Peer-to-Peer Systems

Internet Technologies and Applications

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- Describing and Classifying P2P
- Resource Location in P2P
  - General concepts
  - Unstructured P2P Systems, e.g. Gnutella
  - Hierarchical P2P Systems, e.g. Fasttrack
  - Structured P2P Systems, e.g. DHTs, Chord and BitTorrent
- Comparing P2P Systems

- We focus on file sharing as example of P2P systems
  - Many other applications like distributed file systems, web caching, online gaming, distributed computing, …

Motivation of P2P Systems

- The Internet enables large-scale distributed applications
  - Searching (Google), directories (Yahoo!), auctions (eBay), …
  - Most of the applications use a centralised architecture
    - Information is stored centrally on company servers
    - Users (clients) access the information from servers
  - These centralised, distributed applications require significant development, infrastructure, maintenance and administration
    - In 2003, Google used cluster of 15,000 Linux workstations as search engine server
- An alternative to centralised distributed applications?
  - In recent years, peer-to-peer systems have provided large-scale distributed applications using decentralised architecture
    - File sharing applications most popular: Naptster, Gnutella, BitTorrent
  - No longer require large, complex centralised servers
  - For many applications, scalability, load-sharing and fault-tolerance of P2P systems makes them very attractive

Client/Server versus P2P

- Client/server systems are asymmetric and centralised
  - Clients request data or functionality from a server
  - To cope with large number of potential clients, server may be replicated (e.g. many physical servers, although conceptually only one server)
  - Disadvantages:
    - Single point of failure – if server fails, the entire service is unusable
    - Bandwidth bottlenecks at server
  - Advantages:
    - Easy to control access to resources and functionality (including providing security)
    - Simple and efficient algorithms

- P2P systems are symmetric and decentralised
  - No distinction between clients and servers; a peer may act as either depending on current objective
  - Individual peers must cooperate with each other
  - Advantages:
    - No longer depend on a single server (no single point of failure)
    - Addition of new users, leads to new server and clients (scales well)
  - Disadvantages:
    - Complex algorithms needed
    - Hard to control access and provide security

Practical Benefits of P2P Systems

- Storage
  - Each peer stores some resources (files)
    - Large amounts of storage space available
- Bandwidth
  - No bottlenecks at central servers
  - Can download parts of files from multiple sources
- Knowledge
  - Peers (users) may classify their resources, making searches easier
    - Similar to Yahoo! Directory classifying resources

Classifying P2P

- P2P systems include applications, protocols and algorithms
- Examples:
  - The Internet (IP) is a P2P system (although many Internet applications are client/server-based)
  - eBay at a user-level is a P2P system (although some protocols used are client/server-based)
- P2P applications may still use a client/server programming model
  - E.g. use TCP/IP sockets: a server process listens for connections, a client process initiates connections
- However, the peer computer will usually run both a server and client process

Classifying P2P by Detail

- Another classification of P2P systems is by the levels of detail (or generality) that they provide:
  - P2P Applications
    - Systems used for specific applications
    - Examples: Gnutella, Napster, Kazaa, …
  - P2P Platforms
    - Provide generic architecture for building P2P applications
    - Example: JXTA platform
  - P2P Algorithms
    - Algorithms, especially for resource location, that are used by applications and platforms

Resource Location in P2P Systems

- Resource location is a fundamental problem of P2P systems
  - How do you located a resource in a P2P network?
    - (In a centralised network, you go direct to the server)
- The problem:
  - Given a group of peers *G*, each peer has an address, *p*, and stores some resources, *R(p)*, and each resource is identified by a key, *k*:
  - If you have a key, *k*, for resource *r*, find the peer *p* that stores the resource r
  - To do so, you need an index that maps keys (*k*) to peers (*p*)
  - A peer will not store the entire index, and hence must send requests to locate resources to its neighbours *N*
- Require two protocols to perform:
  - Network Maintenance: nodes can join/leave a group *G*
  - Data Management: peers can search/insert/delete resources from the group

Network Management Protocol

- If a new node *n* wants to join a group, the node must know an existing member *p*
  - Send a join message to *p*
  - If a new node joins the group the neighbourhood information and index information may be re-organised
- If a node *n* wants to leave a group, send a leave message to *p* (or all members of group)
  - Often, the leave is implicit, i.e. there is no leave message
    - E.g. a peer is turned off or fails or has no network connectivity

Data Management Protocol

- Managing resources:
  - search(*k*) should return the peers p that contain the resource *r*, where Key(*r*) = *k*
  - insert(*k*,*r*) should add a resource *r* with key *k*
  - delete(*k*) should delete the resource *r*, where Key(*r*) = *k*

- Implementation of Network and Data Management Protocols
  - Differs among different types of P2P systems

Implementation Choices

- Unstructured versus Structured
  - Unstructured: no information is kept about resources on other peers
    - Nodes are independent of each other; failure resistant
  - Structured: peers store information about other peers' resources
    - Search is much more efficient
- Flat versus Hierarchical
  - Flat: all nodes are equivalent (play same role)
    - Fully distributed, failure resistant
  - Hierarchical: some nodes have special functionality, e.g. only some nodes can search
    - Such is much more efficient
- Loosely versus Tightly Coupled
  - Tightly coupled: only one group of peers, and each peer has a static role in the group
  - Loosely coupled: System may evolve into many groups; role (and address) of peers may change over time

Napster

- History
  - One of the original file sharing applications, released in 1999
  - Reached between 25million and 40million users in 2000/2001
  - Shutdown in 2001/02 due to legal challenges and bankruptcy
- Napster was an application and protocol
- Characteristics
  - Directory based architecture
    - Clients send requests to central server to locate resources (not P2P)
    - Clients then access other peers directly (P2P)
  - Efficient, but lacks several of the benefits of other P2P systems (scalability, fault-tolerance)

Gnutella

- History:
  - Created by two developers from Nullsoft in 2000
  - Mainly used for exchanging files (originally intended for exchanging recipes)
  - Protocol was reverse engineered from the software binary
- Gnutella is a P2P protocol (not an application)
  - Many client applications implement the Gnutella protocol
    - Morpheus, Limewire, Gnucleus, …
- Characteristics:
  - Unstructured P2P system
  - Flat architecture
  - Loosely coupled

Gnutella Protocol

- Message types:
  - Network maintenance: Ping, Pong
  - Data management: Query, QueryHit, Push
- Message distribution
  - Messages are broadcast with Time To Live (TTL) decremented by 1 each time
    - If receive a message with TTL > 0 (and not received before), then forward message to all peers you have connections with
  - Responses to Query messages are sent along same path
- Joining the Gnutella network
  - A new peer, *P*, must contact an existing peer with a Ping message
    - There are dedicated servers that list known peers – initially the new peer must contact one of these
  - Peers receiving Ping message can cache new peers, *P*, IP address/port and respond with Pong message including IP address, port and total size of files it shares
  - New peer, *P*, selects *C* (e.g. 4) of the peers who returned a Pong, and creates permanent connection to them
    - If connections to these *C* peers are lost, the *P* can find new peers to permanently connect to

Gnutella Protocol

- Locating files:
  - *P* sends a Query message to permanent peers, including search criteria
    - If a peer *X* can satisfy criteria, it returns QueryHit listing all matches
      - HTTP can then be used to access the file
    - Otherwise, forward message to all of *X*'s permanent peers
- List of peers:
  - Peer *P* learns about peers from Ping/Pong, QueryHits and Push messages
    - *P* caches a list of peers for future use (e.g. if one of the C permanent connections fails)
- Firewalls:
  - If server peer is behind a firewall, requesting peer may not download file with HTTP
  - Requesting peer sends Push message to server peer, indicating where the server peer can “push” the file to (e.g. upload)

