Internet of Things and Smart Cities Ph.D. School 2014

> COLLECT

CoAP

The Web-based Application-layer Protocol for the Internet of Things

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About the Speaker

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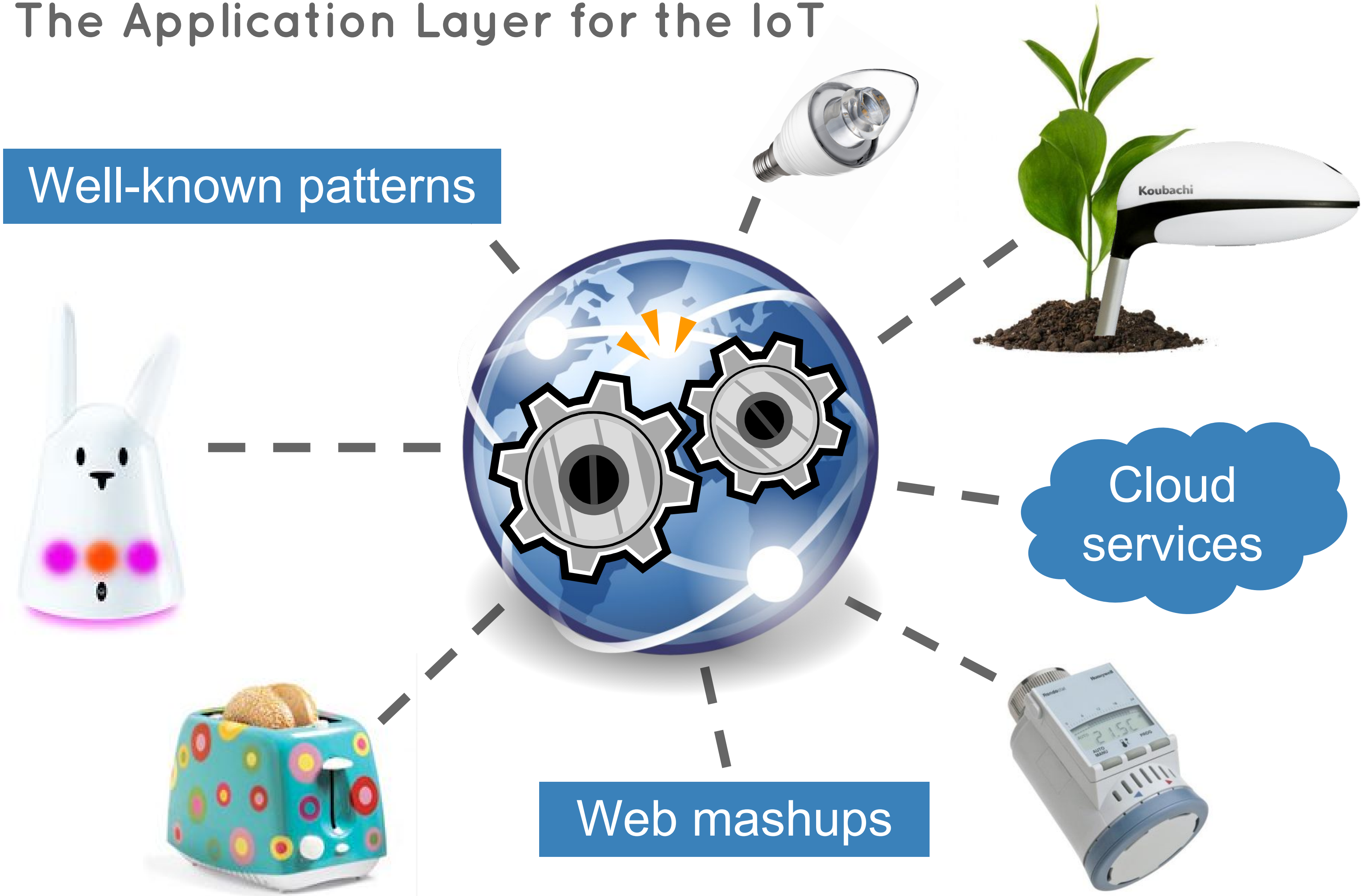
Agenda

- The Web of Things
- The Constrained Application Protocol
- Building RESTful IoT Applications
- Getting Started
  - Erbium (Er) REST Engine
  - Californium (Cf) CoAP framework
  - mjCoAP

The Web of Things (WoT)

The Application Layer for the IoT



Interoperability and Usability

HTTP libraries exist for most platforms

HTTP is the basis for many of our services

Web patterns are well-known

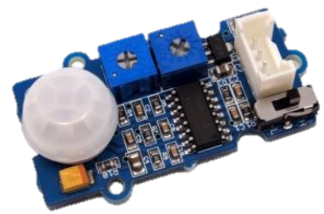
Scripting increases productivity

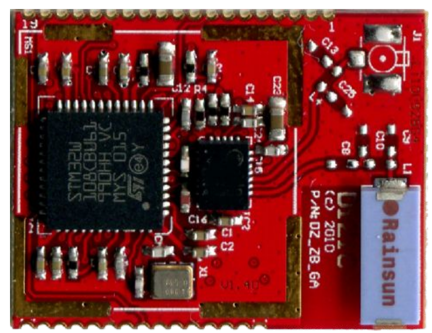
"Kids" can program Web applications

The Web fosters innovation!

Tiny Resource-constrained Devices

Class 1 devices
~100KiB Flash
~10KiB RAM

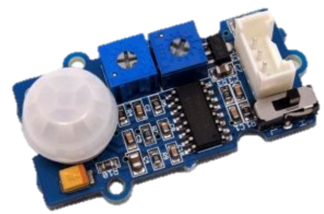


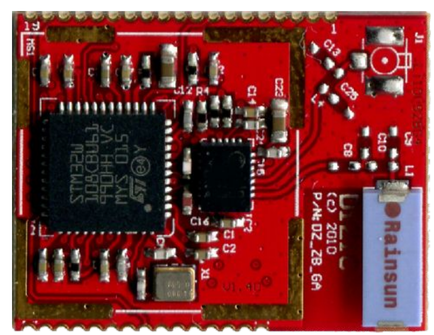


Low-power **networks**

Tiny Resource-constrained Devices

Target
of less than $1





TCP and HTTP
are not a good fit

Constrained Application Protocol

IETF®

Constrained Application Protocol

RESTful protocol designed from scratch

Transparent mapping to HTTP

Additional features for IoT applications

GET, **POST**, **PUT**, **DELETE**
URIs and Internet Media Types

Deduplication
Optional retransmissions

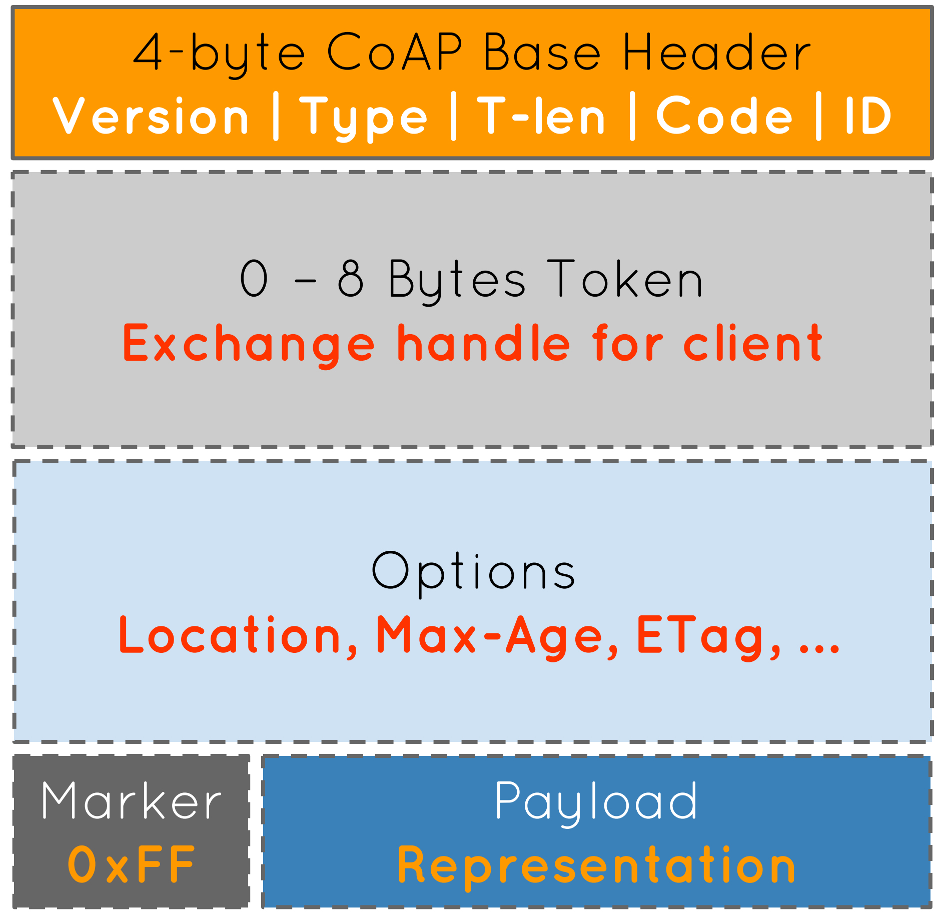
Constrained Application Protocol

Binary protocol

- Low parsing complexity
- Small message size

Options

- Numbers in IANA registry
- Type-Length-Value
- Special option header marks payload if present



CoAP Option Encoding

Delta encoding

- Option number calculated by summing up the deltas
- Compact encoding
- Enforces correct order

Extended header

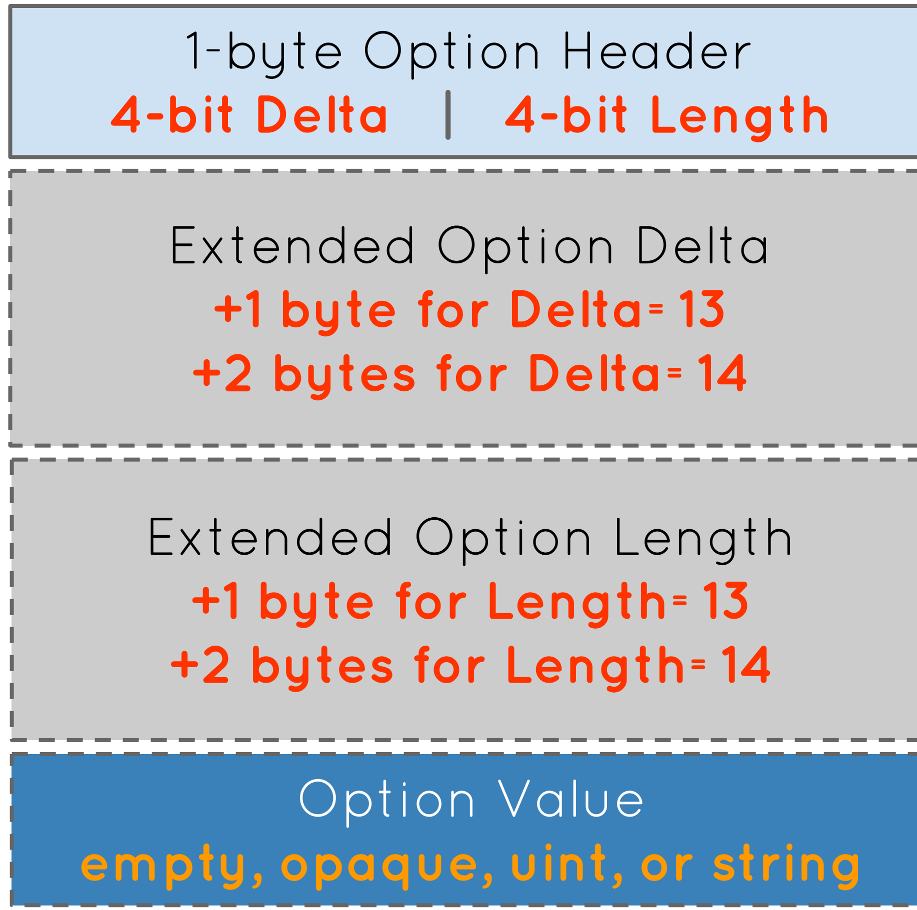
- Jumps to high opt. numbers
- No limitation on opt. length
- Possible values

  +0 bytes: 0 – 12

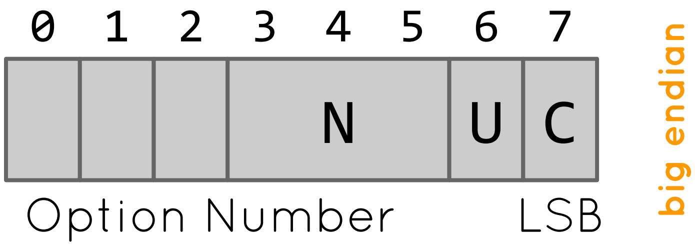
  +1 byte: 13 – 268

  +2 bytes: 269 – 65,804

max. UDP length is 65k



Option Metadata



- Critical (C)
  - Message must be rejected if unknown
  - Elective options be be silently dropped
- UnSafe (U)
  - Proxies may forward messages with unknown options
  - Unless they are marked unsafe
- NoCacheKey (N)
  - Option is not part of the cache key when all three bits are 1 and U=0

Registered Options (RFC 7252)

#	C	U	N	R	Name	Format	Length	Default
1	x			x	**If-Match**	opaque	0-8	(none)
3	x	x	-		**Uri-Host**	string	1-255	IP literal
4				x	**ETag**	opaque	1-8	(none)
5	x				**If-None-Match**	empty	0	(none)
7	x	x	-		**Uri-Port**	uint	0-2	UDP port
8				x	**Location-Path**	string	0-255	(none)
11	x	x	-	x	**Uri-Path**	string	0-255	(none)
12					**Content-Format**	uint	0-2	(none)
14		x	-		**Max-Age**	uint	0-4	60
15	x	x	-	x	**Uri-Query**	string	0-255	(none)
17	x				**Accept**	uint	0-2	(none)
20				x	**Location-Query**	string	0-255	(none)
35	x	x	-		**Proxy-Uri**	string	1-1034	(none)
39	x	x	-		**Proxy-Scheme**	string	1-255	(none)
60			x		**Size1**	uint	0-4	(none)

