Lecture 5

P2P with TomP2P

http://tomp2p.net

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0. Lecture Overview

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5. Advanced Topics in TomP2P
   1. Bloom Filters
14.03.2016 Starker Auftritt der Schweizer IT-Industrie an der weltweit grössten Computermesse. Aber auch die Konkurrenz schläft nicht.

- Coinblesk @CeBIT
- Currently: 2 MA (Andreas, Alessandro), 1 BA (Christian)

09.03.2016 UZH an der CeBIT 2016: Schnell und sicher mit Bitcoins mobil bezahlen

17.03.2016 Blitzschnelle Bitcoins

14.03.2016 Ethereum Blockchain Project Launches First Production Release

- Fundamental change in the protocol makes older versions incompatible → hard fork
- Bitcoin Classic vs. Core
1. Introduction

What is TomP2P

History and project information
TomP2P is a P2P framework/library

- Implements DHT (structured), broadcasts ([un]structured), direct messages (can implement super-peers)
- NAT handling: UPNP, NATPMP, new addition: relays, hole punching (work in progress)
- Direct / indirect (tracker / mesh) storage
- Direct / indirect replication (churn prediction and ~rsync)
- Modes: key,value / multi-key (versioned) value
- Java 6, Maven, Github, Netty, TCP/UDP, MapDB, (Android)
TomP2P extends DHT

- Distributed hash table concept → put(key, value) / get(key)
- Extended DHT operations →
  - put(key1, key2, value)
  - put prepare / put confirm
  - add(value)
  - digest(key) / bloomfilters / versions
  - get(key) + bloomfilters
Introduction

TomP2P
A P2P-based high performance key-value pair storage library

- TomP2P history
  - TomP2P v1: Created in 2004 and used for a distributed DNS project
    - This version used blocking IO operations (1 thread / socket)
  - TomP2P v2: Apache MINA (java.nio framework) / 6K LoC
    - Not well designed for non-blocking operations (event-driven)
  - TomP2P v3: Redesigned for non-blocking operations
    - Switched to Netty / 14K LoC, 6K LoC JUnits
  - TomP2P v4: API refinements, new features
    - Latest feature (work in progress) MapReduce
    - 19K LoC (core), 6K LoC JUnits (core)
  - TomP2P v5 (core 18K LoC): modularization, relays, API refinements
Introduction

TomP2P
A P2P-based high performance key-value pair storage library

• TomP2P started in 24.05.2004
  ▶ Github: watch 34 / star 192 / fork 68 (not sure if good/bad)
  ▶ TomP2P website (although documentation is outdated)
  ▶ 75 users on the mailinglist
  ▶ 11 contributors on github
  ▶ Don’t buy the book!
Introduction

TomP2P
A P2P-based high performance key-value pair storage library

- Academic background (CSG - UZH):
  - Used in EU projects: EC-GIN, Emanics, SmoothIT, SmartenIT, Flamingo
  - Used in research projects: LiveShift, DRFS, Radiommender, Box2Box, Hive2Hive, B-Tracker, PiCsMu, peerwasp, (and non-academic)
- [http://tomp2p.net](http://tomp2p.net)
  - For questions: mailinglist ([http://lists.tomp2p.net/cgi-bin/mailman/listinfo](http://lists.tomp2p.net/cgi-bin/mailman/listinfo))
  - Specific questions: bocek -at- ifi.uzh.ch or tom -at- tomp2p.net
  - Documentation: http://tomp2p.net/doc/ (TomP2P v4.4)
    - If something is missing, ask! – Documentation for v5 is missing!
  - Development: https://github.com/tomp2p
    - Feature request possible if good reasons provided
- (Demo: how to setup TomP2P with Netbeans/git/maven)
Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **A Declarative Interface for Smart-phone Based Sensor Network Systems**, Asanka Sayakkara and Kasun De Zoysa, *IWMS 2012*, Beijing, China
- **Hybrid Peer-to-Peer DNS**, Ricardo Sancho and Ricardo Lopes Pereira, Instituto Superior Tecnico, Porto, Portugal
Introduction

