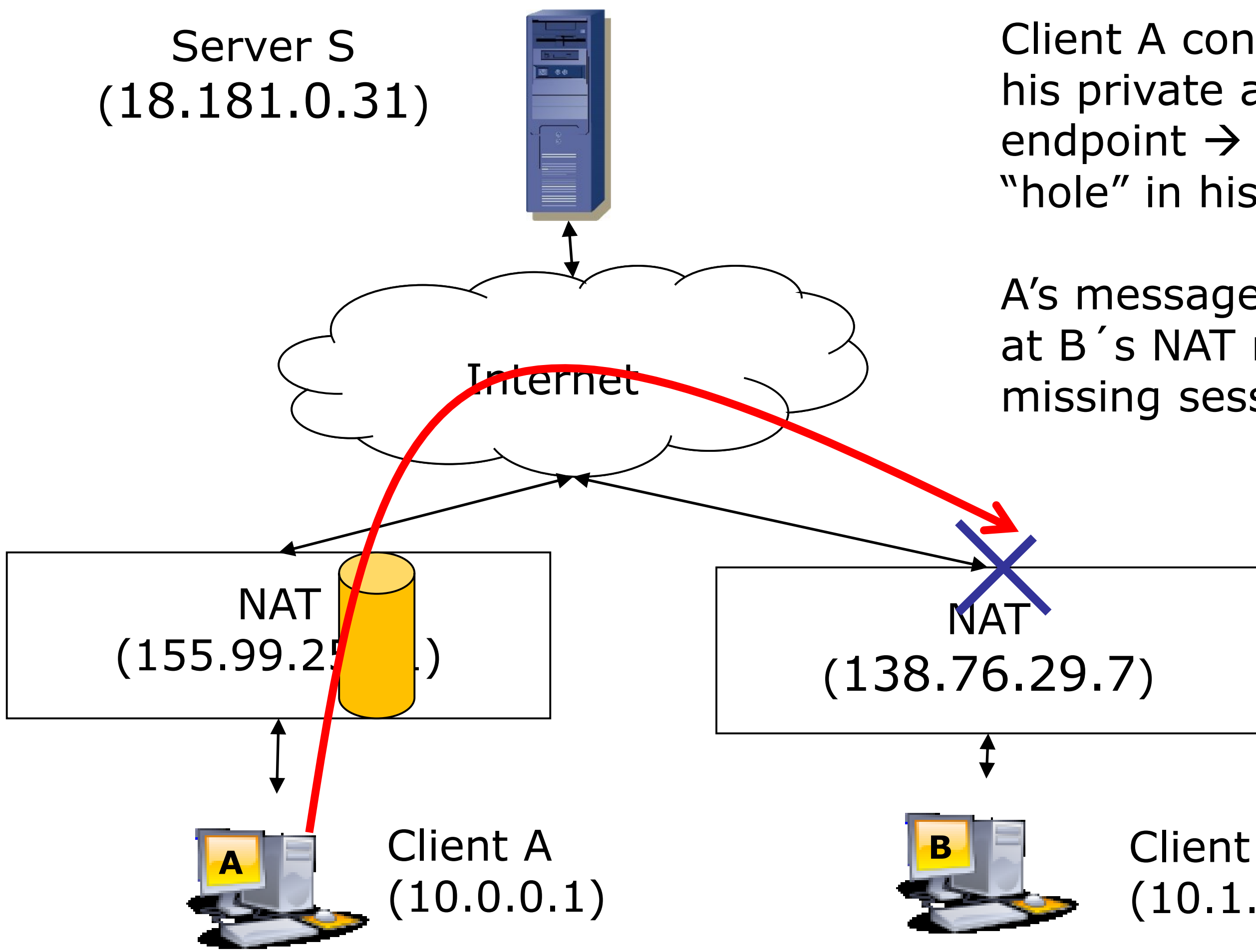


Server S responds to A with private and public endpoint of B and

Server S sends A's private and public endpoints to B

Source: Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