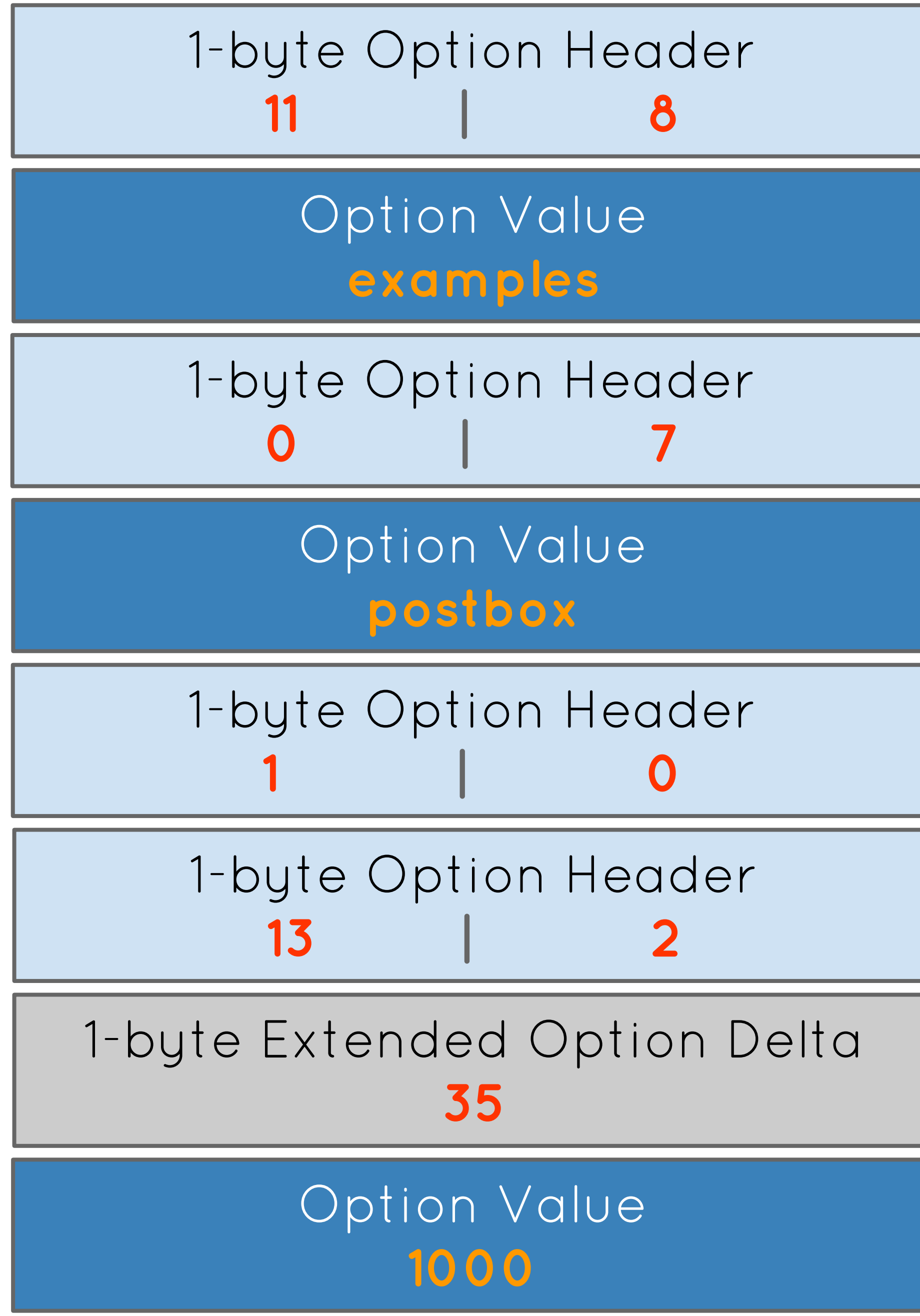
Example

Request

- POST
- Resource **/examples/postbox**
- Content-Format **text/plain**
- **1000** bytes payload

Encoding

- Uri-Path is Option **11**
- Uri-Path is repeatable
- Content-Format is **12**
- text/plain is **0**
- Size1 is Option **60**
- Option Number = Current number + Delta + Extended Delta = 12 + 13 + 35

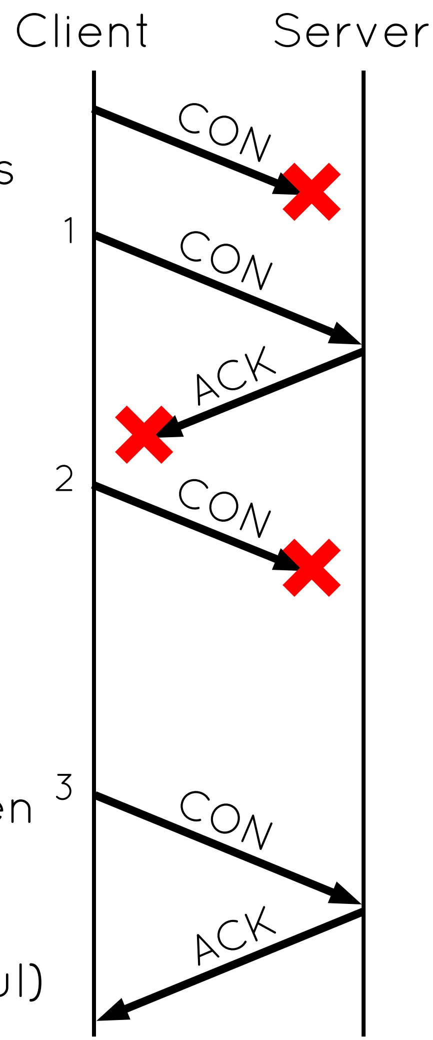


Retransmission of Confirmables

Retransmission after 2–3 s
Randomized timeout to avoid synchronization effects

Binary Exponential Back-Off
Timeout is doubled after each retransmission

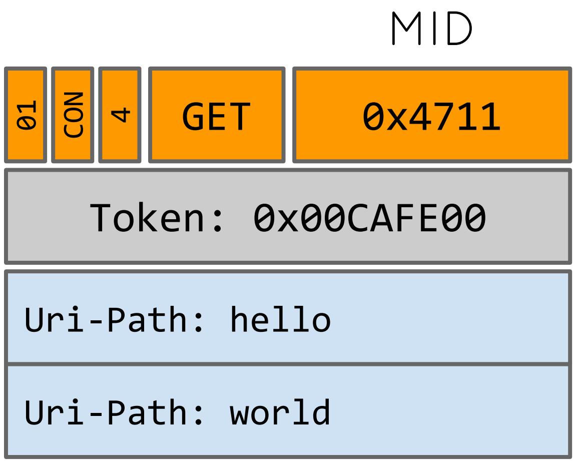
Retransmissions stop when CON is acknowledged or **4 retransmissions** failed (here 3rd one is successful)

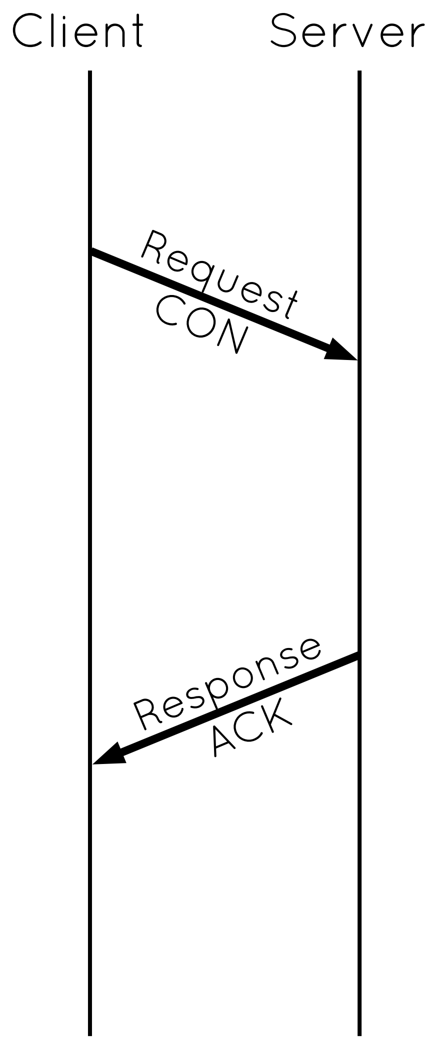


Receiver must send an **Acknowledgement** (ACK) for CONs

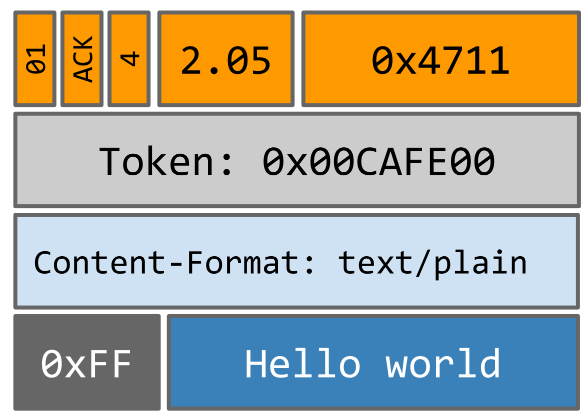
Non-Confirmables are best-effort messages without retransmissions

Requests and Responses





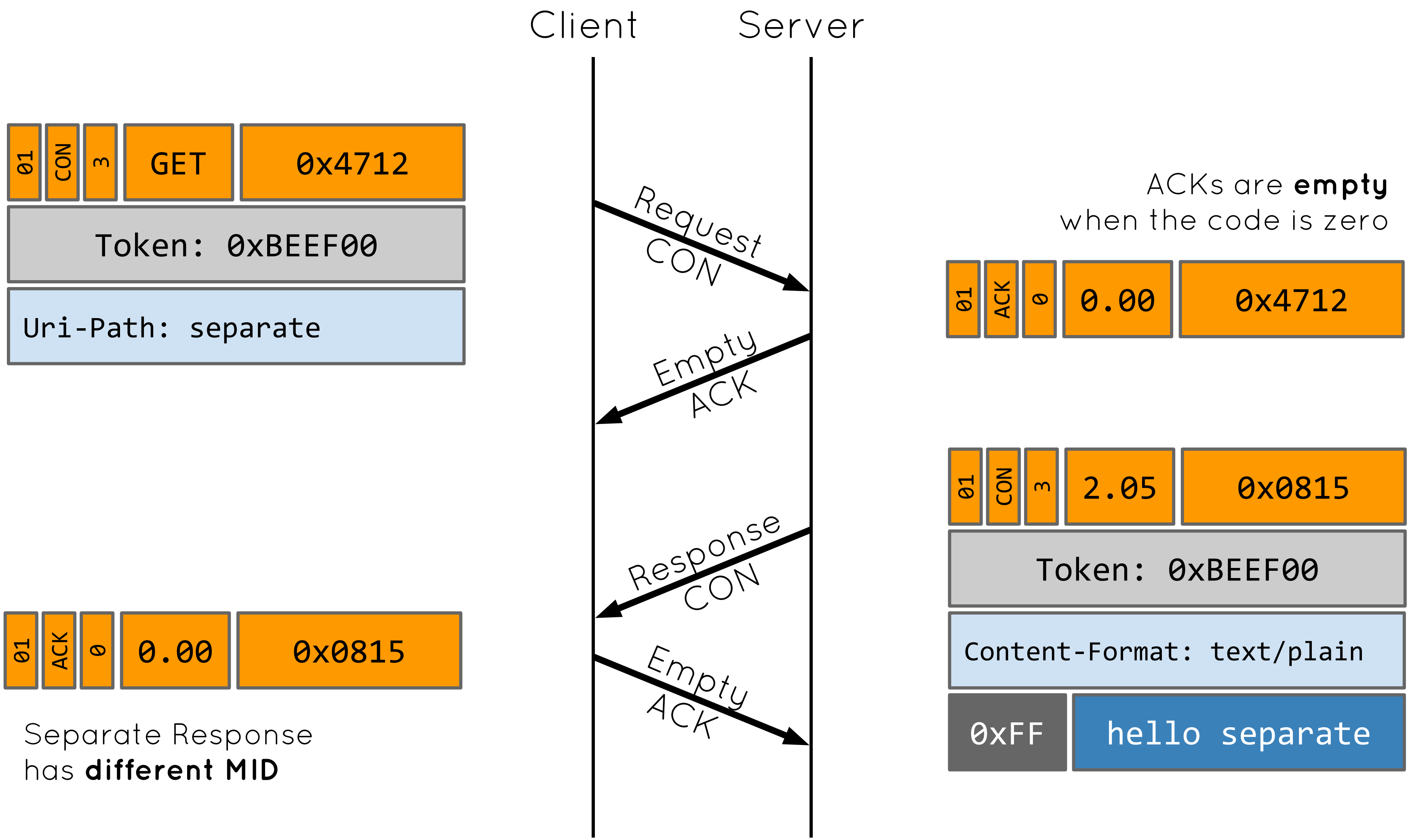
Responses can be **piggybacked** on ACKs