TomP2P
A P2P-based high performance key-value pair storage library

- **Adding Cryptographically Enforced Permissions to Fully Decentralized File Systems** – TUM, Bernhard Amann, Thomas Fuhrmann, April 2011
- **Optimis FP7 IP project**: Optimized Infrastructure Services, D1.2.1.3, Architecture Design document, ended May 2013
- **Distributed Name-based Entity Search**, Fausto Giunchiglia and Alethia Hume, ISWC 2012, Boston
- **A Distributed Directory System**, Fausto Giunchiglia and Alethia Hume, SSWS 2013, Sydney
Introduction

**TomP2P**
A P2P-based high performance key-value pair storage library

- **A P2P Semantic Query Framework for the Internet of Things**, Richard Mietz, Sven Groppe, Oliver Kleine, Daniel Bimschas, Stefan Fischer, Kay Römer and Dennis Pfisterer, PIK, Volume 36, Issue 2 (May 2013)
- **P2P Minecraft**: “The mods described below are about adding peer-to-peer functionalities to Minecraft.”
- **Bitcoin Gateway - A Peer-to-peer Bitcoin Vault and Payment Network**, Omar Syed & Aamir Syed, July 2011
- **Bitsquare.io** – The decentralized bitcoin exchange, switched to Tor
Introduction

- TomP2P with Android (early research)
  - CSG: early adopter
  - TomP2P 5 and Android: work in progress
2. Example

Example and Demo
Example

- Demo: a simple put / get example
- Package net.tomp2p.examples. ExamplePutGet

```java
private static void examplePutGet(final PeerDHT[] peers, final Number160 nr) throws IOException, ClassNotFoundException {
    FuturePut futurePut = peers[PEER_NR_1].put(nr).data(new Data("hallo")).start();
    futurePut.awaitUninterruptibly();
    System.out.println("peer " + PEER_NR_1 + " stored [key: " + nr + ", value: " + "hallo"]");
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    futureGet.awaitUninterruptibly();
    System.out.println("peer " + PEER_NR_2 + " got: " + futureGet.data().object() + " for the key " + nr);
    // the output should look like this:
    // peer 30 stored [key: 0xba419d350dfe8af7ae87be10c45c0284f083ce4, value: "hallo"]
    // peer 77 got: "hallo" for the key 0xba419d350dfe8af7ae87be10c45c0284f083ce4
}
```

- Defaults
  - Replication factor 6, replication not enabled,
  - domain, content, version are zero if not specified
3. Fundamental Concepts

XOR-based iterative routing
Futures
API Overview
Fundamental Concepts (repetition)

- Recursive routing  vs.  iterative routing

+ online status update
- faulty peers cause delay

+ control
- neighbor maintenance
Fundamental Concepts (repetition)

- **TomP2P: iterative XOR-based routing**
  - Node and data item unique 160bit identifier
  - Keys are located on the nodes whose node ID is closest to the key
  - Search for a key:
    - Lookup in neighbor table for closest peer (e.g. peers with ID: 0x1, 0x2, 0x3, 0x4)

<table>
<thead>
<tr>
<th>My ID</th>
<th>Neighbor ID</th>
<th>Distance (XOR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

- Difference to Pastry: one metric, no leaf set / routing table
Fundamental Concepts

- **TomP2P iterative XOR-based routing**
  - Neighbors stored in 159 “bags”, bag has capacity c (Kademlia, c=20)
  - Routing takes $O(\log n) \rightarrow M03$, slides 15
  - By default UDP, message header 63 bytes
  - Routing Mechanism variables, can be tuned
    - directHits, potentialHits – routing sends digest
    - forceTCP – use TCP instead of UDP
    - maxDirectHits, maxNoNewInfo, maxSuccess, maxFailure – stop conditions
    - parallel – number of parallel connections
  - For the CT - don’t worry, default settings are fine 😊
Fundamental Concepts

