Peer-to-peer systems

Netzprogrammierung
(Algorithmen und Programmierung V)
Where are we on our topic map?

Descriptive models for distributed system design

Physical model

Architectural model

Architectural elements

Communicating entities
- Processes
- Objects
- Components
- Web Services

Communication paradigm
- Inter-process communication
  - UDP sockets
  - TCP sockets
  - Multicast
- Indirect communication
- Remote invocation

Roles and responsibilities
- Architectural styles
  - Client-server
  - Peer-to-peer

Place***
- Multiple server
- Proxy/Cache
- Mobile code

Architectural patterns

- Vertical distribution
  - Multi-tier
  - Thin/Fat Client
- Horizontal distribution

Interation model

Interaction model

Failure model

Security model

Claudia Müller-Birn, Netzprogrammierung 2011/12
Our topics today in more detail

Basics of peer-to-peer systems: motivation, characteristics, and examples

Distributed object location and routing in peer-to-peer systems

Unstructured peer-to-peer systems
  • Napster
  • Gnutella

Structured Peer-to-Peer systems based on the concept of distributed hash tables
  • Pastry
Peer-to-peer systems

Introduction
Motivation

Peer-to-peer systems (P2P systems) represent a paradigm for the construction of distributed systems and applications in which data and computational resources are contributed by many hosts on the Internet.

P2P systems enable the sharing of data and resources on a very large scale by eliminating any requirement for separately managed servers and their associated infrastructure.

P2P systems have been used to provide file sharing, web caching, information distribution and other services, exploiting the resources of tens of thousands of machines across the Internet.
Characteristics of peer-to-peer systems

The design of P2P systems ensure that each user contributes resources to the system.

Although user may differ in the resources that they contribute, all the nodes in a P2P system have the same functional capability and responsibility.

The correct operation of a P2P system does not depend on the existence of any centrally administered systems.

A key issue for the efficient operation of an P2P system is the choice of the algorithm for the placement of data across many hosts and subsequent access to it in a manner that balances the workload and ensures availability without adding undue overheads.
Distributed object location and routing

The operation of any peer-to-peer content distribution system relies on a network of peer computers (nodes) and connections (edges) between them.

This network is formed on top of-and independently from-the underlying physical computer (typically IP) network, and is thus referred to as an "overlay" network.

The topology, structure and degree of centralization of the overlay network, and the routing and location mechanisms it employs for messages and content are crucial to the operation of the system.

Overlay networks can be distinguished in terms of their
• centralization and
• structure

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Overlay network centralization

Purely decentralized architectures

- All nodes in the network perform exactly the same tasks, acting both as servers and clients ("servents")
- There is no central coordination of their activities

Hybrid decentralized architectures

- Some of the nodes are supernodes, acting as local central indexes
- Supernodes are dynamically assigned (varies between different systems) and if they fail they are automatically replaced with others

Centralized architectures

- Central server facilitating the interaction between peers
- Server maintains directories of meta-data describing the shared files stored by the peer nodes
- Server performs the lookups and identifying the nodes storing the files
Unstructured overlay network

The placement of content (files) is completely unrelated to the overlay topology.

In an unstructured network, content typically needs to be located.
- Location of resource only known to submitter
- Peers & resources have no special identifier
- Each peer is responsible only for the resources it submitted
- Introduction of new resource at any location

The main task is to search
- Find all peers storing/being in charge of resources fitting to some criteria
- Communicate directly peer-to-peers having identified these peers

Examples: Napster, Gnutella
Structured overlay network

The overlay topology is tightly controlled and files (or pointers to them) are placed at precisely specified locations. These systems essentially provide a mapping between content (e.g. file identifier) and location (e.g. node address), in the form of a distributed routing table.

- Location of resources not only known to submitter
- Each peer may well be responsible for resources it has not submitted
- Introduction of new resource(s) at specific location, i.e. to give peers and resources (unique) identifiers
- PeerIDs and ObjectIDs (RessourceIDs) should be from the same key set
- Each peer is responsible for a specific range of ObjectIDs (i.e., RessourceIDs)

The main task is to lookup

- To “route” queries across the overlay network to peers with specific IDs

Example: Pastry
<table>
<thead>
<tr>
<th>Client-Server</th>
<th>Peer-to-Peer</th>
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<tbody>
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1. Server is the central entity and only provider of service and content.  
   → Network managed by the Server  
2. Server as the higher performance system.  
3. Clients as the lower performance system  
Example: WWW

(Eberspächer, & Schollmeier 2005)
Peer-to-peer systems
Napster
Brief introduction into Napster

In June 1999, the first peer-to-peer file sharing system, Napster was released.

It is a centralized unstructured peer-to-peer system that requires a central server for indexing and peer discovery.

Napster provided a service where they indexed and stored file information that users of Napster made available on their computers for others to download, and the files were transferred directly between the host and client users after authorization by Napster.