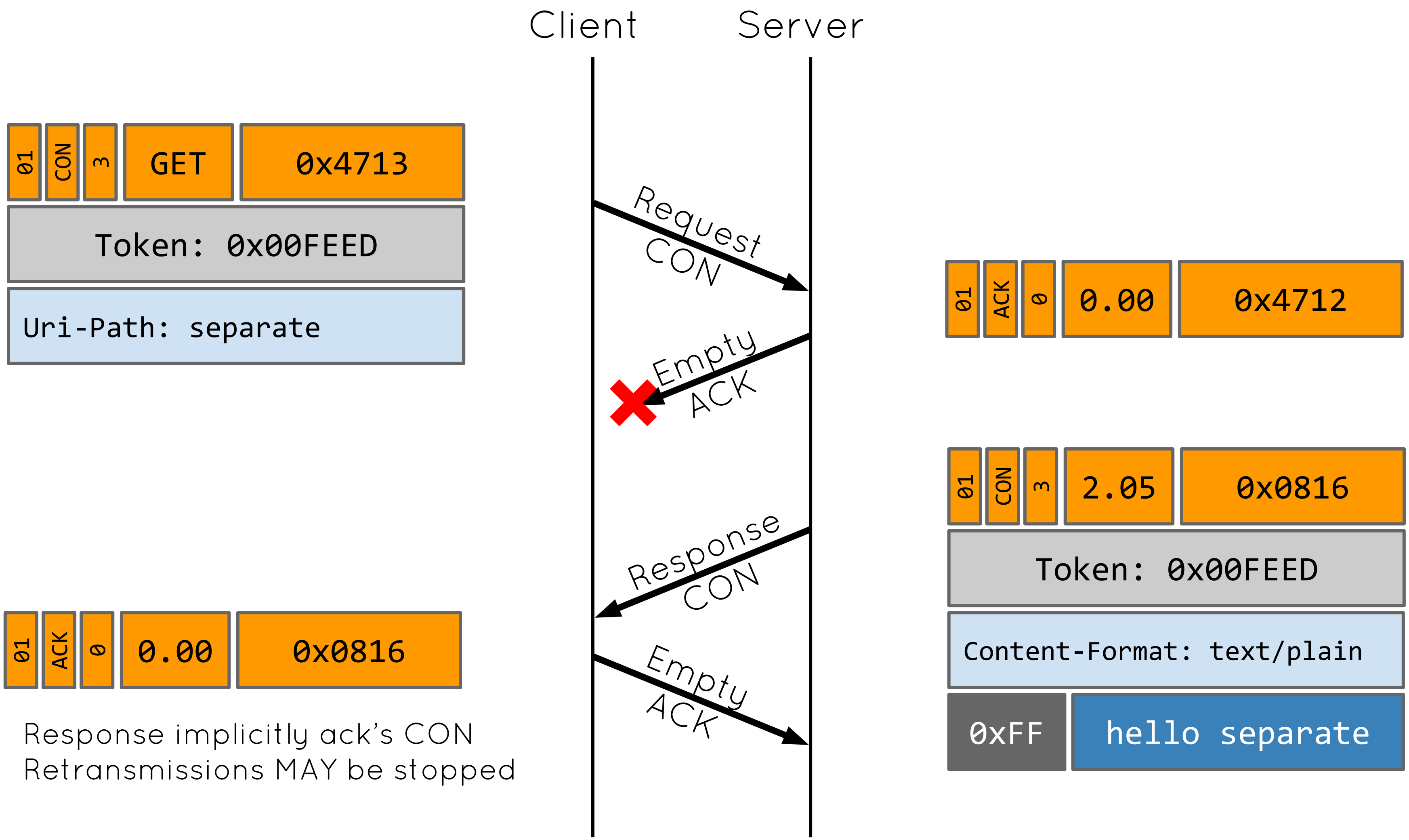
ACK is matched to CON through MID

Response is matched to request through Token **why?**

Separate Responses

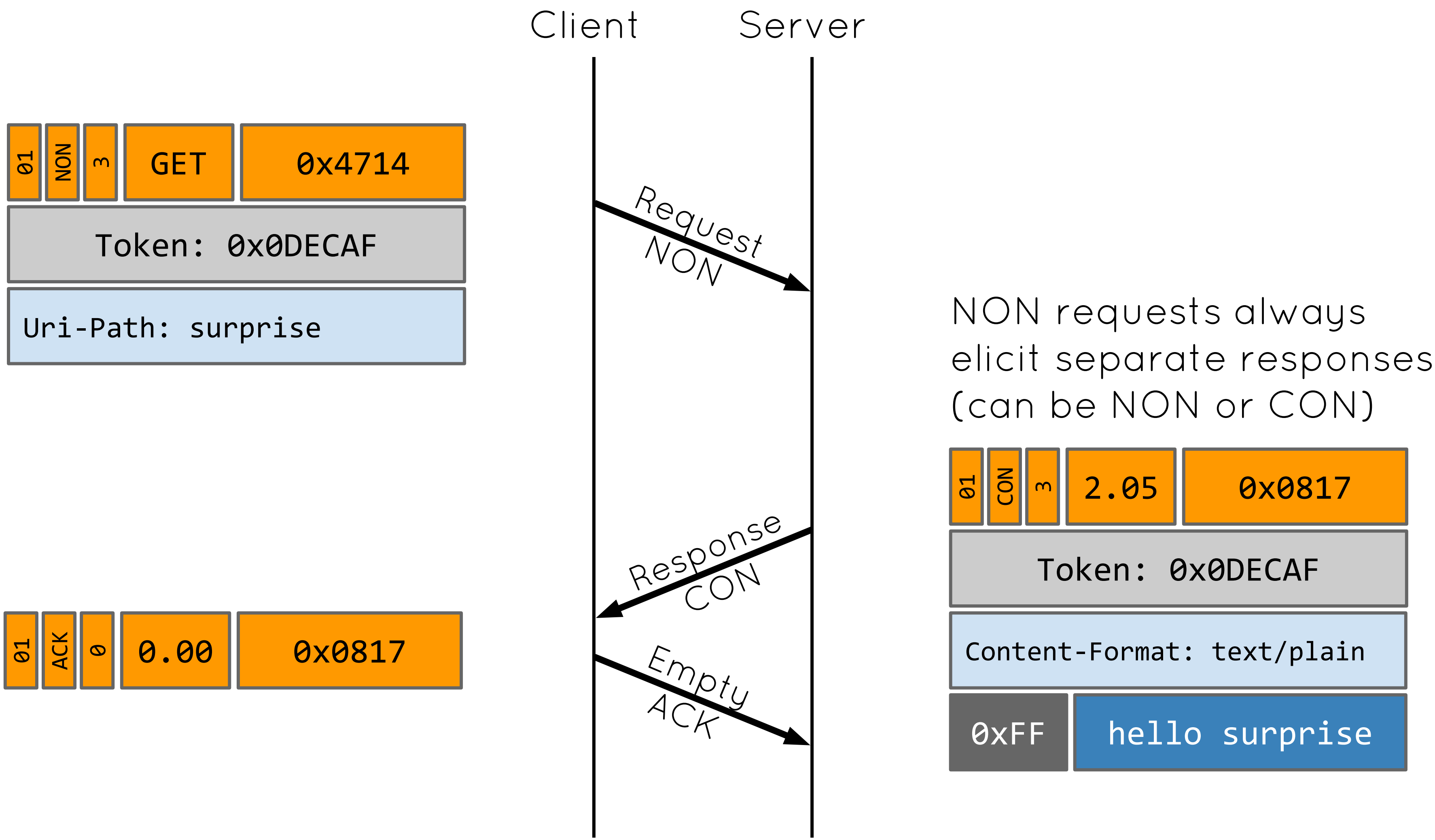


Implicit Acknowledgements

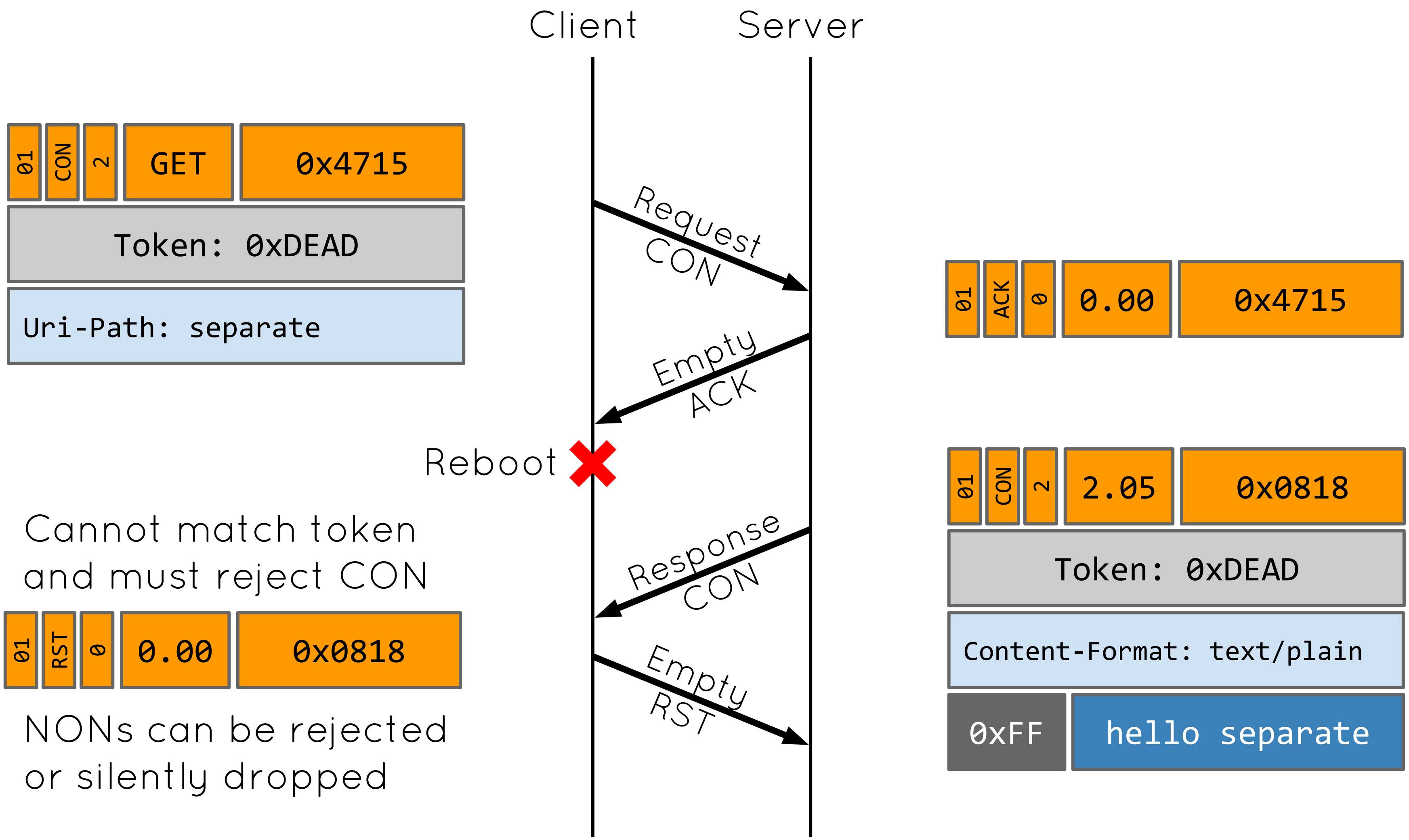


Response implicitly ack's CON
Retransmissions MAY be stopped

Mixed Separate Responses

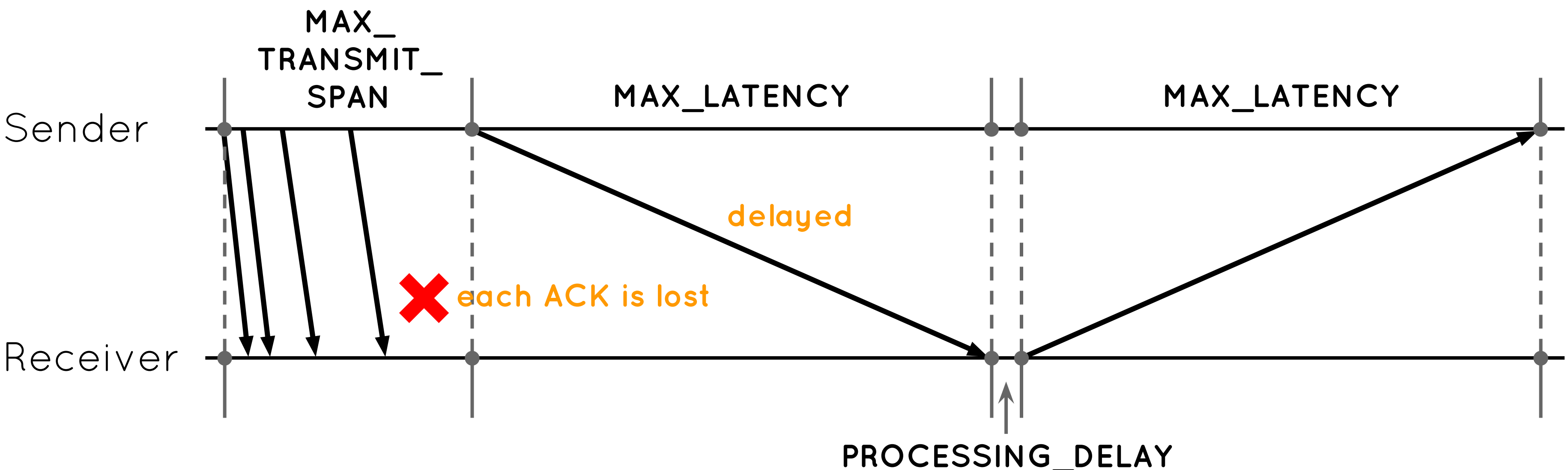


Reset Messages



Deduplication

Worst case transmission

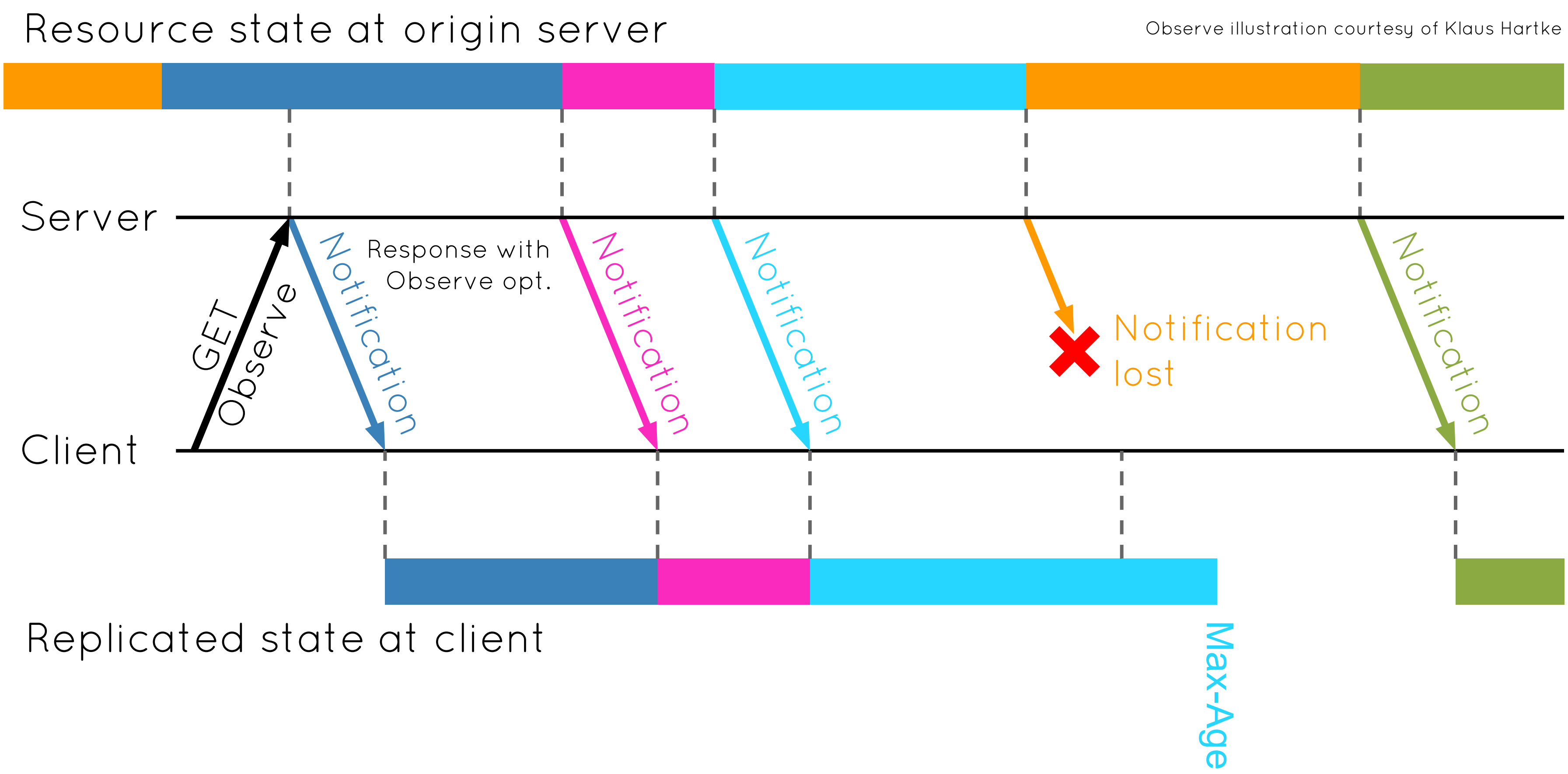


Store sender+**MID** to filter duplicates

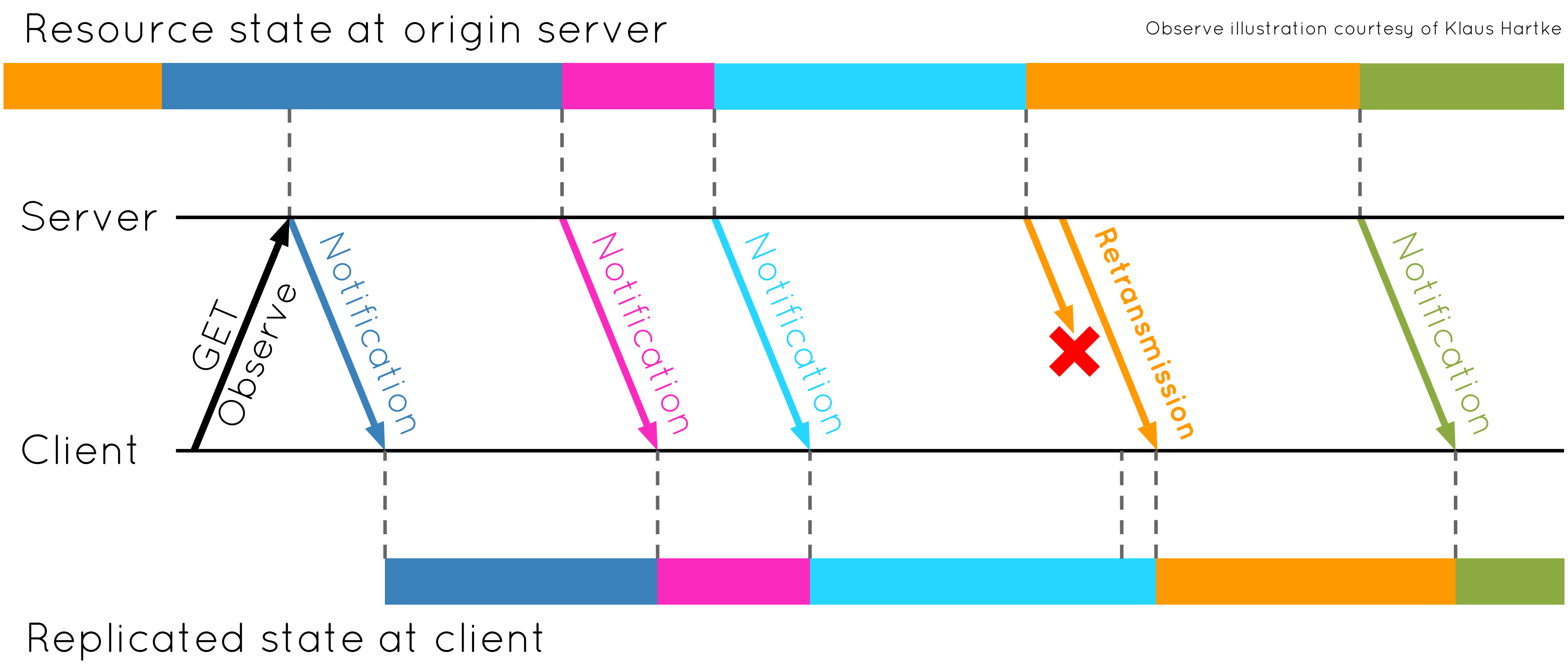
Can be relaxed!
(idempotent requests)