4.3. UDP Hole Punching – Third Step

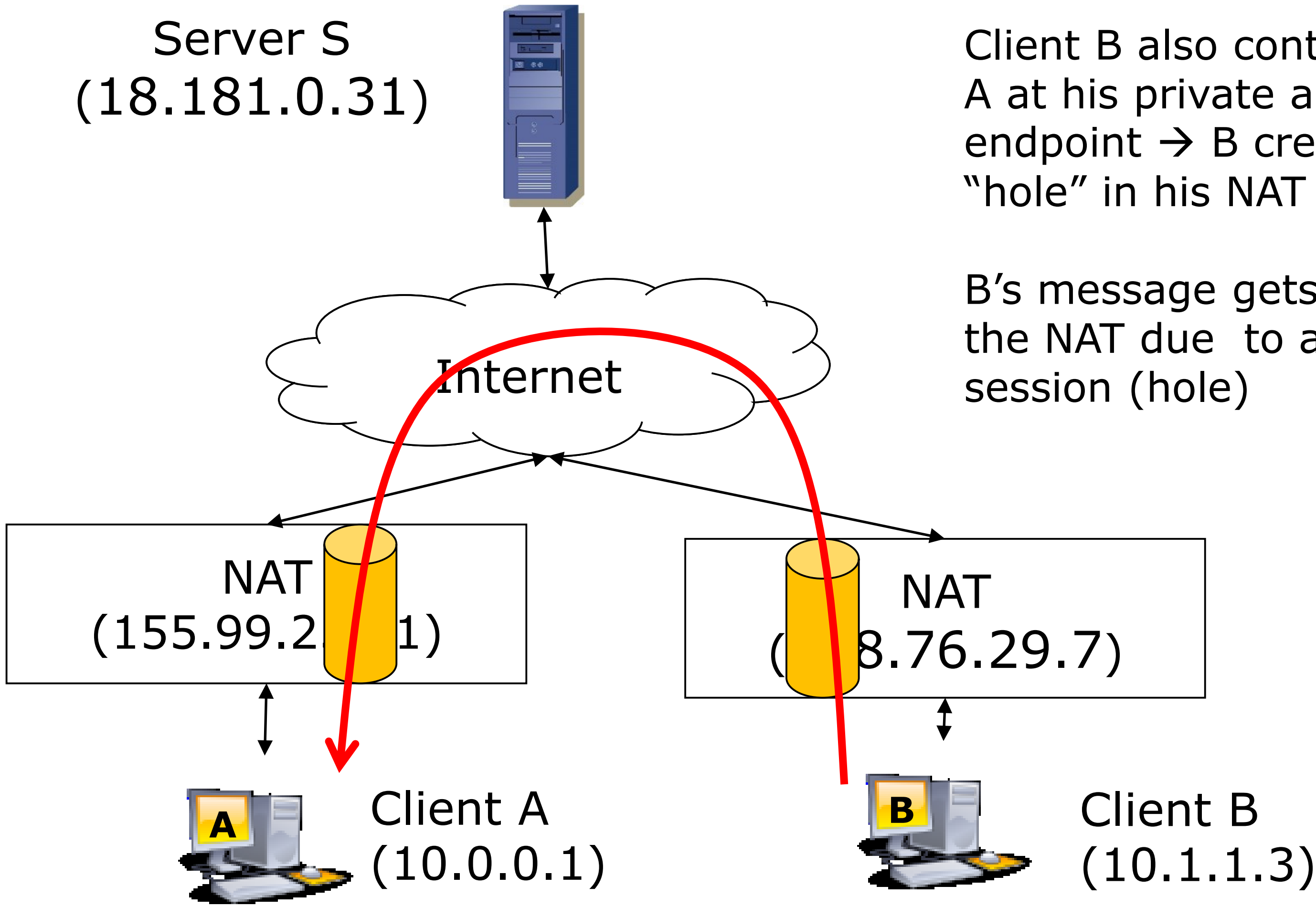


Client A contacts Client B at his private and public endpoint → A creates a "hole" in his NAT