Issues with Gnutella

- Simple broadcast of messages is inefficient
  - Example: if TTL is 7, and C is 4, a single Gnutella message may generate 26,240 messages in network
  - Every node that receives a request scans its local database (time consuming)
  - There are methods to improve the broadcast messaging:
    - Expanding ring search
      - Start with TTL=1. If no result found, set TTL=2 and try again. Then try TTL=3 and so on.
    - Random walker search
      - K random walkers are sent by requesting peer. Subsequent peers only send requests to one neighbour, but with high TTL.
      - Can greatly reduce the message overheard, but increases the search time

Fasttrack

- History:
  - Developed in 2001
  - Several of the Fasttrack networks (e.g. Grokster, Kazaa) have been shutdown or limited by legal suits
- Fasttrack is a P2P protocol (not application)
  - Clients implementing Fasttrack include: Kazaa, Grokster and iMesh
- Characteristics:
  - Hierarchical P2P system
  - Super-peer architecture

Super-Peer Architecture

- Aim to combine efficiency of centralised architecture (e.g. Napster) with robustness of flat architecture (e.g. Gnutella)
- Three types of peers:
  - Super-super-peers: used on startup to provide list of super-peers
  - Super-peers: maintain index information and forward messages between other super-peers (similar to Gnutella)
  - Ordinary peers: contact super-peers to advertise resources and access index information (i.e. search). Similar to a centralised approach
- Client software (e.g. Kazaa) can dynamically change node from peer to super-peer
  - Depends on computer and network speed; only powerful computers with high bandwidth will become super-peers

Distributed Hash Tables

- History
  - Motivated by disadvantages of Napster (centralised), Gnutella (inefficient) and similar P2P protocols for file sharing
  - Research has been used for file sharing, instant messaging, distributed file systems, web caching and other fields
- DHTs are P2P algorithms (not protocol or application)
  - Chord, Pastry and Tapestry are specific DHT algorithms
  - BitTorrent is an example protocol/application that uses DHTs
  - Coral Content Distribution Network also uses DHTs
- Characteristics
  - Structured P2P system
  - Flat architecture
  - Tightly coupled

Chord: an example DHT

- *N* nodes in network
  - Aim to distribute files amongst the nodes, and locate the files
- Consistent hashing is used to assign ID's to nodes and resources
  - SHA-1 hash of node IP address produces 160-bit *ID*
  - SHA-1 has of file name produces 160-bit key, *k*
- Visualise nodes as circle, ordered by *ID*
- Resource with key *k* is stored at node with *ID* = *k*
  - If node with *ID* = *k* does not exist, resource is stored at node with next highest *ID*
- Node *n* joins network:
  - Need to reassign keys from successor(*n*)
- Node *n* leaves the network:
  - Need to reassign keys to successor(*n*)

Chord: Inserting and Searching

- To insert data, insert(*data*)
  - Node calculates hash of data (e.g. the file) to get *k*
  - Routing is used to find the node that stores key *k* ($node_k$)
  - Data is stored on the node
- To search for data, search(*k*)
  - Node calculates hash of data to get *k*
  - Routing is used to find the node that stores *k*
  - Any access method (e.g. HTTP) is used to retrieve data from $node_k$

Chord: Routing

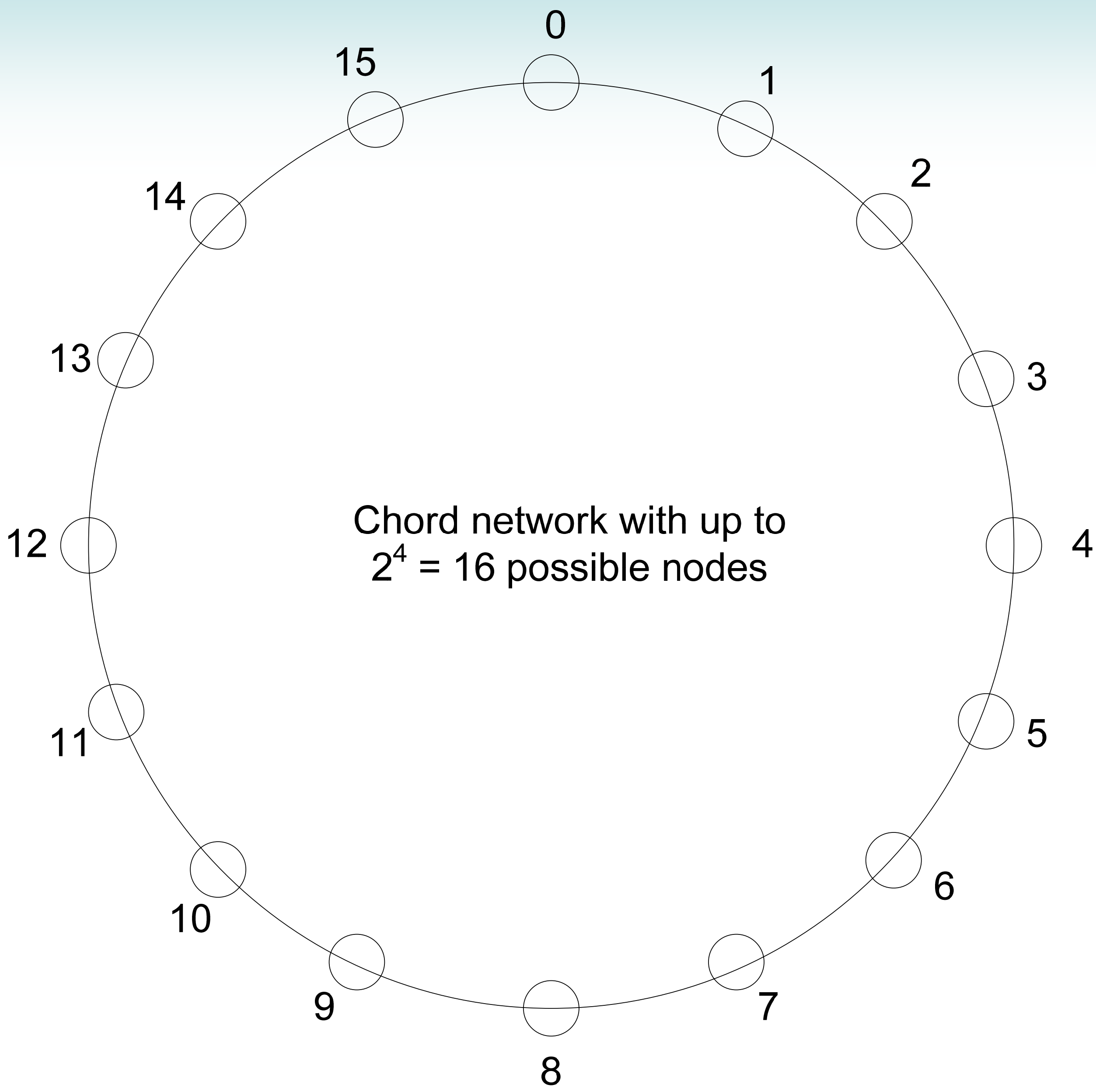
- Simple Routing
  - Each node *n* maintains route to successor(*n*)
    - Node *n* knows the IP address/port number of successor(*n*)
  - A simple (but naïve) approach is to then try to find key by checking each subsequent successor
    - Example: node 0 knows the IP address/port of node 1; node 1 knows IP address/port of node 3; and so on
    - But may have to traverse all nodes to find key
  - But can provide more efficient search than this (at expensive of maintain more connections)
- Routing in Chord
  - Each node *n* maintains route to first node that succeeds *n* by 2^{i-1}
    - Example: node 0 knows route to 1, 2, 4, 8 (or next subsequent node if does not exist); node 1 knows route to 2, 3, 5, 9; and so on
  - Search queries are sent to closest node to the requested key *k*