Features for the IoT

Observing Resources



Observing Resources - CON Mode



Mode depends on application

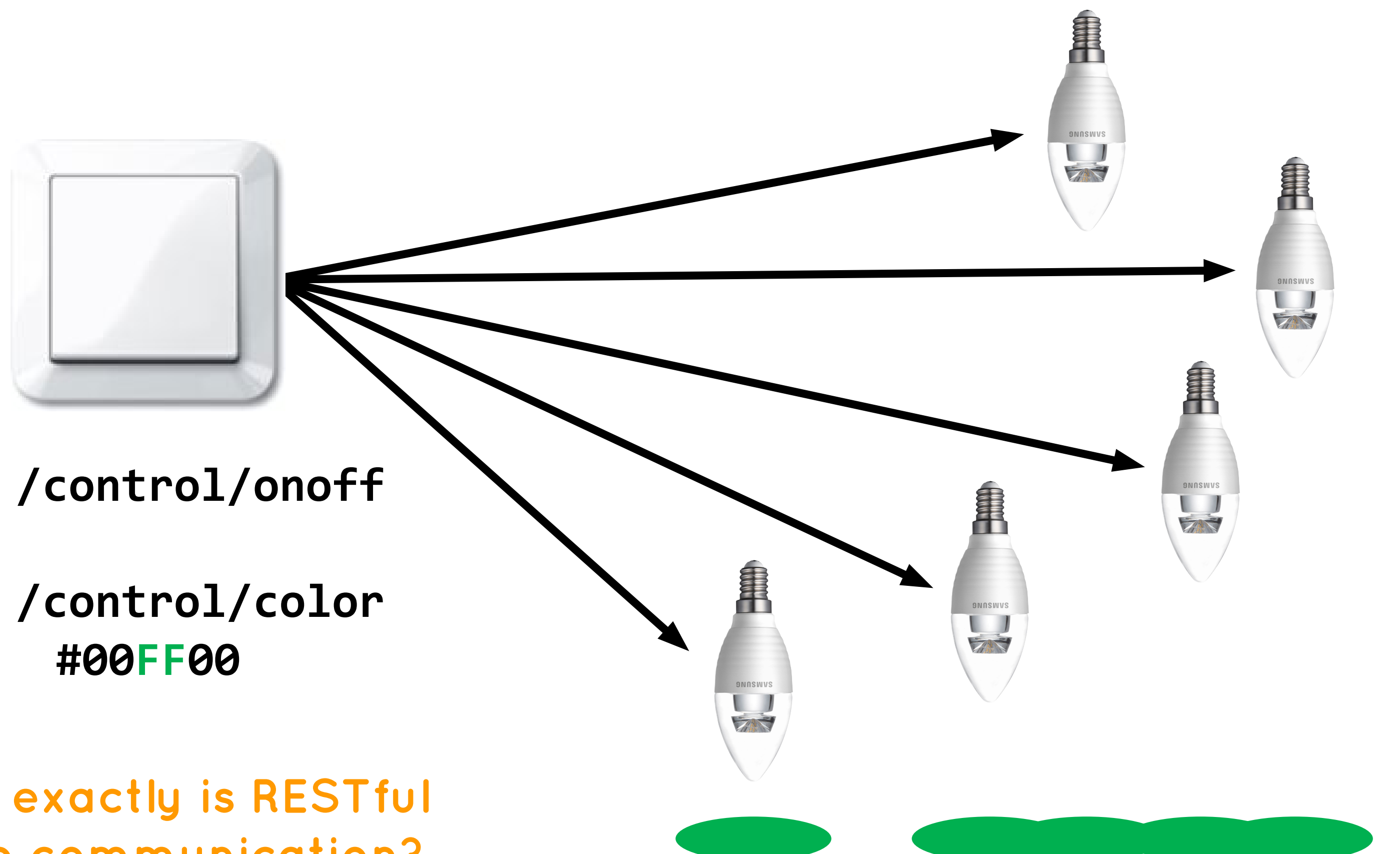
~ random events: CON

~ periodic samples: NON

Group Communication

`GET /status/power`

`all-lights.floor-d.example.com`



`PUT /control/onoff`

`PUT /control/color #00FF00`

What exactly is RESTful group communication?

Resource Discovery

Based on **Web Linking** (RFC5988)

Extended to **Core Link Format** (RFC6690)

```
GET /.well-known/core

</config/groups>;rt="core.gp";ct=39,
</sensors/temp>;rt="ucum.Cel";ct="0 50";obs,
</large>;rt="block";sz=1280,
</device>;title="Device management"
```

Decentralized discovery — **Multicast Discovery**

Infrastructure-based — **Resource Directories**

Alternative Transports

e.g.,
Short Message Service (SMS)

Addressable through URIs

`coap+sms://+123456789/bananas/temp*`

Could power up subsystems for IP connectivity after SMS signal

* illustration only, +123456789 unfortunately not allowed by URI

Security

Based on **DTLS** (TLS/SSL for Datagrams)

Focus on Elliptic Curve Cryptography (**ECC**)

Pre-shared secrets, certificates, or raw public keys

Hardware acceleration in IoT devices

e.g.,

IETF is currently working on

- Authentication/authorization (ACE)
- DTLS profiles (DICE)

Status of CoAP

“Proposed Standard” since 15 Jul 2013

RFC 7252

Next working group documents in the queue

- Observing Resources
- Group Communication
- Blockwise Transfers

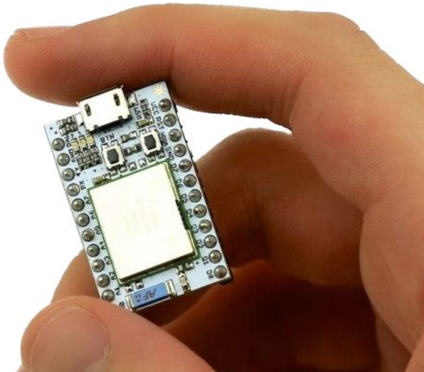
- Resource Directory
- HTTP Mapping Guidelines

Status of CoAP

In use by

- OMA Lightweight M2M
- IPSO Alliance
- ETSI M2M / OneM2M

- Device management for network operators
- Lighting systems for smart cities
- Innovative products, e.g., Spark.io

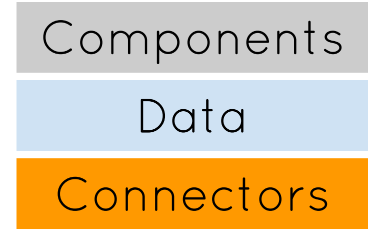


Building RESTful IoT Applications

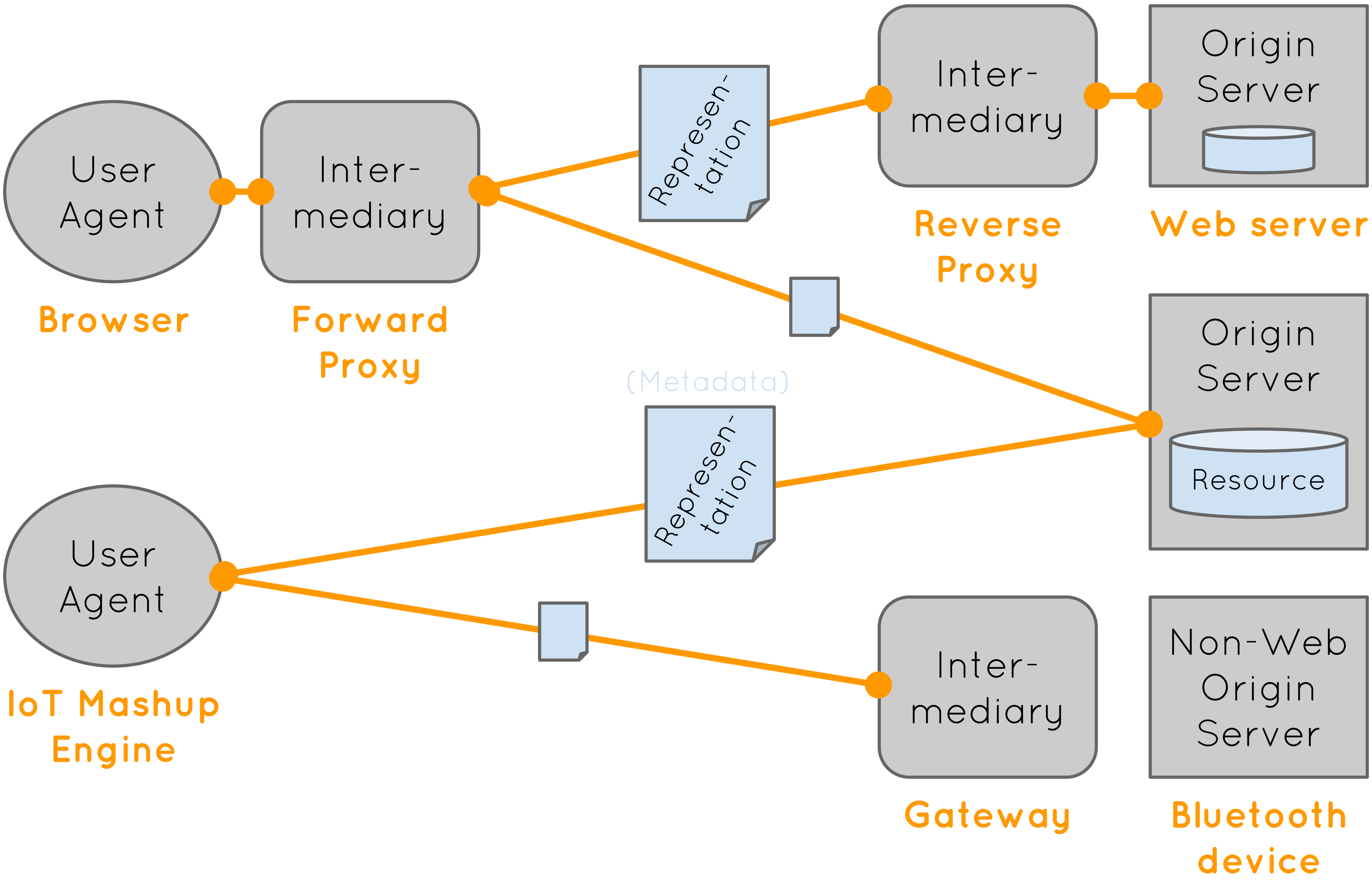
What is REST?

Representational **S**tate **T**ransfer
is the architectural style that
powers the World Wide Web

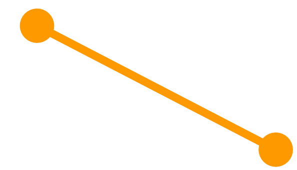
(i.e., **a set of constraints** applied to
the **elements** within the architecture)


Components
Data
Connectors

Elements


User
Agent
Browser
Inter-
mediary
Forward
Proxy
Represen-
tation
Inter-
mediary
Reverse
Proxy
Origin
Server
Web server
(Metadata)
Origin
Server
Resource
Represen-
tation
User
Agent
IoT Mashup
Engine
Inter-
mediary
Gateway
Non-Web
Origin
Server
Bluetooth
device

Client-Server Constraint



How to connect the components?

Separation of concerns

- Origin servers provide the data through a **server** connector
- User-Agents provide the user/application interface and initiate interaction through a **client** connector

⇒ components can evolve independently

Stateless Constraint

How to do request-response?

REST is all about state in a distributed system!

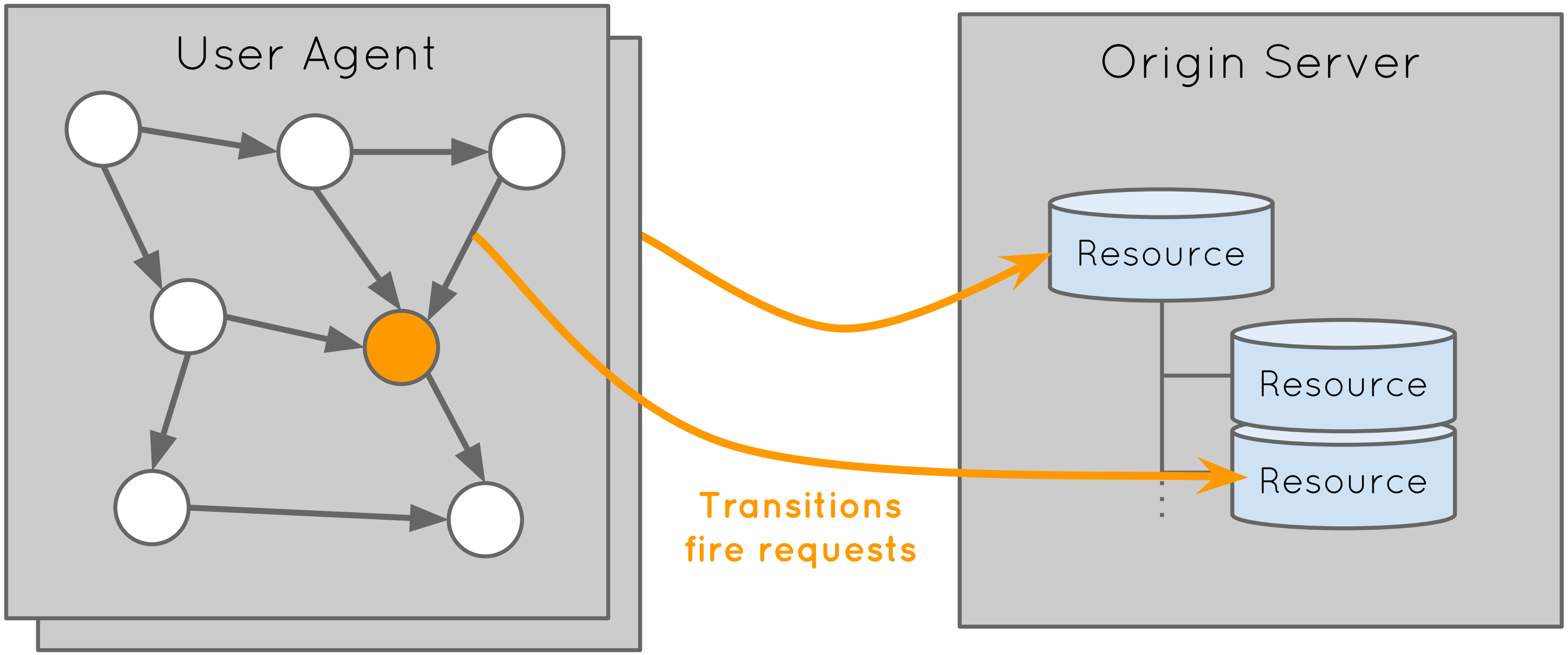
Requests are constrained by "**Stateless**"

Each request must contain all the information
to understand the request so that servers can
process it without context (the state of the client)

Bad cookies!