A's message gets dropped at B´s NAT router due to missing session

Source:Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

4.3. UDP Hole Punching – Fourth Step

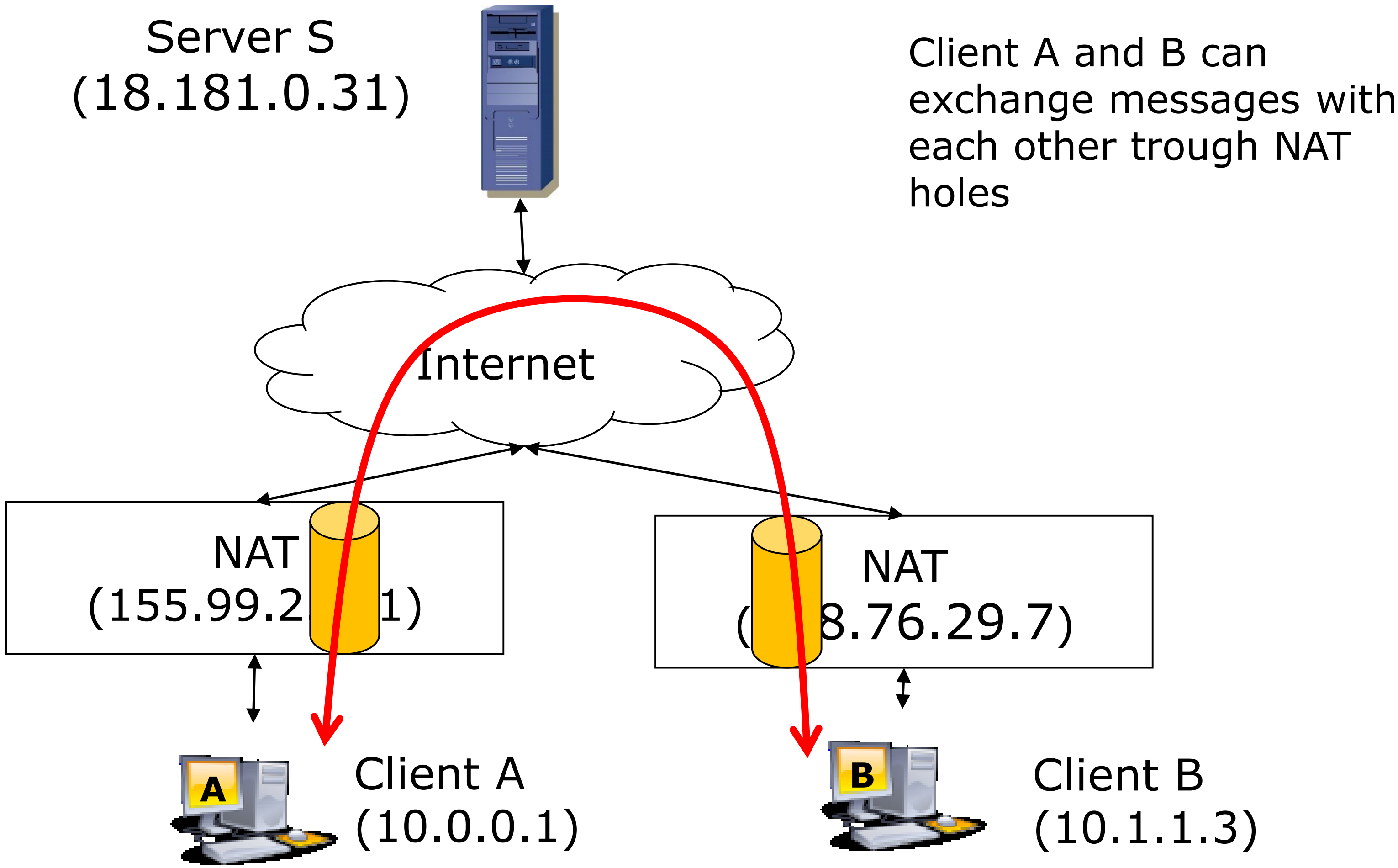


Client B also contacts Client A at his private and public endpoint → B creates a "hole" in his NAT

B's message gets trough the NAT due to active session (hole)

Source: Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

4.3. UDP Hole Punching – Fifth Step



Client A and B can exchange messages with each other trough NAT holes

Source:Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation

4.3. Hole Punching

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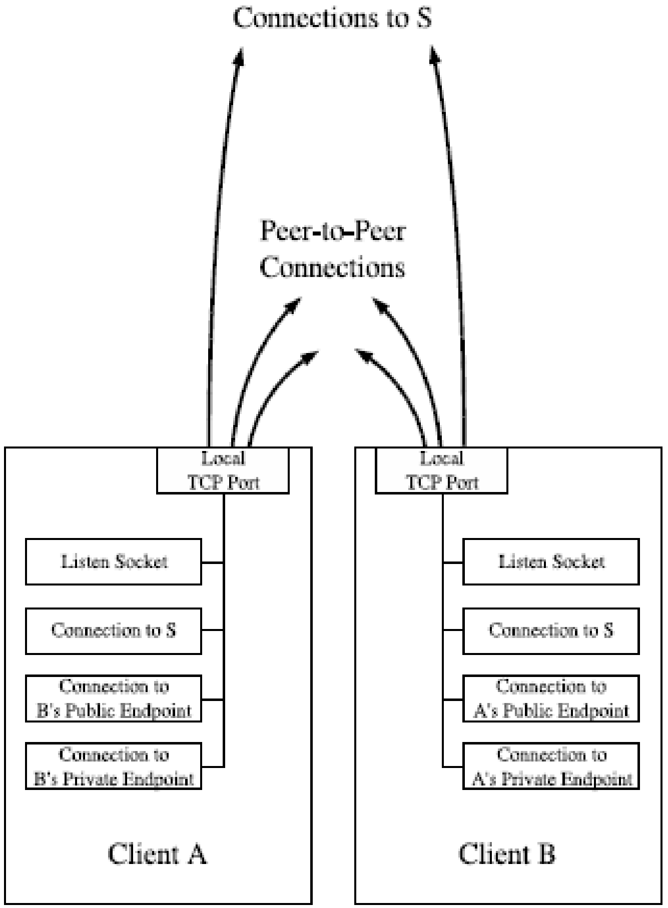
- UDP-NAT holes are closed after specific life time
  - Resending packets necessary
  - Re-opening hole on-demand
- Hole Punching also works for TCP
  - TCP socket option SO_REUSEADDR option necessary in order to bind multiple sockets to the same local port
- Success of hole punching cannot be guaranteed
  - Different NAT vendors
  - Symmetric NAT vs. cone NAT
  - Drop SYN packet vs. TCP RST packet



Source:Bryan Ford, Pyda Srisuresh – Peer-to-Peer Across Network Address Translation