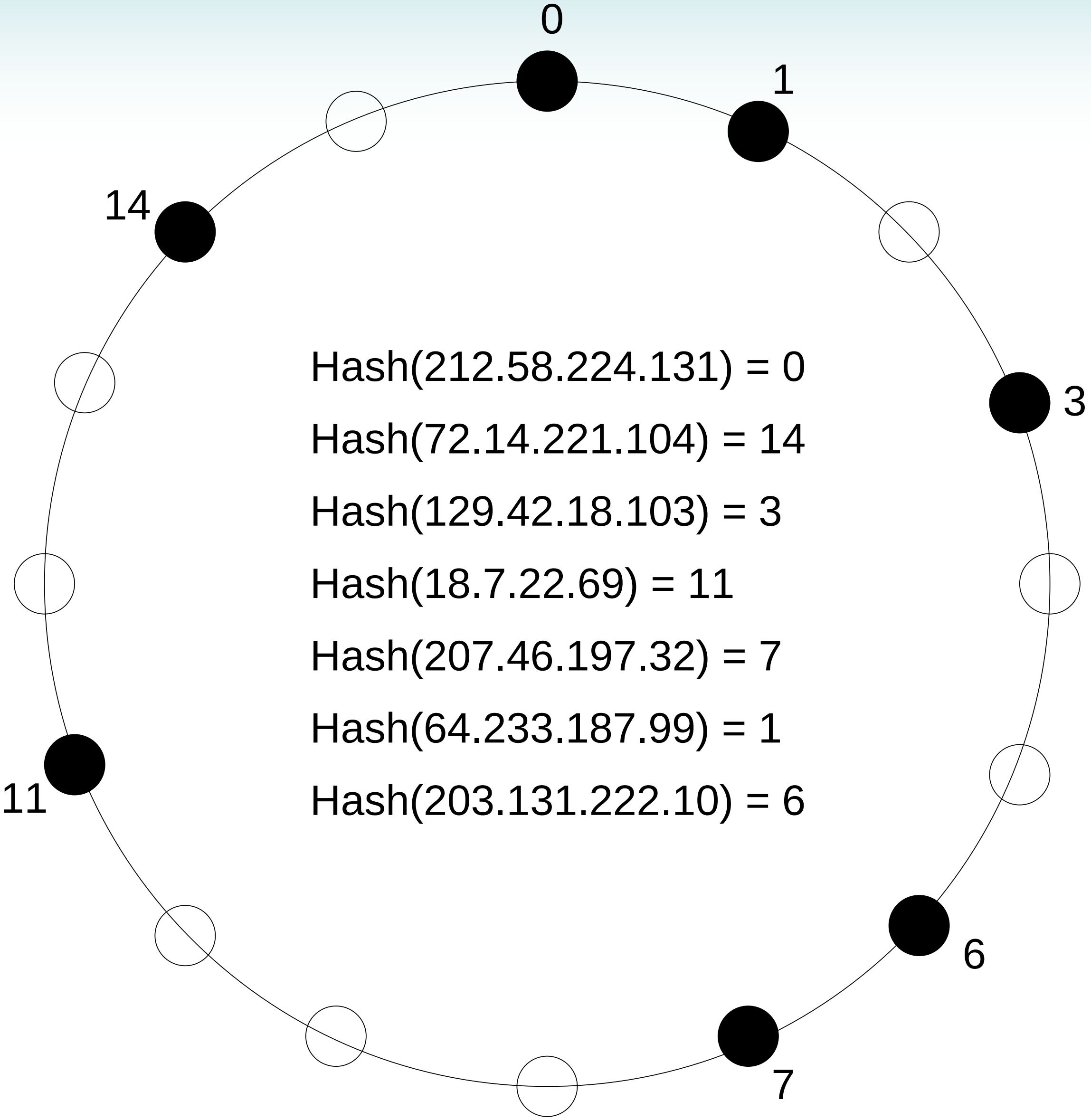
Chord: Routing Example

- Node 0 routing (or finger) table:
  - Start = 1; Interval = 1 → 1; Successor = 1
  - Start = 2; Interval = 2 → 3; Successor = 3
  - Start = 4; Interval = 4 → 7; Successor = 7
  - Start = 8; Interval = 8 → 15; Successor = 9
- (The 3rd line can be read as: “in order to find a node with key 4, 5, 6 or 7, then send to node 7”)
- Node 9 routing (or finger) table:
  - Start = 10; Interval = 10 → 10; Successor = 11
  - Start = 11; Interval = 11 → 12; Successor = 11
  - Start = 13; Interval = 13 → 0; Successor = 14
  - Start = 2; Interval = 1 → 8; Successor = 3

Chord: Routing Example

- Assume a search(*k*=13) is performed at node 0
  - Node 0 knows node 9 has coverage of the keys from 8 to 15
  - Node 0 sends a search message to node 9
  - Node 9 does not have the data with key 13
  - Node 9 knows node 14 has coverage of the keys from 13 to 0
  - Node 9 sends a search message to node 14
  - Node 14 has the data with key 13
  - Node 14 responds directly to node 0
    - Assumes the original search query includes node 0's IP address/port
- Key benefits:
  - A node stores information about a small number of other nodes
    - Routes to *m* nodes, if there are up to 2^m nodes in the network
    - This is good – reduces amount of maintenance between nodes
  - A node can quickly locate the resource


0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Chord network with up to
2^4 = 16 possible nodes