July 2001 Napster was shut down as a result of legal proceedings.
Napster’s method of operation

1. File location request
2. List of peers offering the file
3. File request
4. File delivered
5. Index update
Lessons learned from Napster

Napster took advantage of special characteristics of the application, such as music files are never updated, and no guarantees are required concerning the availability of individual files.

The advantage of centralized systems is that they are simple to implement and they locate files quickly and efficiently.

Their main disadvantage is that they are vulnerable to censorship, legal action, surveillance, malicious attack, and technical failure, since the content shared, or at least descriptions of it and the ability to access it are controlled by the single institution, company or user maintaining the central server.

Furthermore, these systems are considered inherently unscalable, as there are bound to be limitations to the size of the server database and its capacity to respond to queries. Large web search engines have however repeatedly provided counterexamples to this notion.
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(Eberspächer, & Schollmeier 2005)
Peer-to-peer systems

Gnutella 0.4
Introducing Gnutella

Gnutella is originally created by Justin Frankel of Nullsoft. As a unstructured approach, there is no overall control over the topology or the placement of objects within the network. Additionally, there is no central coordination of the activities in the network. Users connect to each other directly in an ad-hoc fashion through a software application.

Similarities between Gnutella and Napster
• Users place the files they want to share on their hard disks and make them available to everyone else for downloading in peer-to-peer fashion.
• Users run a piece of Gnutella software to connect to the Gnutella network.

Differences between Gnutella and Napster
• There is no central database that knows all of the files available on the Gnutella network. Instead, all of the machines on the network tell each other about available files using a distributed query approach.
• There are many different client applications available to access the Gnutella network.
Gnutella protocol messages

Broadcast Messages
• **Ping**: initiating message (“I’m here”)
• **Query**: search pattern and TTL (time-to-live)

Back-Propagated Messages
• **Pong**: reply to a ping, contains information about the peer
• **Query response**: contains information about the computer that has the needed file

Node-to-Node Messages
• **GET**: return the requested file
• **PUSH**: push the file to me

(Horowitz 2002)
Gnutella characteristics

Scalability
• When a node receives a ping/query message, it forwards it to the other nodes
• Existing mechanisms to reduce traffic

TTL counter
• Cache information about messages they received, so that they don't forward duplicated messages

Anonymity
• Gnutella provides for anonymity by masking the identity of the peer that generated a query
Gnutella search mechanism

Steps:

1. Node 2 initiates search for file A

(Horowitz 2002)
Gnutella Search Mechanism

Steps:

1. Node 2 initiates search for file A
2. Sends message to all neighbors

(Horowitz 2002)
Gnutella Search Mechanism

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3. Neighbors forward message

(Horowitz 2002)
Gnutella Search Mechanism

Steps:

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3. Neighbors forward message
4. Nodes that have file A initiate a reply message

(Horowitz 2002)
Gnutella Search Mechanism

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Gnutella Search Mechanism

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1. Node 2 initiates search for file A
2. Sends message to all neighbors
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4. Nodes that have file A initiate a reply message
5. Query reply message is back-propagated
6. File download

(Horowitz 2002)
Gnutella search strategy: Flooding

Simple and robust
• No state maintenance needed
• High tolerance to node failures
Effective and of low latency
• Always find the shortest / fastest routing paths
HOPS = 0

HOPS = 1

HOPS = 2

HOPS = 3

HOPS = 4

HOPS = 5

HOPS = 6

Pure Flooding in P2P Overlay
Gnutella search strategy: Flooding

Simple and robust
• No state maintenance needed
• High tolerance to node failures

Effective and of low latency
• Always find the shortest / fastest routing paths

Problems of Flooding
• Loops in Gnutella networks
  - Caused by redundant links
  - Result in endless message routing
• Current solutions by Gnutella
  - Detect and discard redundant messages
  - Limit TTL (time-to-live) of messages
### Client-Server vs. Peer-to-Peer

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### Unstructured P2P vs. Structured P2P

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2. Any terminal entity can be removed without loss of functionality  
3. → No central entities | 1. All features of Peer-to-Peer included  
2. Any terminal entity can be removed without loss of functionality  
3. → dynamic central entities |  
Example: WWW | Example: Napster | Example: Gnutella 0.4, Freenet | Example: Gnutella 0.6, JXTA |

(Eberspächer, & Schollmeier 2005)
Peer-to-peer systems

Gnutella 0.6
Improvements of the new protocol

The new protocol implements a unstructured, hybrid architecture.

All peers still cooperate to offer the service but some nodes, i.e. ultrapeers, are designated to have additional resources.

Normal nodes, i.e. leaves, connect themselves to a small number of ultrapeers which are heavily connected to other ultrapeers (> 32 connections).

The maximal number of hops required for exhaustive search is dramatically reduced.

A new protocol has been introduced: the Query Routing Protocol (QRP) which has been designed to reduce the number of queries issued by each node.