- Distributed operations use futures (~promises, Guava)
- Future objects
  - Keeps track of future events, while the “normal” program flow continues → addListener() or await()
  - await(): Operations are executed in same thread
  - addListener(): Operations are executed in same or other thread
- Demo: blocking operation (net.tomp2p.examples.ExamplePutGet)

```java
private static void exampleGetBlocking(final PeerDHT[] peers, final Number160 nr)
    throws ClassNotFoundException, IOException {
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    // blocking operation
    futureGet.awaitUninterruptibly();
    System.out.println("result blocking: " + futureGet.data().object());
    System.out.println("this may *not* happen before printing the result");
}```
Fundamental Concepts

- Demo: non-blocking operation (net.tomp2p.examples.ExamplePutGet)
  
  ▶ New utilities necessary (loops as recursions)
  
  ▶ Advise: use `addListener(...)` as much as possible!
  
  ▶ `operationComplete(...)` must be always called (problem if not)

```java
private static void exampleGetNonBlocking(final PeerDHT[] peers, final Number160 nr) {
    FutureGet futureGet = peers[PEER_NR_2].get(nr).start();
    // non-blocking operation
    futureGet.addListener(new BaseFutureAdapter<FutureGet>() {
        @Override
        public void operationComplete(FutureGet future) throws Exception {
            System.out.println("result non-blocking: " + future.data().object());
        }
    });
    System.out.println("this may happen before printing the result");
}
```
Fundamental Concepts

• Future utilities
  ▶ FutureForkJoin(int nr, boolean cancel, K... Forks)
    - Joins already “forked” futures. Waits until all or nr future finished. If nr reached, futures may be cancelled (e.g. abort download)
  ▶ FutureLateJoin(int nrMaxFutures, int minSuccess)
    FutureLaterJoin()
    - No need to add the futures in the constructor, can be added later
  ▶ FutureDone()
    - A generic future used in many places, can be placeholder

• ForkJoin in Java7
  ▶ Fork and join framework – future utilities in TomP2P focus on join, forking is done “manually”

• Needs face-lifting, Java8 with CompletableFuture
Fundamental Concepts

- **Fun with futures: loops**

```java
Future loop() {
    Future future = new Future();
    recLoop(future);
    return future;
}

void recLoop(Future future) {
    int active = 0;
    for (int i = 0; i < parallel; i++) {
        // if future finished, it will be set to null
        if (futureResponses[i] == null)
            active++;
        else if (futureResponses[i] != null) active++;
    }
    if (active == 0) future.weAreDone();
    FutureForkJoin<FutureResponse> fp = new FutureForkJoin<FutureResponse>(1, futureResponses);
    fp.addListener(new BaseFutureAdapter<FutureForkJoin<FutureResponse>>() {
        @Override
        public void operationComplete(FutureForkJoin<FutureResponse> future)
            throws Exception {
            boolean finished = evaluate(future);
            if (finished) future.weAreDone();
            else recLoop(future);
        }
    });
    
    recLoop(future);
}
```
Fundamental Concepts

- Java 8 lambda expressions not used
- .NET and other languages have better support for async

▶ Example

```csharp
public async Task MyMethod()
{
    Task<int> longRunningTask = LongRunningOperation();
    //indeed you can do independent to the int result work here