Hash(212.58.224.131) = 0

Hash(72.14.221.104) = 14

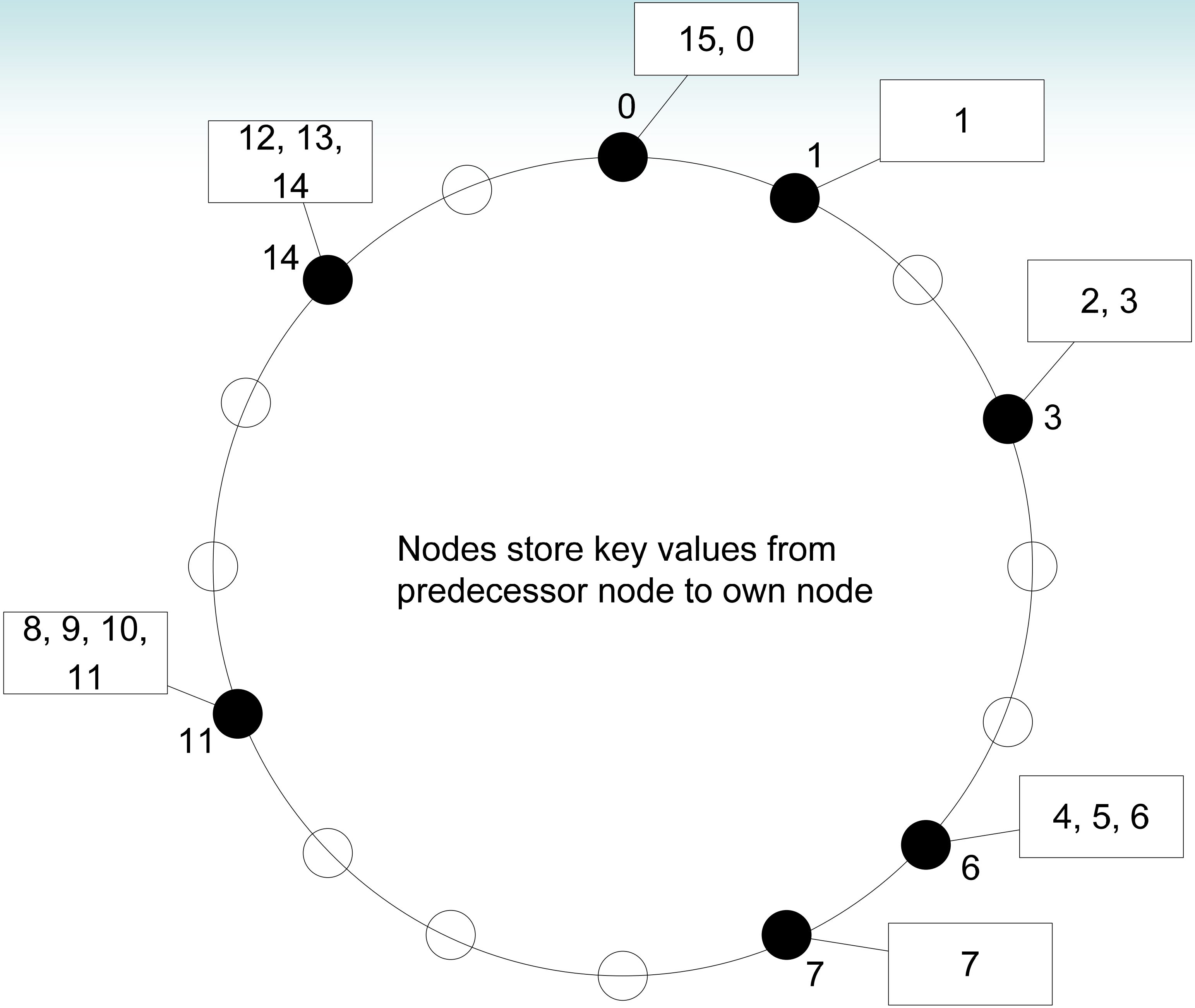
Hash(129.42.18.103) = 3

Hash(18.7.22.69) = 11

Hash(207.46.197.32) = 7

Hash(64.233.187.99) = 1

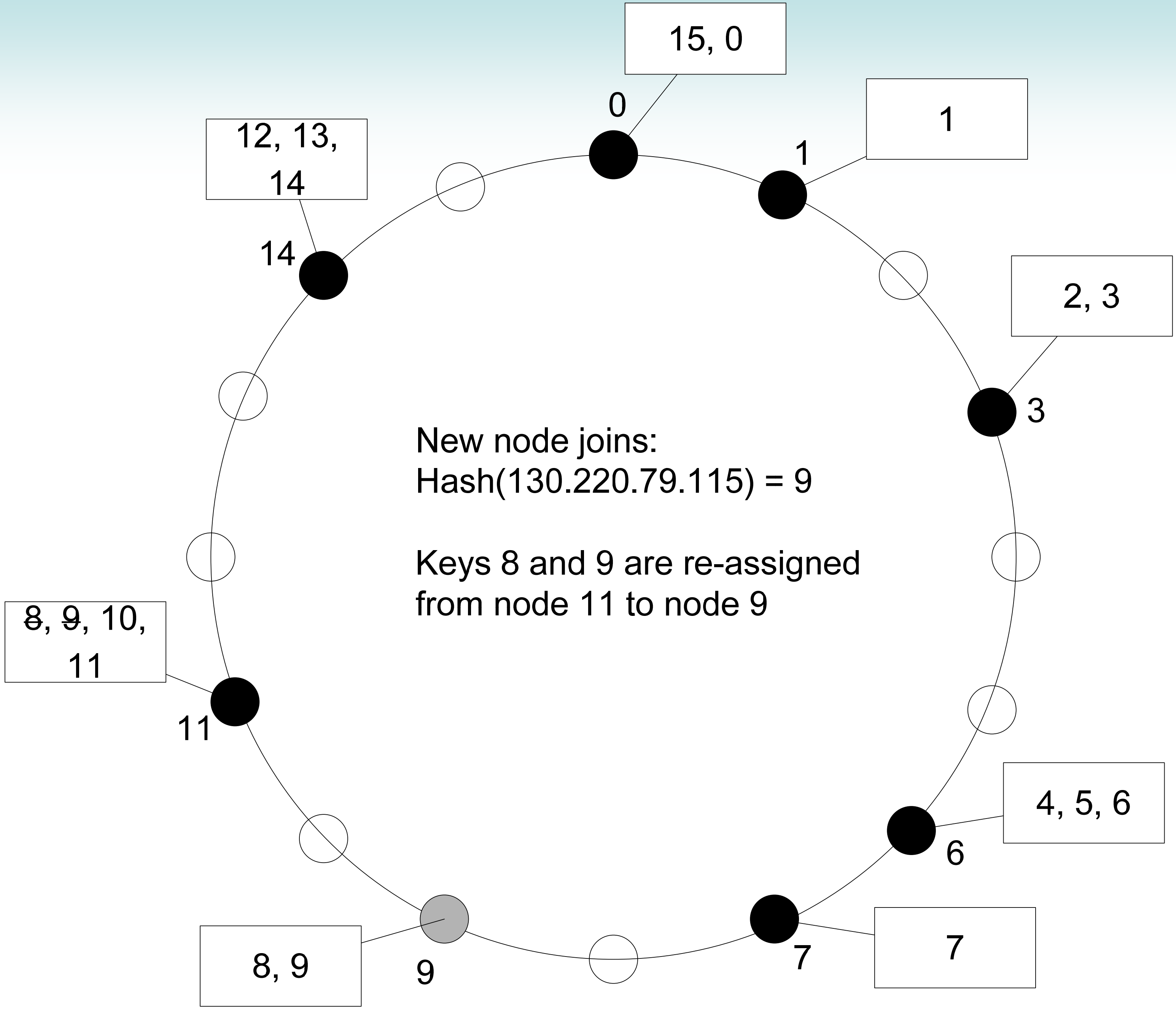
Hash(203.131.222.10) = 6



15, 0
0
1
1
12, 13, 14
14
2, 3
3
Nodes store key values from predecessor node to own node
8, 9, 10, 11
11
4, 5, 6
6
7
7