Additionally, each node produces a Query Routing Table (QRT) containing the hash values representing the files available on that node.
Key elements in the Gnutella 2 protocol
## Client-Server vs. Peer-to-Peer

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<td>4. Connections in the overlay are “fixed”</td>
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<td>Examples: Chord, CAN</td>
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(Eberspächer, & Schollmeier 2005)
Peer-to-peer systems
Pastry
Overview about Pastry

P2P overlay that is using Dynamic Hash Tables (DHT) with prefix-based routing with both peer ID and object ID.

Prefix routing narrows the search for the next node along the route by applying a binary mask that selects an increasing number of hexadecimal digits from the destination GUID after each hop.

It is originally developed Microsoft and Rice Uni but a free version (FreePastry) exists that is a prototypical Implementation of Pastry. The latter is mostly used by scientific community.

Similar algorithms are Chord and CAN.
Motivation for distributed indexing

Flooding
- Communication Overhead
- False negatives

Distributed Hash Table
- Scalability: O(log N)
  - i.e. Never (answer YES... if it is NOT there)
- More resistant against changes
  - Failures, Attacks
  - Short time users

Central Server
- Bottlenecks:
  - Memory, CPU, Network
  - Availability

Communication Overhead
- O(N)
- O(log N)
- O(1)

Node State
- O(1)
- O(log N)
- O(N)
Mode of operation of a distributed hash table

every node stores and maintains part of hash table

every object / resource has a (hash) key which is stored at node responsible for its key

lookup(key) -> node or data directly
Lookup where it is stored and how it is identified there
Distributed hash table: steps of operation

1. Mapping of nodes and data - same address space
   - Peers and content are addressed using flat identifiers (IDs)
   - Common address space for data and nodes
   - Nodes are responsible for data in certain parts of the address space
   - Association of data to nodes may change since nodes may disappear

2. Storing / Looking up data in the DHT
   - “Look-up” for data = routing to the responsible node
   - Responsible node not necessarily known in advance
   - Deterministic statement about availability of data
First four rows of a Pastry routing table

<table>
<thead>
<tr>
<th>$p =$</th>
<th>GUID prefixes and corresponding nodehandles $n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 1 2 3 4 5 6 7 8 9 A B C D E F</td>
</tr>
<tr>
<td></td>
<td>n n n n n n n n n n n n n</td>
</tr>
<tr>
<td>1</td>
<td>60 61 62 63 64 65 66 67 68 69 6A 6B 6C 6D 6E 6F</td>
</tr>
<tr>
<td></td>
<td>n n n n n n n n n n n n n</td>
</tr>
<tr>
<td>2</td>
<td>650 651 652 653 654 655 656 657 658 659 65A 65B 65C 65D 65E 65F</td>
</tr>
<tr>
<td></td>
<td>n n n n n n n n n n n n n</td>
</tr>
<tr>
<td>3</td>
<td>65A0 65A1 65A2 65A3 65A4 65A5 65A6 65A7 65A8 65A9 65AA 65AB 65AC 65AD 65AE 65AF</td>
</tr>
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<td>n n n n n n n n n n n n n</td>
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Pastry routing example

0 | FFFFFFFFFFFFFF (2^{128})

65A1FC

D46A1C

D4213F

D13DA3

D462BA

D467C4

D471F1
Distributed objects and components I (CORBA)

**Summary**
Comparison of discussed algorithms

<table>
<thead>
<tr>
<th>PsP system</th>
<th>Model</th>
<th>Parameters</th>
<th>Hops to locate data</th>
<th>Routing state</th>
<th>Peers joins and leaves</th>
<th>Reliability</th>
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<tbody>
<tr>
<td>Napster</td>
<td>Centralized metadata index; Location inquiry from central server; Download directly from peer</td>
<td>None</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Central server returns multiple download locations; client can retry</td>
</tr>
<tr>
<td>Gnutella</td>
<td>Broadcast request to as many peers as possible, download directly</td>
<td>None</td>
<td>no guarantee</td>
<td>Constant</td>
<td>Constant</td>
<td>Receive multiple replies from peers with available data; requester can retry</td>
</tr>
<tr>
<td>Pastry</td>
<td>Plaxton-style global mesh</td>
<td>N – number of peers in network, b – base of the chosen identifier</td>
<td>logbN</td>
<td>logbN</td>
<td>logN</td>
<td>Replicate data across multiple peers; Keep track of multiple paths to each peer</td>
</tr>
</tbody>
</table>
What have we discussed today?

• We discussed different approaches to realize peer-to-peer systems. The earliest representative was pretty close to the c/s architecture.

• The approaches can be differentiated concerning the network structure and centrality. Starting here, we can explain the three/four examples and their general differences.

• We had a short introduction into overlay networks and how they are used.

• The concept of distributed hash tables in the context of structured peer-to-peer systems has been described and we are now able to explain it.
References