⇒ visibility, reliability, and scalability

Application as Finite State Machine



Only the clients keep application state

(session/client state)

Servers store data that is independent from the individual client states

(resource state)

Cache Constraint

Responses to requests must have implicit or explicit cache-control metadata

Clients and intermediaries can store responses and **re-use** them to locally answer future requests

⇒ efficiency, scalability, and user-perceived performance

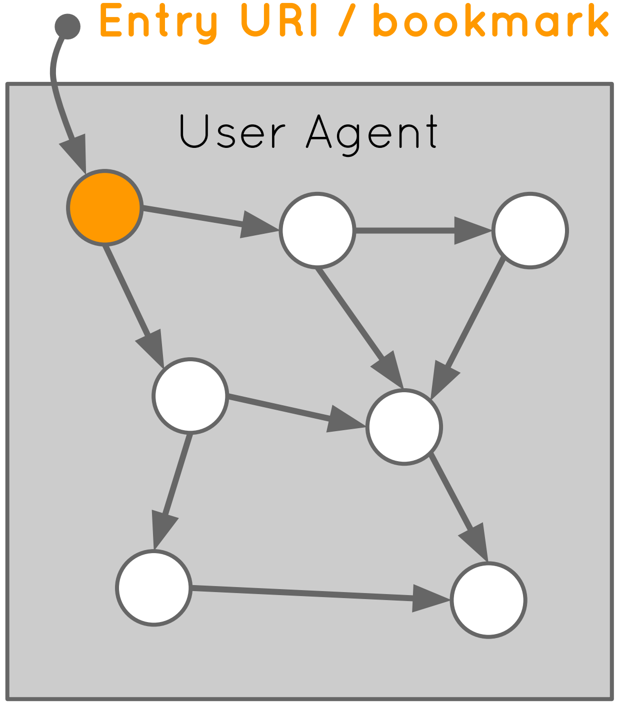
Uniform Interface Constraint

All RESTful Web services use the same interfaces that are defined by

- **URIs** to identify resources
- **Representations** to manipulate resources
  - State transfer
  - No RPC-like service calls
- **Self-descriptive messages** (also see Stateless)
  - Well-defined media types
  - Standard set of methods
  - Independent from transport protocol
- **HATEOAS**...

(Well-defined media types and Standard set of methods: **define semantics**)

Hypermedia As The Engine Of Application State



Application as finite-state machine (FSM) at the client

- Clients start from an **entry URI** or a bookmark
- Response to the GET request has a **hypermedia** representation
- It contains **Web links** that define the transitions of the FSM
- Client chooses link to follow and **issues the next requests** (i.e., triggers a transition)
- URIs and possible transitions are **never hardcoded** into the client: the client "learns" the application on the fly through the media type and link relations
- However, it can also go **back**

⇒ loose coupling to evolve independently

Hypermedia

Media types define

- the **representation format** as well as
- the **processing model**

for the data model of a Web resource

HTML is easy: humans can reason!

What about **machine-to-machine**?

Internet Media Types (formerly known as MIME)

`application/xml` or `application/json` or `text/plain`

(reusable, **meaningless**)

`application/senml+json`

(reusable, standardized)

`application/prs.my-actuator-control`

(**personal**, meaningful)

In general

Reuse media types as far as possible

(http://www.iana.org/assignments/media-types/media-types.xhtml)

Standardize your own if nothing fits

internally or globally (RCF 6838)

Layered System Constraint

Intermediaries can be placed at various points to modify the system

- Caching proxies
- Load balancers
- Firewalls
- Gateways to connect legacy systems

Fully transparent, as one layer cannot see beyond the next layer

⇒ adaptability, scalability, security

(Code-On-Demand)

Optional, easy to understand, and
a constraint that does not constrain,
but important for the Web as we know it

Allows to update client features
after deployment, e.g., **JavaScript** in the
browser to improve the user interface

⇒ improves system extensibility

but reduces visibility

Summary

Elements of a RESTful architecture

- User agents (client connectors)
- Origin servers (server connectors)
- Intermediaries (client and server at once)
- Data (resources, representations, metadata)

REST **Constraints**

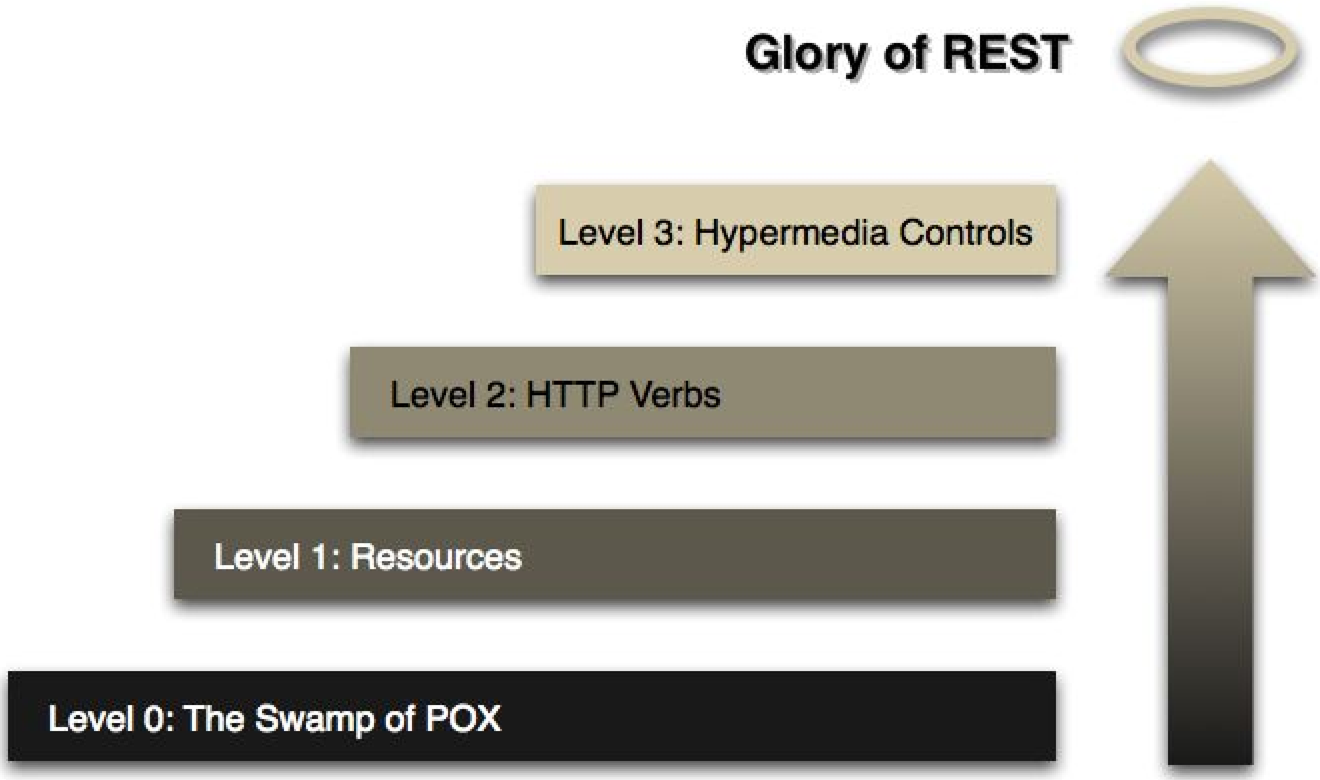
- Client-Server
- Stateless
- Cache
- Uniform Interface (HATEOAS!)
- Layered System
- (Code-On-Demand)

How to Become RESTful

for object- and service-oriented people

Richardson Maturity Model

http://martinfowler.com/articles/richardsonMaturityModel.html



Level 0: The Swamp of POX

(POX = plain old XML)

Happens when HTTP is just used as **transport protocol** or **tunnel** because *"port 80/443 is safe and always open"*

The Web service only has a **single URI** and clients post **RPC**s that trigger an action (e.g., WS-* and JSON-RPC)

Level 1: Resources

Expose each service entity as
Web resource with individual URI
for global addressability

But Level 1 still uses **RPC**s

- `POST /sensors/temperature?method=read`
- `POST /sensors/temperature?method=configure {"a":3,"b":4}`

Level 2: ~~HTTP~~CoAP Verbs :)

...and of course **representations**
to manipulate resources

GET	**safe** and **idempotent**
POST	not safe and not idempotent
PUT	not safe but **idempotent**
DELETE	not safe but **idempotent**

safe:	no side-effects on the resource
idempotent:	multiple invocations have the same effect as a single invocation

Level 2: ~~HTTP~~CoAP Verbs :)

Verbs map to CRUD operations:

`POST` **Create** a new (sub-)resource

- request body can have initial state
- response body can be an action result
  - **`Location-*`** options can contain link to new resource

`GET` **Read** the resource state

- no request body
- response body has representation

`PUT` **Update** the resource state

- request body has updated representation
- response can have only code or action result in body

`DELETE` **Delete** the resource

- no request body
- response can have only code or action result in body

Level 2: Still not REST (but helpful)

often called **"RESTful"**

Level 2 API specifications usually look like this:

- /config/profile
  - **GET**
    - **Request**: no parameters
    - **Response**: application/json

Property	***Type***	***Description***
id	int	identifier of the profile
name	string	name of the profile
…		

  - **PUT**
    - **Request**: application/json

      …
- /actuators/pump

Main problem: **tight coupling**

(hard-coded URIs, non-reusable message descriptions)

Level 3: Hypermedia Controls

HATEOAS

- Define media types for the application
- Embed links to drive application state
- Provide initial URI

"**A REST API should spend almost all of its descriptive effort in defining the media type(s) used for representing resources and driving application state, or in defining extended relation names and/or hypertext-enabled mark-up for existing standard media types.**" http://roy.gbiv.com/untangled/2008/rest-apis-must-be-hypertext-driven

Level 3 IoT Applications?

Sensors and actuators are rather easy to model

- Resources that provide sensor data
- Resources that provide and accept parameters

All CoAP nodes provide an initial URI

/.well-known/core

First reusable media types for IoT applications

- `application/link-format` (RFC 6690)
- `application/senml` (draft-jennings-senml)
- `application/coap-group+json` (draft-ietf-core-groupcomm)

Level 3 IoT Applications?

The CoRE Link Format provides **attributes** for links

- Can be more detailed than relation names
- Give meaning to generic media types
- Single values/parameters can be in text/plain

Bad because of "typed resources"?

We are just at the beginning!

⇒ **Bottom-up semantics for M2M**

Other REST Mechanisms

Exception Handling with response codes

- 4.xx Client errors
- 5.xx Server errors

Content negotiation

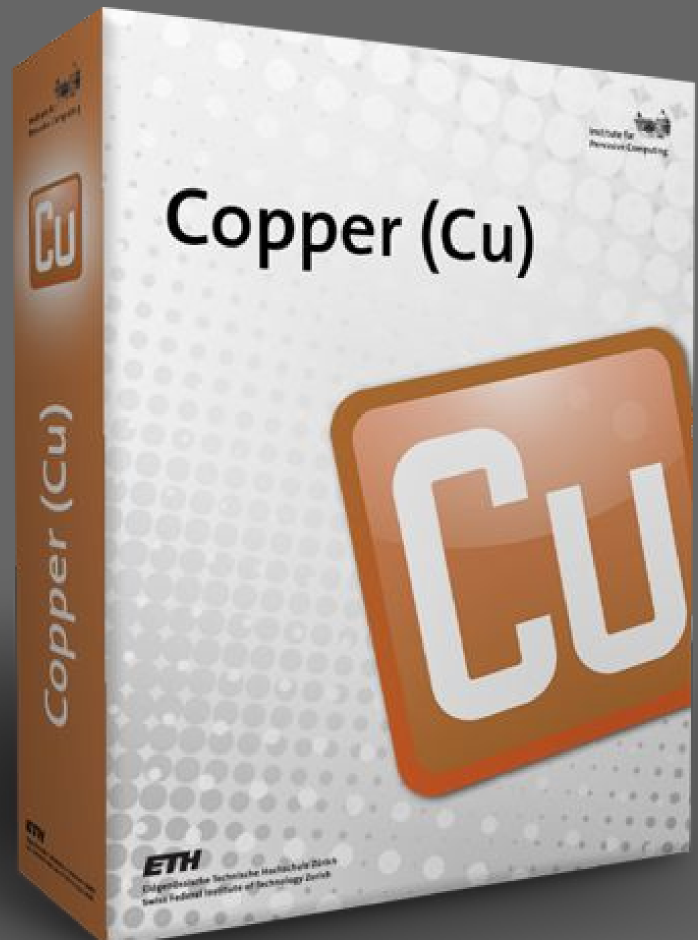
- Accept option

Conditional requests for concurrency

- ETag
- If-Match
- If-None-Match

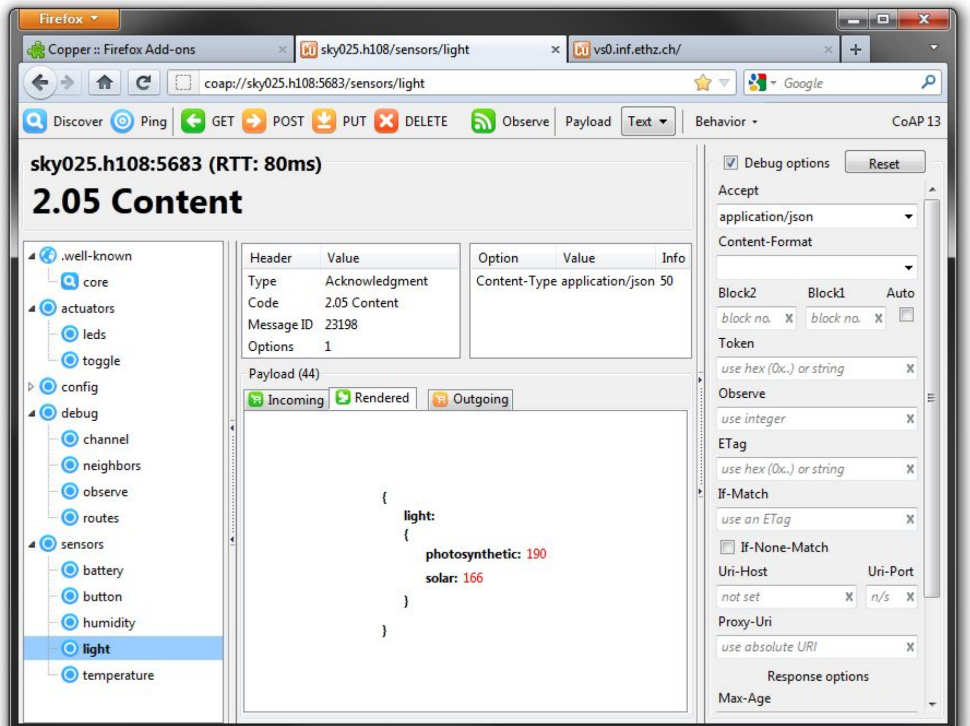
CoAP and REST

Questions?