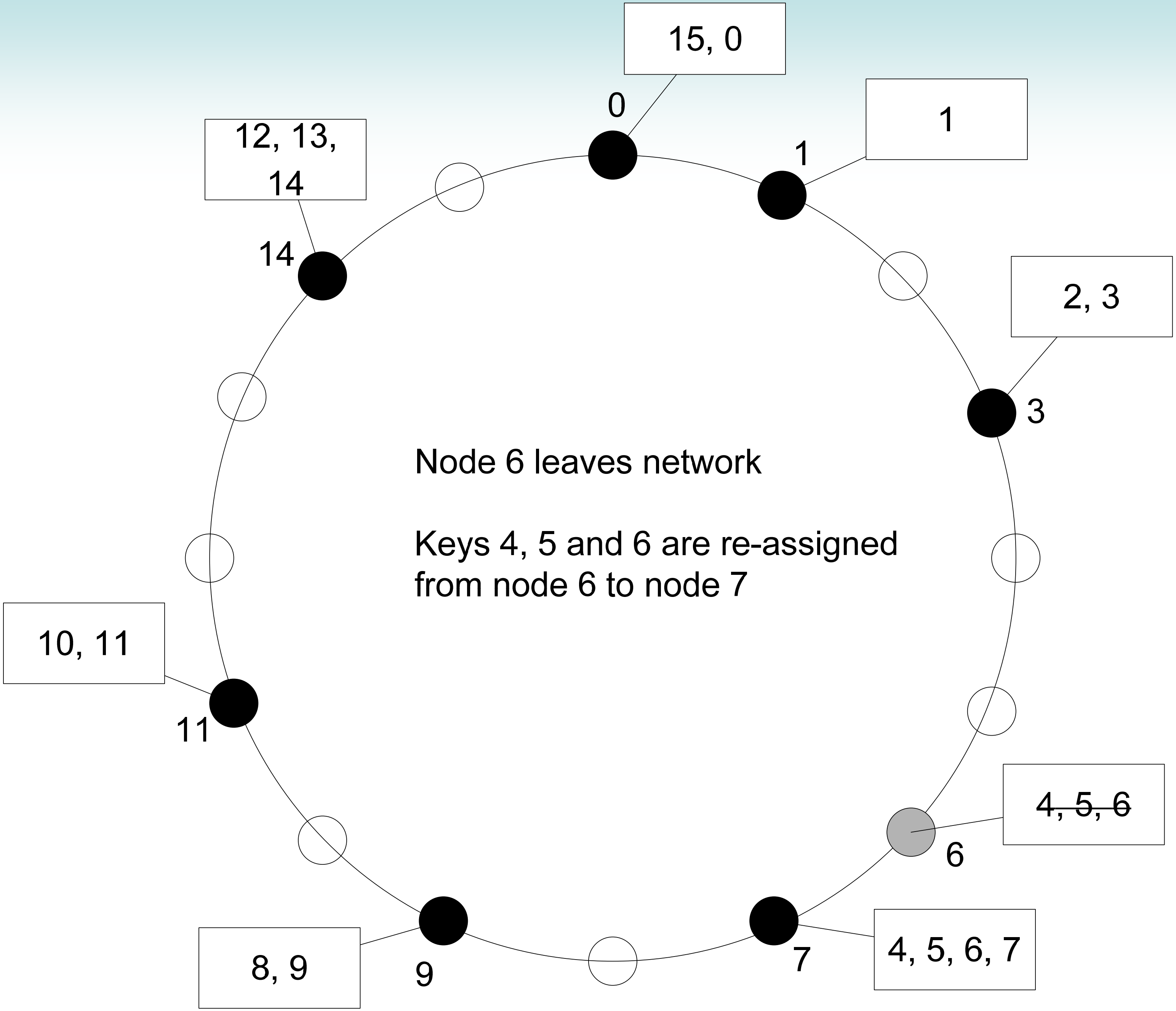
New node joins:
Hash(130.220.79.115) = 9

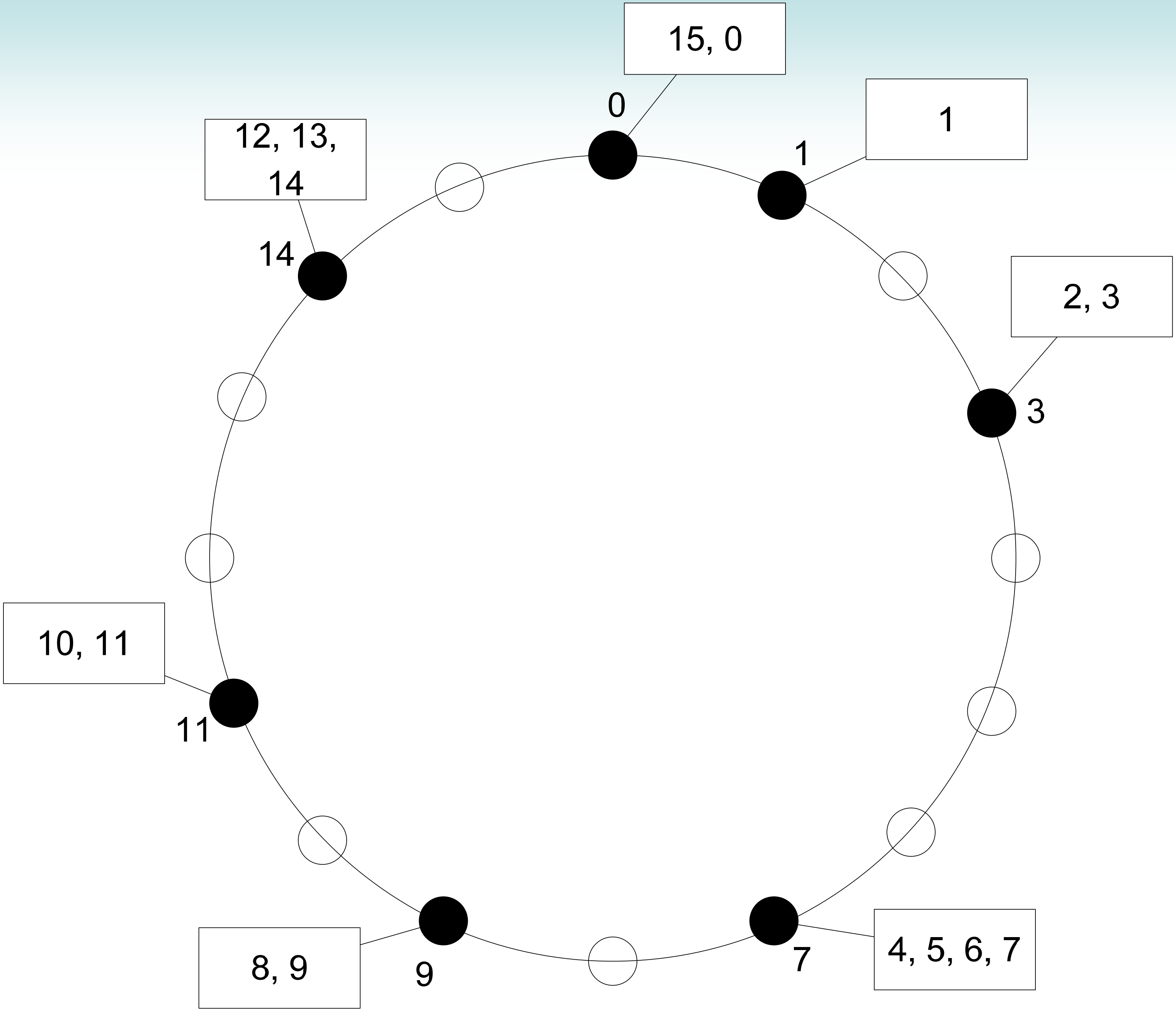
Keys 8 and 9 are re-assigned
from node 11 to node 9