    //and now we call await on the task
    int result = await longRunningTask;
    //use the result
    Console.WriteLine(result);
}

public async Task<int> LongRunningOperation() // assume we return an int from this
{
    await Task.Delay(1000); // 1 seconds delay
    return 1;
}
```
Fundamental Concepts

- **API Overview: Peer.java**
  - Core methods, network related
    - `sendDirect()`
    - `bootstrap()`
    - `announceShutdown()`
    - `ping()`
    - `discover()`
    - `broadcast()`
  - Methods for DHTs (PeerDHT.java)
    - `put(key, value)`
    - `get(key)`
    - `add(key)`
    - `digest(key)`
    - `remove(key)`
    - `send(key)`
    - `parallelRequest(key)` // mostly used internally
Fundamental Concepts

• Extensions

  ▶ TomP2P can store multiple values for a key
    □ put() (location_key, content_key, value) → content_key specified in Builder
    □ get().all() → returns a map with [content_key, value]
    □ add() (location_key, value) → is translated to put() (location_key, hash(value), value)

  ▶ TomP2P support domains
    □ Avoid collision for same keys
    □ Domains are used for protection (more details later)
    □ Domains specified in Builder
    □ put() (key, domain, value) → get() (key, domain)
**Fundamental Concepts 4.x**

- **Configurations Example**
  - Configuration with builder pattern
    ```java
    byte data = new byte((int) 1); // Use byte instead of String
    RoutingConfiguration rc = new RoutingConfiguration(0, 0, 1);
    RequestP2PConfiguration pc = new RequestP2PConfiguration(1, 0, 0);
    FuturePut fdht = peers[444].put(peers[30].peerID()).data(new Number160(5), data)
      .domainKey(Number160.createHash("test")).routingConfiguration(rc)
      .requestP2PConfiguration(pc).start();
    ```
  - System-wide configuration when creating Peer
    ```java
    Number160 peerId = new Number160(rnd);
    PeerMap peerMap = new PeerMap(new PeerMapConfiguration(peerId));
    master = new PeerBuilder(peerId)
      .ports(port).enableMaintenance(maintenance)
      .bindings(bindings).peerMap(peerMap).start().addAutomaticFuture(automaticFuture);
    peers[0] = new PeerBuilderDHT(master).start();
    ```
5. Components with Examples

DHT
Tracker
Components with Examples (repetition)

- **DHT vs. Tracker**
  - M03, slide 27: DHT “stored by value” – direct storage
  - M03, slide 28: Tracker “stored by reference” – indirect storage
Components with Examples

- **B-Tracker**
  - Centralized tracker – one machine gets traffic
  - DHT: store reference on 20 peers – 20 peers gets traffic
  - PEX: exchange information every minute (push)
  - B-Tracker, every downloading peer becomes a tracker → forms mesh
    - Better balance of load
    - To avoid duplicates send compressed list of known peers
  - B-Tracker in TomP2P enabled by default
Components with Examples

- **Demo: Tracker** *(net.tomp2p.examples.ExampleTracker)*
  - Create 100 peers,
  - Add to tracker, get from tracker
  - Stored on 3 peers: TrackerBuilder.java (can be configured)
  - Attachment of data is possible *(attachement(Data))*