Copper (Cu)
Cu
Cu
Copper (Cu)
ETH

CoAP live with Copper!

CoAP protocol handler for Mozilla Firefox



Browsing and bookmarking of **CoAP URIs**

Interaction with Web resources like RESTClient or Poster

Treat IoT devices like RESTful Web services

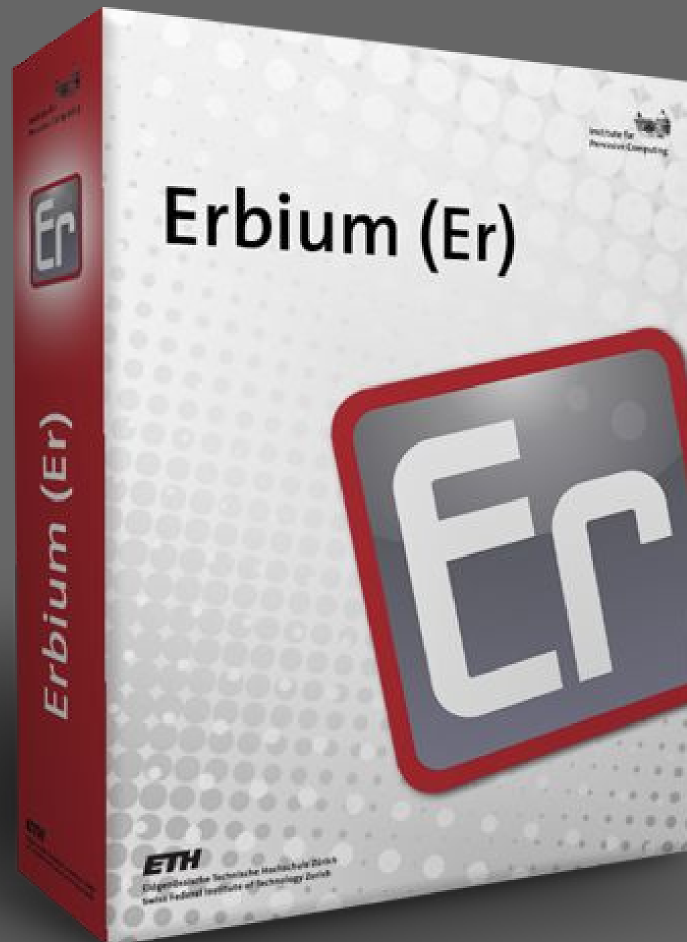
CoAP live with Copper!

Available sandboxes

coap://iot.eclipse.org/

coap://vs0.inf.ethz.ch/

coap://coap.me/


Erbium (Er)
Er
Erbium (Er)
Er
ETH

Erbium (Er) REST Engine

Contiki OS CoAP implementation

- written in C
- focus on small footprint but also usability

For

- Thin Server Architecture
  (thus, minimal client support)
- RESTful wrapper for sensor/actuator hardware

Two Layers (Contiki apps)

rest-engine

- Web resource definitions
- RESTful handling of requests
- users implement **resource handlers**

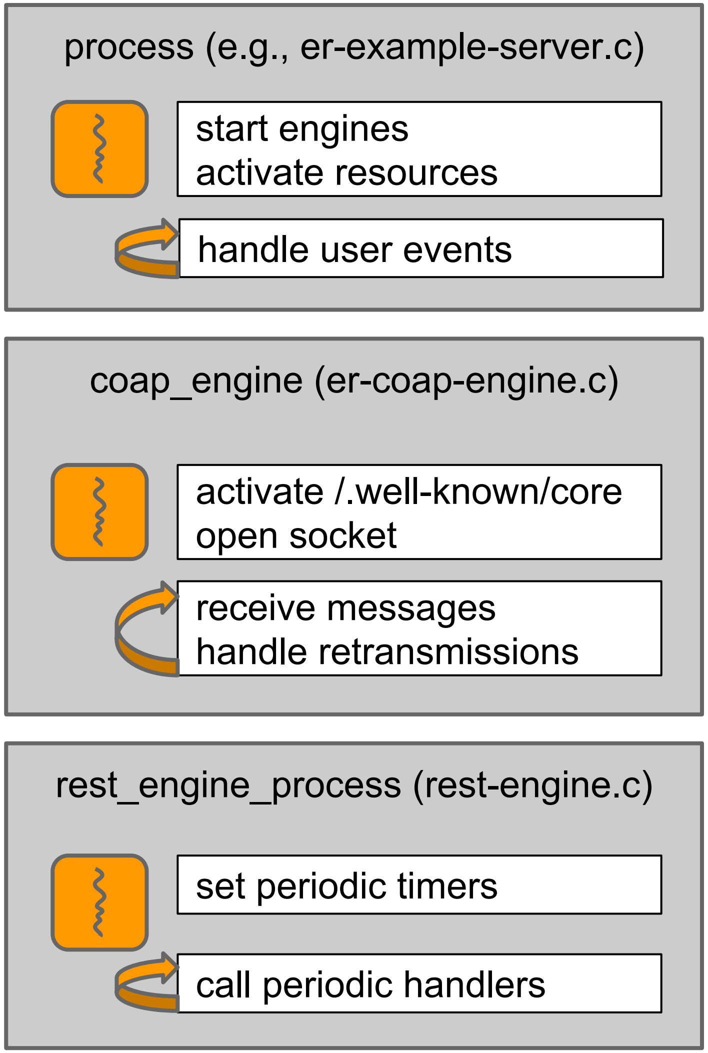
er-coap

- CoAP implementation
- maps REST functions to protocol
- hides **protocol-specific operations**

Code Structure

Keep it modular

- er-coap / er-coap-constants
  protocol format & parsing
- er-coap-engine
  control flow (client/server)
- er-coap-transactions
  retransmissions
- er-coap-separate
- er-coap-observe
- er-coap-block
- er-coap-res-well-known…
- er-coap-conf
  tweak for application needs



Resource Handler API

Create a C module for each resource

- choose resource type (see next slide)
- set CoRE Link Format information
- implement resource handlers
  - `GET`
  - `POST`
  - `PUT`
  - `DELETE`

  or set to NULL for **`4.05 Method Not Allowed`**
- activate resources in main process

Five Resource Macros

- `RESOURCE`
  simple CoAP resource
- `PARENT_RESOURCE`
  manages virtual **sub-resources** (e.g., for URI-Templates)
- `SEPARATE_RESOURCE`
  long-lasting handler tasks ⇒ **separate responses**
- `EVENT_RESOURCE`
  observable resource that is **manually** triggered
- `PERIODIC_RESOURCE`
  observable resource that is triggered by **timer**

Minimal Client API

One call to issue requests

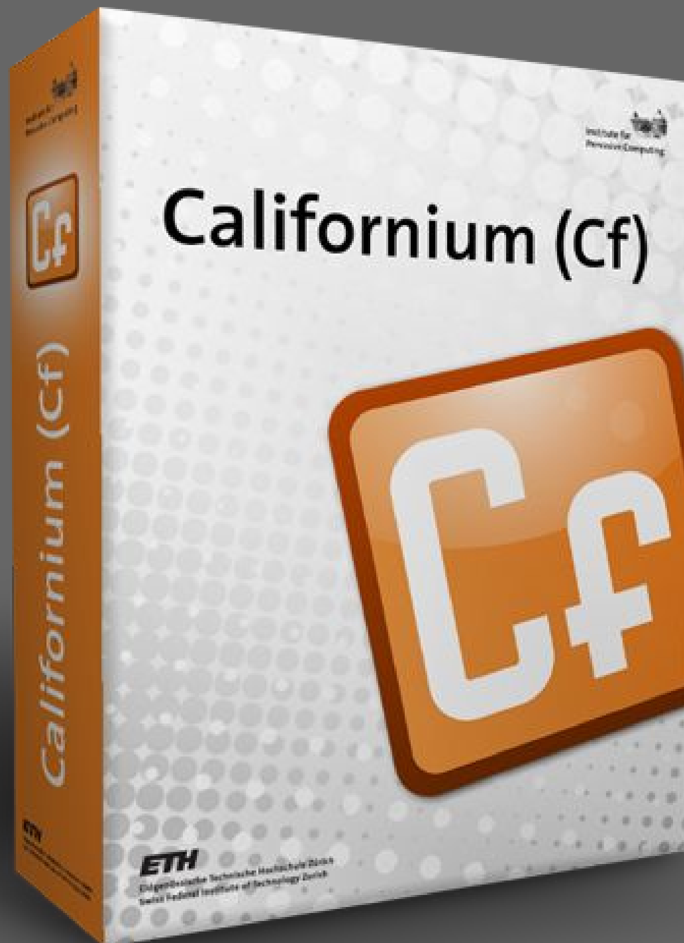
`COAP_BLOCKING_REQUEST()`

Call blocks until response is received

- linear program code for interactions
- also handles blockwise transfers

Working on **`COAP_ASYNC_REQUEST()`**

- support for observe and separate response
- some projects already have custom solutions


Californium (Cf)
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Californium (Cf) CoAP framework

Unconstrained CoAP implementation

- written in Java
- focus on scalability and usability

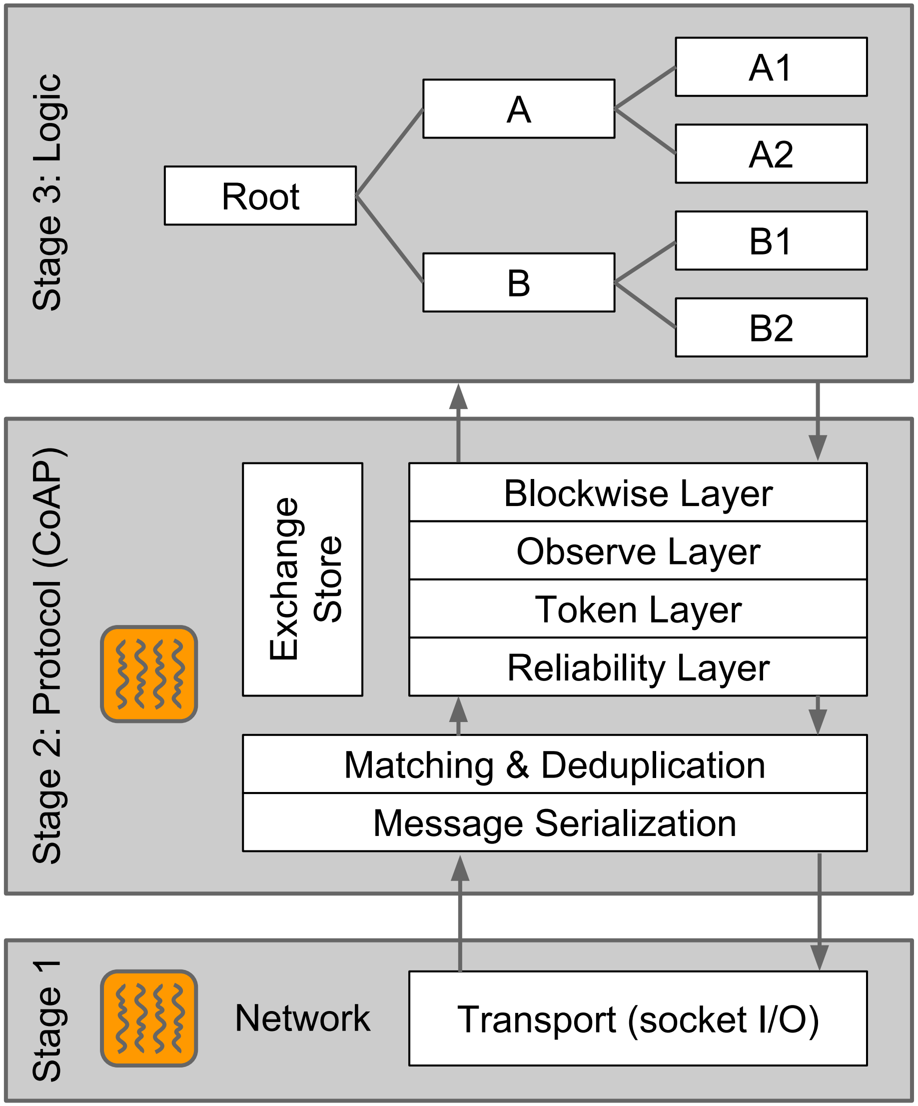
For

- IoT cloud services
- Stronger IoT devices
  (Java SE Embedded or special JVMs)

3-stage Architecture

Stages

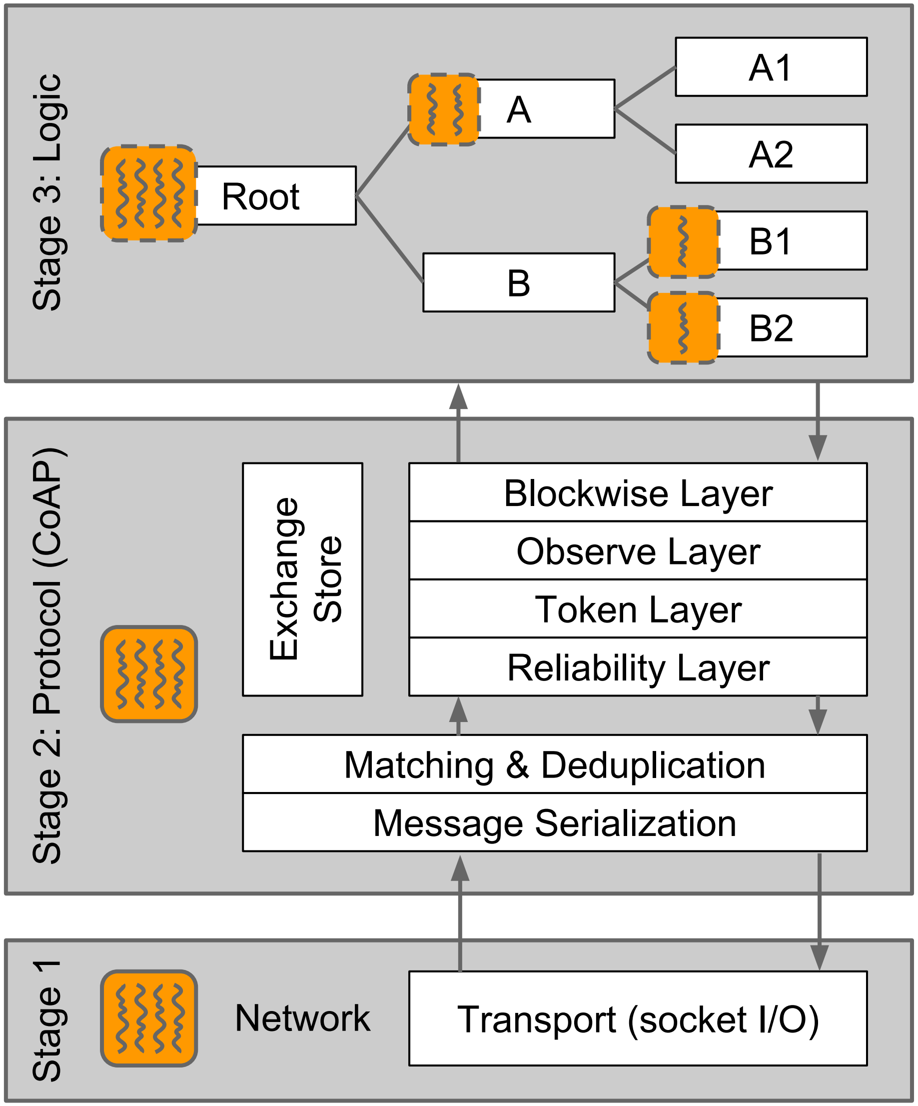
- Decoupled with message queues
- independent concurrency models
- Adjusted statically for platform/application
- Stage 1 depends on OS and transport
- Stage 2 usually one thread per core