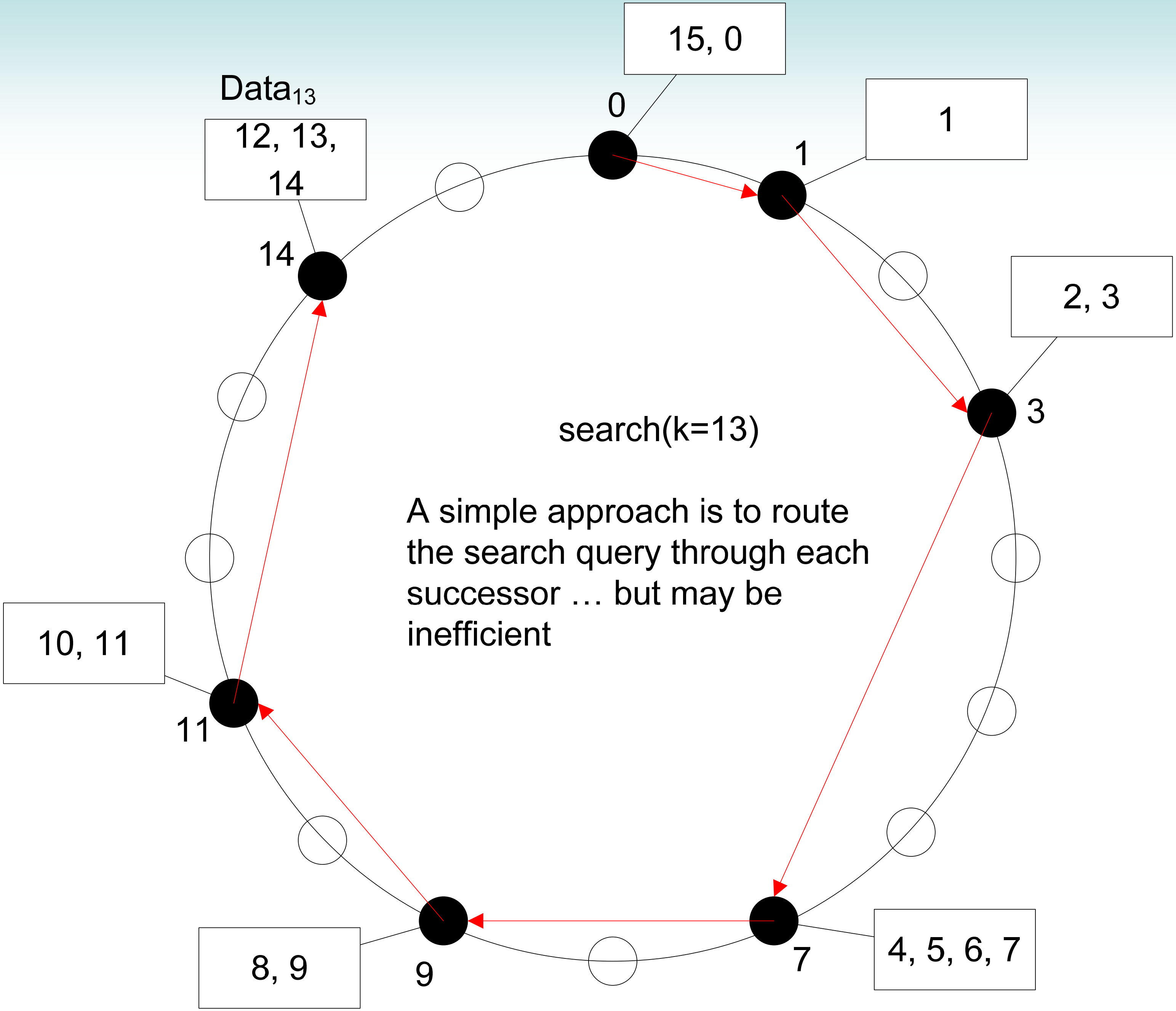


Node 6 leaves network

Keys 4, 5 and 6 are re-assigned from node 6 to node 7

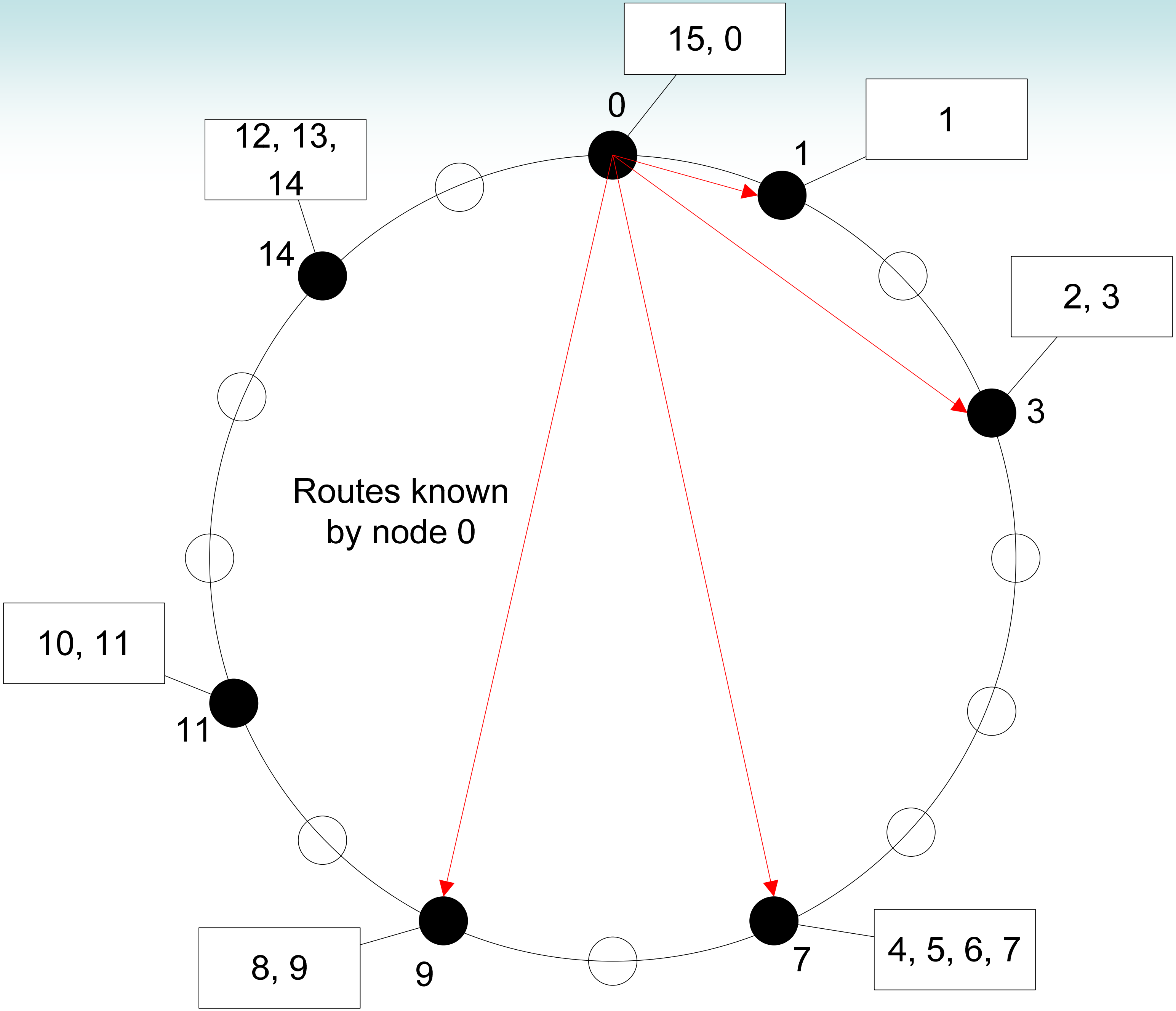