```java
private static void example(final PeerTracker[] peers) throws IOException, ClassNotFoundException {
    FutureTracker futureTracker = peers[12].addTracker(new Number160.createHash("song1")).start().awaitUninterruptibly();
    System.out.println("added myself to the tracker with location [song1]: "+futureTracker.isSuccess() +" I'm: "+peers[12].peerAddress());
    FutureTracker futureTracker2 = peers[24].getTracker(new Number160.createHash("song1")).start().awaitUninterruptibly();
    System.out.println("peer24 got this: "+futureTracker2.trackers());
    System.out.println("currently stored on: "+futureTracker2.trackerPeers());
}
```
Components with Examples

• Demo: Tracker
  ▶ Although demo uses `await()`, try not to use it
  ▶ Tracker vs. DHT what is better for the CT? You decide!

• Further interesting aspects for the challenge task:
  ▶ To be discussed on Thursday
  ▶ Reminder: Thursday starts the challenge task
  ▶ Task presentation and Scrum introduction
5. Bloom Filters
Traditional Bloom Filter

- An array of $m$ bits, initially all bits set to 0
- A bloom filter uses $k$ independent hash functions
  - $h_1, h_2, \ldots, h_k$ with range $\{1, \ldots, m\}$
- Each key is hashed with every hash function
  - Set the corresponding bits in the vector
- Operations
  - Insertion
    - The bit $A[h_i(x)]$ for $1 < i < k$ are set to 1
  - Query
    - Yes if all of the bits $A[h_i(x)]$ are 1, no otherwise
  - Deletion
    - Removing an element from this simple Bloom filter is impossible
Insertion of an Element

Strings $s_i$

Hash Functions

$\begin{align*}
&h_1(s_i) \\
&h_2(s_i) \\
&\vdots \\
&h_k(s_i)
\end{align*}$

Bloom Filter

$m$ bits

1

1
Query of an Element, $m=18$, $k=3$

- Insert $x$, $y$, $z$
- Query $w$

http://en.wikipedia.org/wiki/Bloom_filter
Properties

• **Space Efficiency**
  ▶ Any Bloom filter can represent the entire universe of elements
    ▪ In this case, all bits are 1

• **No Space Constraints**
  ▶ Add never fails
  ▶ But false positive rate increases steadily as elements are added

• **Simple Operations**
  ▶ Union of Bloom filters: bitwise OR
  ▶ Intersection of Bloom filters: bitwise AND
False-Positive Probability

- No false negative, but false positive
- False-positive probability:
  - $n$ number of strings; $k$ hash functions; $m$-bit vector
  \[
  f = \left(1 - e^{-\frac{n k}{m}}\right)^k
  \]

\[\text{False-positive probability}\]

$=>$ Given $m/n$, there is an optimal number of hash functions (opt. $k = m/n \ln 2$) (when 50% of the bits are set)
Examples

- Example for False-positives
  - Insertions
    - Hash ("color printer") => (1,4,6)
    - Hash ("digital camera") => (3,4,5)
    - Bloom filter (1,3,4,5,6)
  - Query
    - Hash ("heat sensor") => (3,4,6)
    - Matches since bits 3,4,6 are all set to 1
  - Online

- False-negative
  - Query
    - Hash ("color printer") => (1,4,6) , matches (1,3,4,5,6) → no false-negative
Bloom Filter Variants (1)

- **Compressed Bloom Filters**
  - When the filter is intended to be passed as a message
  - False-positive rate is optimized for the compressed bloom filter (uncompressed bit vector $m$ will be larger but sparser)
  - However, compression/decompression, more memory

- **Generalized Bloom Filter**
  - Two type of hash functions $g_i$ (reset bits to 0) and $h_j$ (set bits to 1)
  - Start with an arbitrary vector (bits can be either 0 or 1)
  - In case of collisions between $g_i$ and $h_j$, bit is reset to 0
  - Store more bits with low false positive
  - Produces either false positives or false negatives
Bloom Filter Variants (2)

- **Counting Bloom Filters**
  - Entry in the filter not be a single bit but a counter
  - Delete operation possible (decrementing counter)
  - **Variable-Increment Counting Bloom Filter**

- **Scalable Bloom Filter**
  - Adapt dynamically to number of elements, consist of regular Bloom filters
  - “A SBF is made up of a series of one or more (plain) Bloom Filters; when filters get full due to the limit on the fill ratio, a new one is added; querying is made by testing for the presence in each filter”
Example and Applications

- **Demo**
  - Setup: Bloom Filter of size 128 bits, 20 Number160 objects

- **Applications: Distributed Caching, Spell checking, Routing, (distributed) Databases**

- **B-Tracker uses Bloom Filters**
  - “To avoid duplicates send compressed list of known peers”
  - Idea: store peers in Bloom Filter and send it. Other peers only send us peer not in the Bloom Filter
    - Less traffic (request is larger, reply may be smaller)
    - False positive are possible

- **Demo: Bloom Filter for get() in TomP2P**