Stage 3: Server Role

Web resources

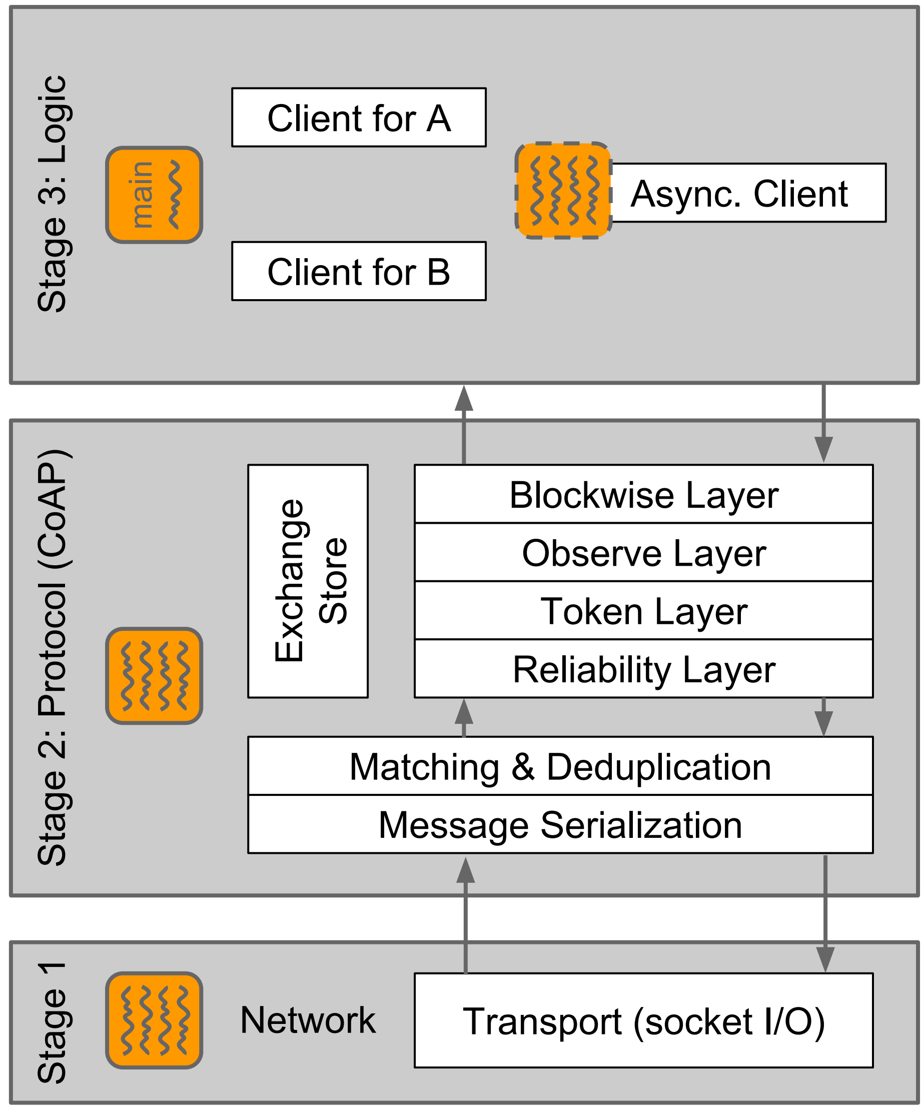
- Optional thread pool for each Web resource
- Inherited by parent or transitive ancestor
- Protocol threads used if none defined



Stage 3: Client Role

Clients with response handlers

- Object API called from main or user thread
- Synchronous: Protocol threads unblock API calls
- Asynchronous: Optional thread pools for response handling (e.g., when observing)



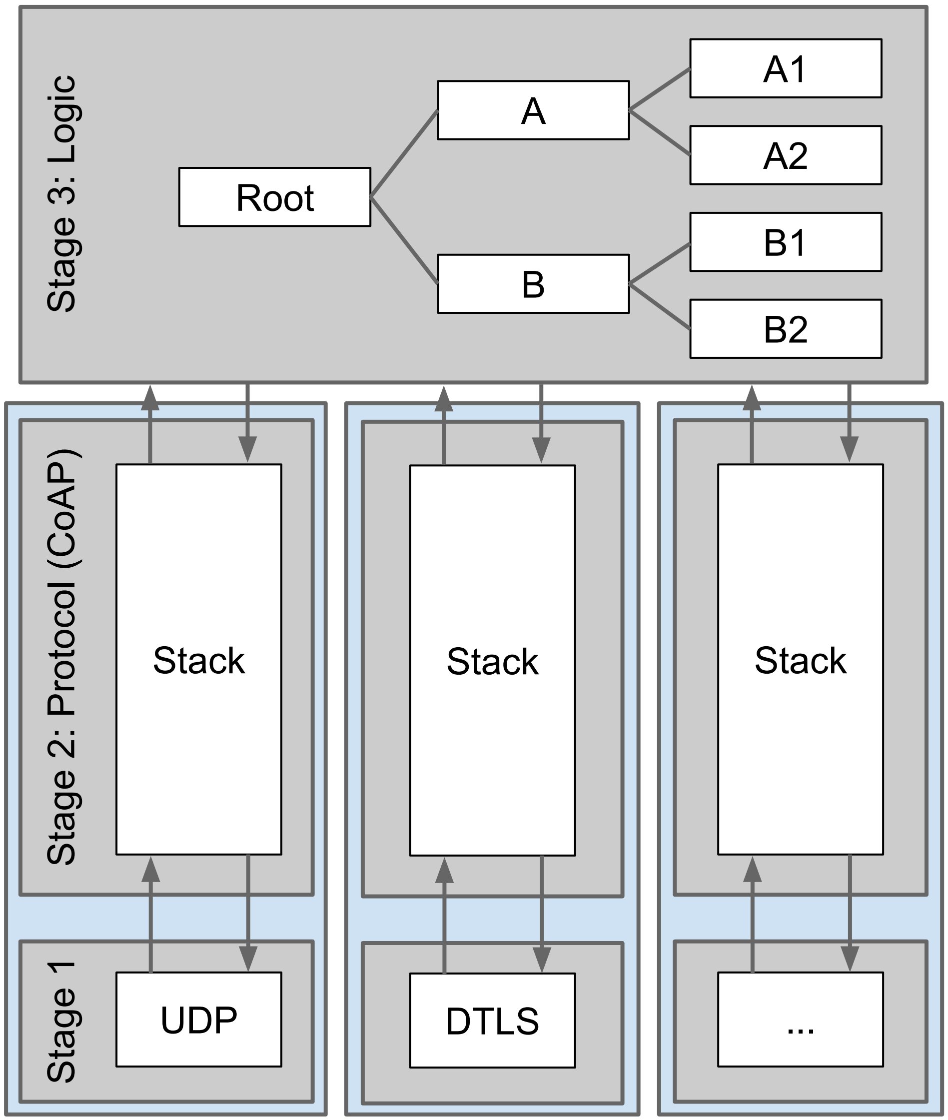
Endpoints

Encapsulate stages 1+2

Enable

- multiple channels
- stack variations for different transports

Individual concurrency models, e.g., for DTLS

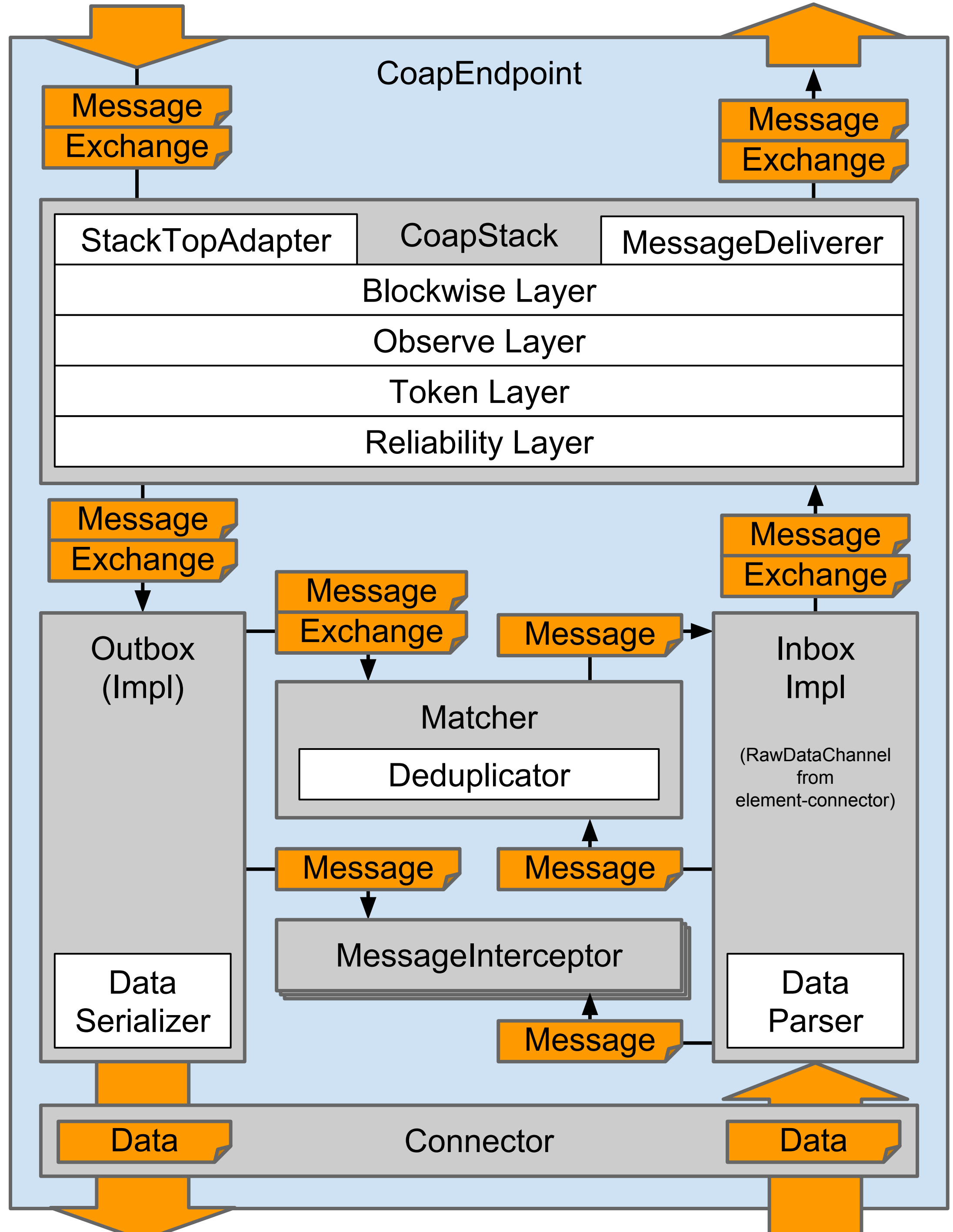


Endpoints

Implemented in **CoapEndpoint**

Separation of bookkeeping and processing

Exchanges carry state



mjCoAP

mjCoAP

Java-based CoAP implementation

Focuses on fast and easy development of CoAP-based applications

Lightweight (small footprint) and compatible with Java-enabled devices

- Java SE
- Embedded Java/Java ME

mjCoAP

mjCoAP provides a simple set of APIs for creating server-side and client-side applications

Design principles:

- asynchronous (callback)
- lightness
- easy-to-use/fast-development
- re-usability (can be used to implement other protocols that share the message same syntax - e.g. CoSIP[1])

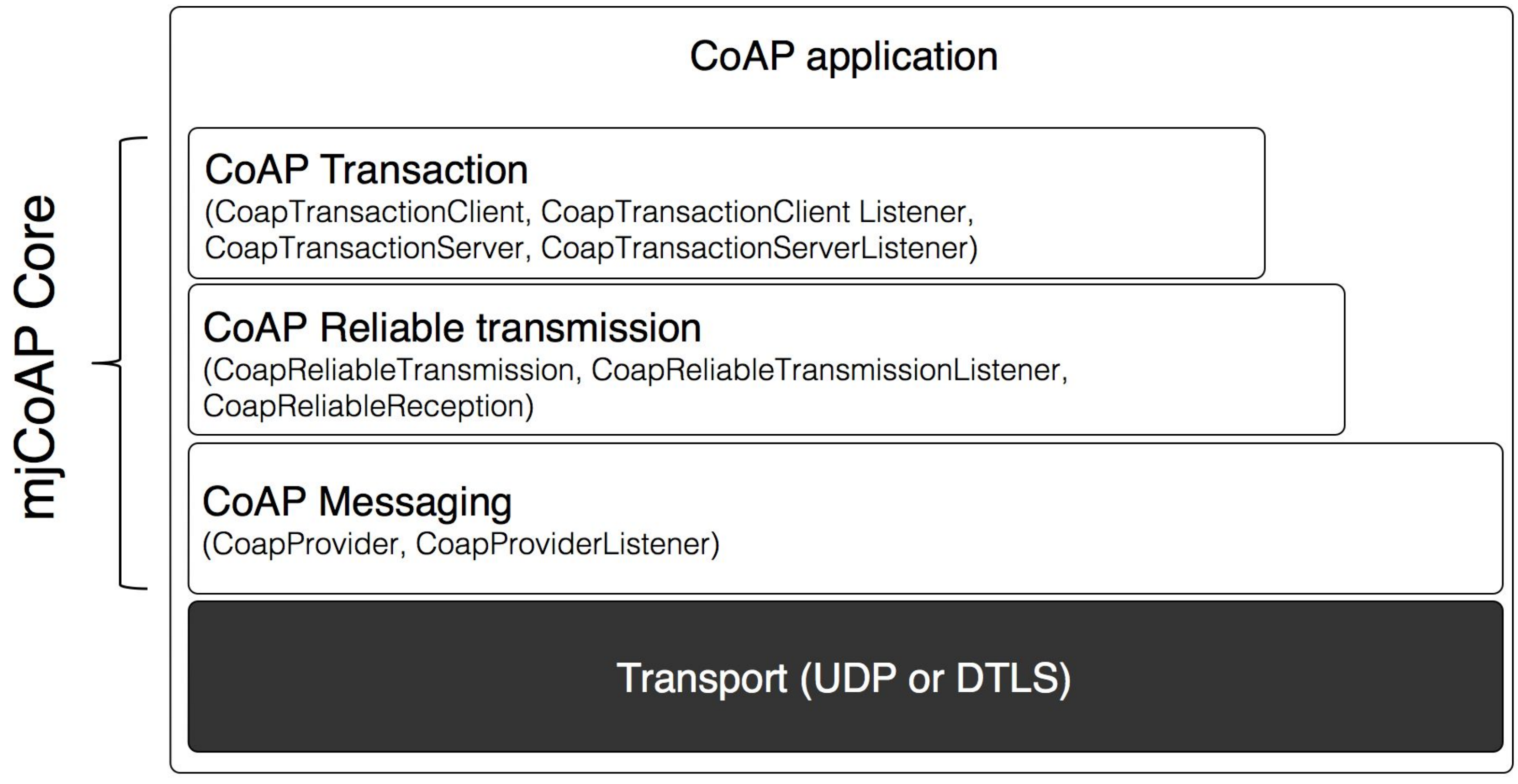
[1] S. Cirani, M. Picone and L. Veltri ,"A session initiation protocol for the Internet of Things", Scalable Computing: Practice and Experience, Volume 14, Number 4, pp. 249–263, DOI 10.12694/scpe.v14i4.931, ISSN 1895-1767