15, 0
0
1
1
12, 13, 14
14
2, 3
3
10, 11
11
8, 9
9
4, 5, 6, 7
7

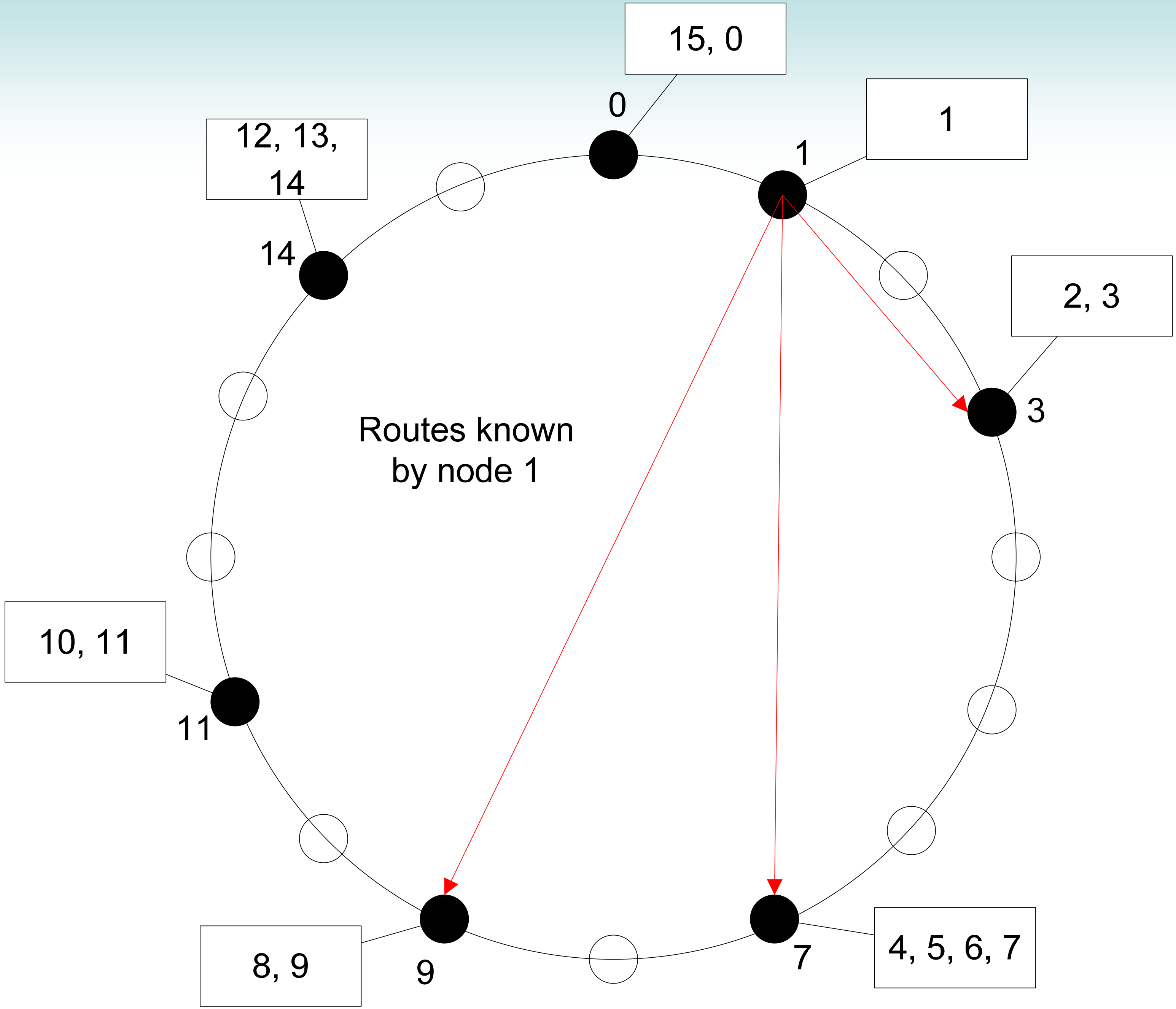


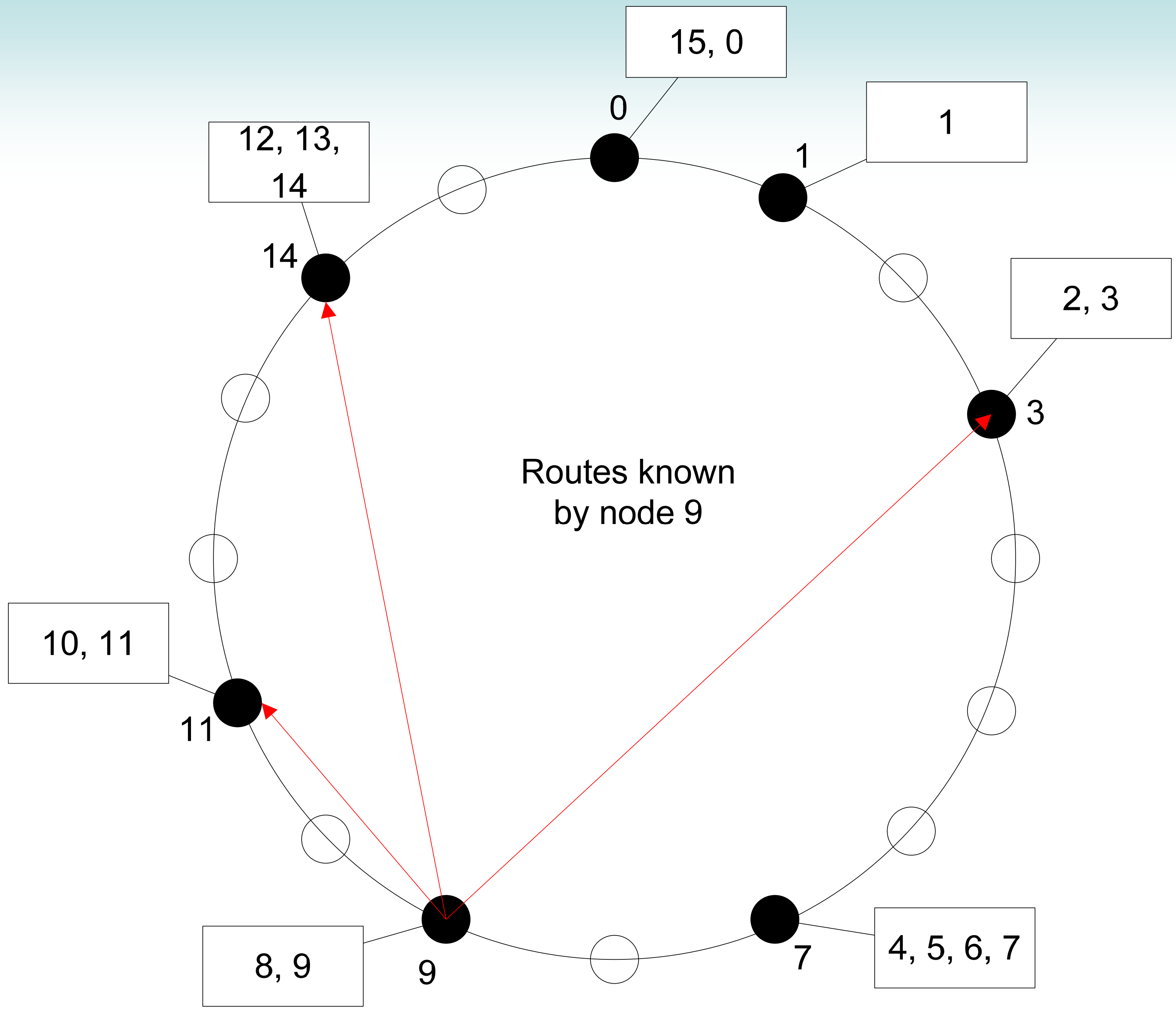
search(k=13)

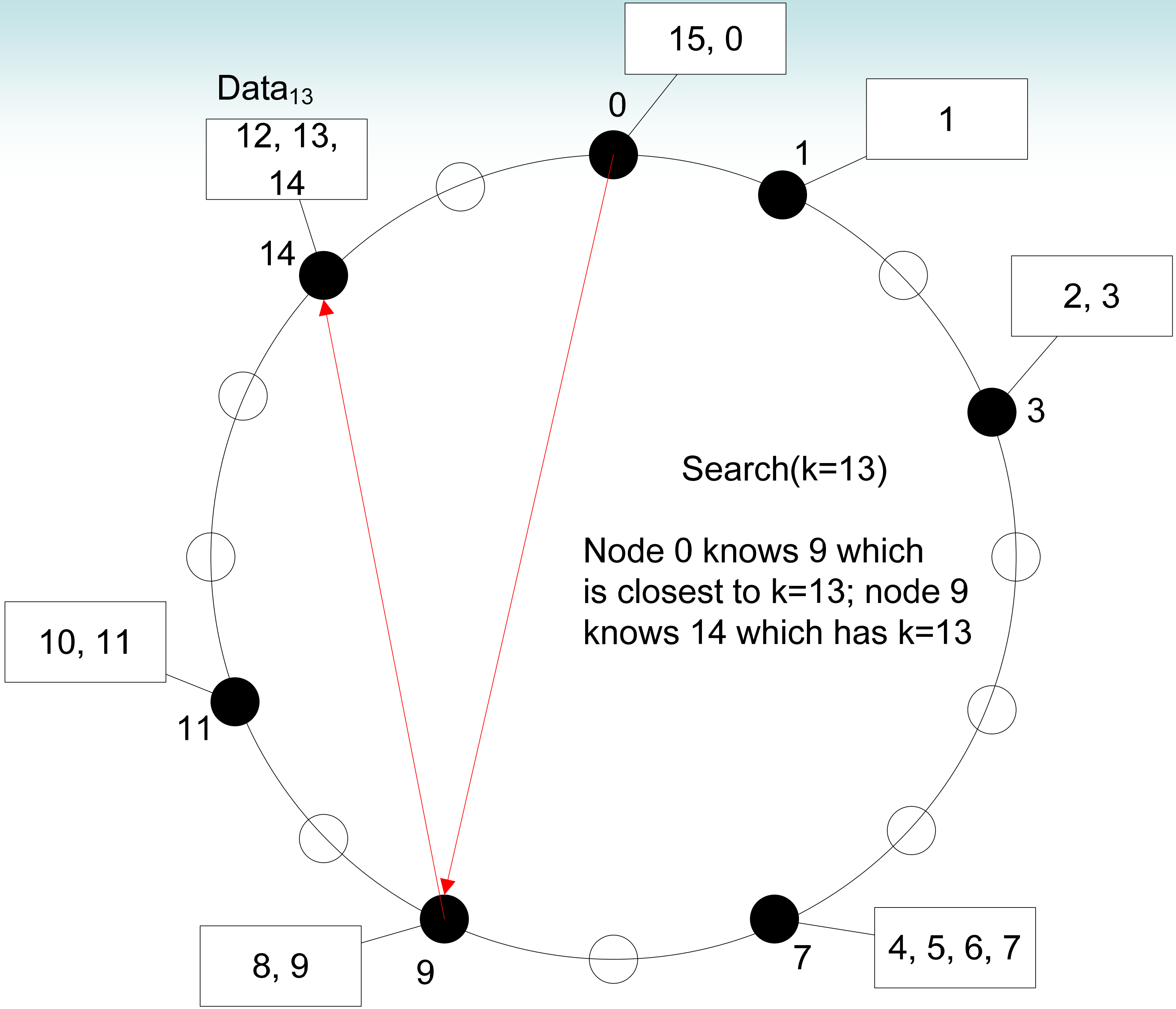
A simple approach is to route the search query through each successor … but may be inefficient



15, 0
0
1
1
2, 3
3
12, 13,
14
14
Routes known
by node 0
10, 11
11
8, 9
9
7
4, 5, 6, 7


15, 0
0
1
1
12, 13,
14
14
2, 3
3
Routes known
by node 1
10, 11
11
8, 9
9
7
4, 5, 6, 7


15, 0
0
1
1
12, 13,
14
14
2, 3
3
Routes known
by node 9
10, 11
11
8, 9
9
7
4, 5, 6, 7


15, 0
0
1
1
Data13
12, 13,
14
14
2, 3
3
Search(k=13)
Node 0 knows 9 which
is closest to k=13; node 9
knows 14 which has k=13
10, 11
11
8, 9
9
7
4, 5, 6, 7

Performance Comparison of P2P Techniques

Approach	*Latency*	*Messages*	*Update cost*	*Storage*
Unstructured (Gnutella)	log(n)	n	1	1
Directory Server (Napster)	1	1	1	n (max), 1 (avg)
Full replication	1	1	n	n
Super-peers (Fasttrack)	log(c)	C	1	C (max), 1 (avg)
DHT (Chord)	log(n)	log(n)	log(n)	log(n)

n = number of peers; C = number of super-peers

Comparison of P2P Techniques

- Search Capabilities
  - Currently, unstructured and hierarchical P2P systems (e.g. Napster, Gnutella, Fasttrack) support any type of search criteria
    - E.g. a search phrase is handled locally on a peer – it can use traditional database and pattern matching techniques
      - search(thammasat) can return all data that contains “thammasat” or related to “thammasat”
    - This is one reason for their popularity, despite lower performance
  - Structured techniques like DHTs are limited by the structure of keys used
    - In basic form, only support equality predicate
    - E.g. search(*k*) will only return data that has exact key *k*
  - There are techniques in development to enhance structured techniques for better search criteria

Comparison of P2P Techniques

- Replication
  - Many peers in P2P networks are unreliable, offline
  - The data may be replicated in the network to make it more accessible
  - Natural replication occurs in Gnutella, Napster etc. because after peers download a file, they then make it available for others to download
  - Unstructured networks like Chord, Pastry can support or controlled replication of data
    - E.g. insert(data,k) in Chord stores copies of the data at multiple nodes

P2P Issues

- Security
  - Most systems have minimal or no security mechanisms
  - Trust and reputation management is needed
    - Need to be able to trust peers to provide accurate results and data
    - Reputation schemes allow peers to gain positive/negative feedback
  - Anonymity versus Identification
    - Anonymity: try to hide who is accessing resources, provide free-speech
      - E.g. Freenet makes it very hard for tracing where data came from; hence hard to legally prove who is storing/distributing illegal content
    - Identification: necessary in commercial systems to manage access and trust
  - Denial of service attacks
    - E.g. False routing information in Chord can make the system useless (cannot find keys)
    - E.g. easy to flood a Gnutella network, severely reducing performance