Paper on mjCoAP

[2] S. Cirani, M. Picone, and L. Veltri, “mjCoAP: An Open-Source Lightweight Java CoAP Library for Internet of Things applications”, Workshop on Interoperability and Open-Source Solutions for the Internet of Things, in conjunction with SoftCOM 2014, September 2014

Layered Architecture

mjCoAP is formed by 3 sub-layers



Messagging layer

- Responsible for sending and receiving CoAP messages over UDP

- At this layer, all messages are handled without inspection (requests and responses, CON/NON/ACK/RST)

- Main classes:
  - **CoapProvider** (send messages)
  - **CoapProviderListener** (receive messages with `onReceivedMessage()` callback)

Reliable Transmission layer

- Responsible for reliable transmission of CON CoAP messages (both requests and responses)

- This layer takes care of:
  - Retransmitting messages that are not ACKed
  - Notifying failure (timeout) and success (ACK)

- Support for *piggybacked* and *separate* responses

Reliable Transmission layer

- Main classes:
  - **CoapReliableTransmission**
  - **CoapReliableTransmissionListener**
  - **CoapReliableReception**

Transaction layer

- Request/response exchange
- Reliable transmissions are handled by the underlying layer
- At the client-side, send a request and receive the corresponding response
- At the server-side, receive a request and send the response

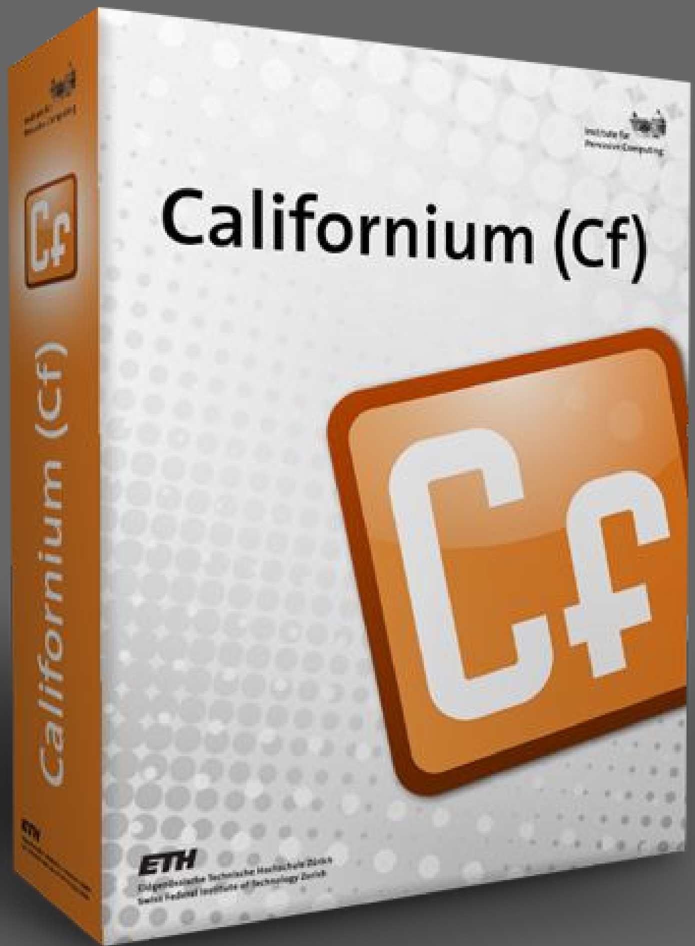
Transaction layer

- Main classes:
  - **CoapTransactionClient**
  - **CoapTransactionClientListener**
  - **CoapTransactionServer**
  - **CoapTransactionServerListener**

Follow the Slides

http://goo.gl/anfy5w

Let's get concrete!


Californium (Cf)
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ETH

Californium (Cf)

Five repositories on GitHub

- https://github.com/eclipse/californium
  Core library and example projects
- https://github.com/eclipse/californium.element-connector
  Abstraction for modular network stage (Connectors)
- https://github.com/eclipse/californium.scandium
  DTLS 1.2 implementation for network stage (DtlsConnector)
- https://github.com/eclipse/californium.tools
  Stand-alone CoAP tools such as console client or RD
- https://github.com/eclipse/californium.actinium
  App server for server-side JavaScript*

*not yet ported to new implementation and using deprecated CoAP draft version

Code structure

https://github.com/eclipse/californium

- Libraries (“californium-” prefix)
  - **californium-core** CoAP, client, server
  - **californium-osgi** OSGi wrapper
  - **californium-proxy** HTTP cross-proxy
- Example code
- Example projects (“cf-” prefix)

Code structure

https://github.com/eclipse/californium

- Libraries
- Example code
  - **cf-api-demo** API call snippets
- Example projects

Code structure

https://github.com/eclipse/californium

- Libraries
- Example code
- Example projects
  - **cf-helloworld-client** basic GET client
  - **cf-helloworld-server** basic server
  - **cf-plugtest-checker** tests Plugtest servers
  - **cf-plugtest-client** tests client functionality
  - **cf-plugtest-server** tests server functionality
  - **cf-benchmark** performance tests
  - **cf-secure** imports Scandium (DTLS)
  - **cf-proxy** imports californium-proxy

Maven

Maven handles dependencies **and more**

Call

```
mvn clean install
```

in this order (internal dependencies)

- californium.element-connector
- californium.scandium
- californium
- *

to build and install the **artifacts**

Server API

Important classes (see org.eclipse.californium.core)

- **CoapServer**
- **CoapResource**
- **CoapExchange**

Learn about other classes through auto-complete

Basic steps

- Implement custom resources by extending **CoapResource**
- Add resources to server
- Start server

Server API - resources

```java
import static org.eclipse.californium.core.coap.CoAP.ResponseCode.*; // shortcuts

public class MyResource extends CoapResource {
	@Override
	public void handleGET(CoapExchange exchange) {
		exchange.respond("hello world"); // reply with 2.05 payload (text/plain)
	}
	@Override
	public void handlePOST(CoapExchange exchange) {
		exchange.accept(); // make it a separate response

		if (exchange.getRequestOptions()....) {
			// do something specific to the request options
		}
		exchange.respond(CREATED); // reply with response code only (shortcut)
	}
}
```

Server API - Creation

```
public static void main(String[] args) {

    CoapServer server = new CoapServer();

    server.add(new MyResource("hello"));

    server.start(); // does all the magic
}
```

Client API

Important classes

- **CoapClient**
- **CoapHandler**
- **CoapResponse**
- **CoapObserveRelation**

- Instantiate **CoapClient** with target URI
- Use offered methods get(), put(), post(), delete(), observe(), validate(), discover(), or ping()
- Optionally define **CoapHandler** for asynchronous requests and observe

Client API - Synchronous

```
public static void main(String[] args) {

    CoapClient client1 = new CoapClient("coap://iot.eclipse.org:5683/multi-format");

    String text = client1.get().getResponseText(); // blocking call
    String xml = client1.get(APPLICATION_XML).getResponseText();

    CoapClient client2 = new CoapClient("coap://iot.eclipse.org:5683/test");

    CoapResponse resp = client2.put("payload", TEXT_PLAIN); // for response details
    System.out.println( resp.isSuccess() );
    System.out.println( resp.getOptions() );

    client2.useNONs();  // use autocomplete to see more methods
    client2.delete();
    client2.useCONs().useEarlyNegotiation(32).get(); // it is a fluent API
}
```

Client API - Asynchronous

```java
public static void main(String[] args) {

    CoapClient client = new CoapClient("coap://iot.eclipse.org:5683/separate");

    client.get(new CoapHandler() { // e.g., anonymous inner class

        @Override public void onLoad(CoapResponse response) { // also error resp.
            System.out.println( response.getResponseText() );
        }

        @Override public void onError() { // I/O errors and timeouts
            System.err.println("Failed");
        }
    });
}
```

Client API - Observe

```
public static void main(String[] args) {

    CoapClient client = new CoapClient("coap://iot.eclipse.org:5683/obs");

    CoapObserveRelation relation = client.observe(new CoapHandler() {

        @Override public void onLoad(CoapResponse response) {
            System.out.println( response.getResponseText() );
        }

        @Override public void onError() {
            System.err.println("Failed");
        }
    });

    relation.proactiveCancel();
}
```

Advanced API

Get access to internal objects with

advanced() on
CoapClient, **CoapResponse**, **CoapExchange**

Use clients in resource handlers with

createClient(uri);

Define your own concurrency models with

ConcurrentCoapResource and
CoapClient.useExecutor() / setExecutor(exe)


Erbium (Er)
Er
ETH

Erbium (Er)

Erbium is part of Contiki OS

https://github.com/contiki-os/contiki

You already have it :)

- Libraries (in `./apps/`)
  - **er-coap** CoAP
  - **rest-engine** resources, REST calls
- Examples (in `./examples/er-rest-example`)
  - **er-example-server** how to add resources
  - **er-example-client** how to issue requests
  - **er-plugtest-server** ETSI Plugtest test cases
  - ./resources/**res-*** resource modules

Erbium (Er) Project Files

Makefile

```
# ensure proper IPv6 configuration

# add libraries
APPS += er-coap
APPS += rest-engine
```

project-conf.h

```
/* if needed, tweak parameters found in
   apps/er-coap/er-coap-conf.h */
```

Erbium (Er) Server Program

Global

```
extern resource_t <resources>;
```

In PROCESS

```
rest_init_engine();
rest_activate_resource(&<resource>, <URI-Path>);
SENSORS_ACTIVATE(<sensor>); /* if used by resource */
```

In PROCESS while(1) loop

```
PROCESS_WAIT_EVENT();
if (ev==<notification event>) <event resource>.trigger();
if (ev==<response ready>) <separate resource>.resume();
```

Erbium (Er) Resources I

```
#include "rest-engine.h"

static void res_get_handler(void *request, void *response,
    uint8_t *buffer, uint16_t preferred_size, int32_t *offset);

RESOURCE(res_<name>,
    "title=\"<human readable>";ct=0", /* see CoRE Link Format */
    res_get_handler,
    NULL, /* or res_post_handler */
    NULL, /* or res_put_handler */
    NULL /* or res_delete_handler */
    );
```

Erbium (Er) Resources II

```
static void res_get_handler(void *request, void *response,
    uint8_t *buffer, uint16_t preferred_size, int32_t *offset)
{
    /* use REST.get_* functions to access request */

    /* use REST.set_* functions to access response */

    /* use buffer to create response body */
    /* do not exceed preferred_size */
    /* engine handles block transfers up to REST_MAX_CHUNK_SIZE */
    /* use offset to fragment manually if larger */
}
```

Erbium (Er) Client Program I

Global or **static** in PROCESS

```
uip_ipaddr_t server_ip;
coap_packet_t request[1];
```

In PROCESS

```
coap_init_engine(); /* not rest_ because CoAP-only */
coap_init_message(request, COAP_TYPE_CON, <coap_method_t>, 0);
coap_set_header_uri_path(request, <URI-Path>);
/* if COAP_POST or COAP_PUT only */
coap_set_payload(request, <string>, <length>);
coap_set_header_content_format(request, <coap_content_format_t>);
COAP_BLOCKING_REQUEST(&server_ip, <port>, request,
    client_response_handler);
```

Erbium (Er) Client Program II

Global: response handler function

```
void client_response_handler(void *response)
{
    /* use coap_get_* functions */

    /* OR */

    coap_packet_t *const coap_res = (coap_packet_t *)response;
    /* client is CoAP-only, no need for indirection */
    /* use coap_res-> to access fields */
}
```

mjCoAP

CoapProvider

- It is the fondumental class that enables CoAP messaging in an application
- A **`CoapProvider`** is bound to a specific UDP port
- Provides a **`send()`** method
- Forwards incoming messages to registered **`CoapProviderListener`**s

CoapProvider API

```
import org.zoolu.coap.core.*;
import org.zoolu.coap.message.*;
public class CoapClient implements CoapProviderListener{

	private CoapProvider coapProvider;

	public CoapClient(){
		this.coapProvider = new CoapProvider(CoapProvider.ANY_PORT); // get random port
		this.coapProvider.setListener(CoapMethodId.ANY, this); // receive all messages
	}

	public void send(CoapMessage message) {
		this.coapProvider.send(message);
		System.out.println("SENT: " + message);
	}

	@Override
	public void onReceivedMessage(CoapMessage message) {
		System.out.println("RECV: " + message);
	}

}
```

CoapProvider API

```
public static void main(String[] args) {

    CoapClient client = new CoapClient();

    CoapRequest request =
        CoapMessageFactory.createCONrequest(
                CoapMethod.GET,
                "coap://localhost/test");

    client.send(request);

}
```

CoapTransactionClient API

```
import java.net.*;
import org.zoolu.coap.core.*;
import org.zoolu.coap.message.*;
import org.zoolu.net.*;
public class CoapTransactionClient {

        private CoapProvider coapProvider;

        public CoapTransactionClient(){
                this.coapProvider = new CoapProvider(CoapProvider.ANY_PORT);
        }

        public void request(CoapMethod method, String resource, byte[] payload, CoapTransactionClientListener
listener) {
                URI uri = new URI(resource);
                CoapRequest req = CoapMessageFactory.createCONrequest(method,uri);
                req.setPayload(payload);
                new CoapTransactionClient(coapProvider, new SocketAddress(uri.getHost(),uri.getPort()),
                listener).request(req);
        }
}
```

CoapTransactionClient API

```
public static void main(String[] args) {

        CoapTransactionClient client = new CoapTransactionClient();
        client.request(CoapMethod.GET,"coap://localhost/test",null,
                new CoapTransactionClientListener({
                        @Override
                        public void onTransactionResponse(CoapTransactionClient tc, CoapMessage resp)
                                System.out.println("RECV: " + resp);
                        }

                        @Override
                        public void onTransactionFailure(CoapTransactionClient tc)
                                System.out.println("FAILED");
                        }

                });
        );
}
```

Questions?

HANDS-ON!