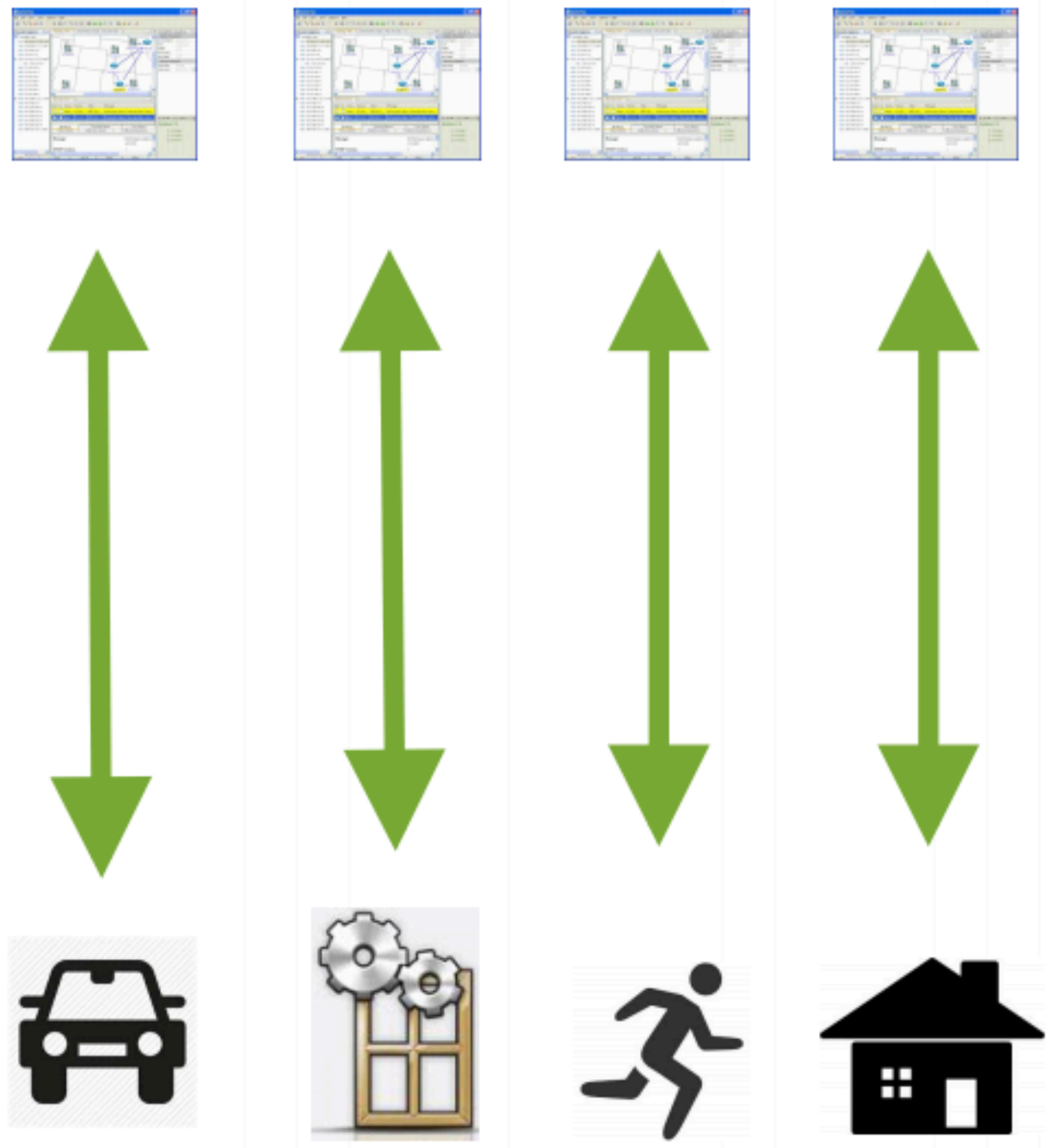
Lecture #9
CoAP - Constrained Application Protocol

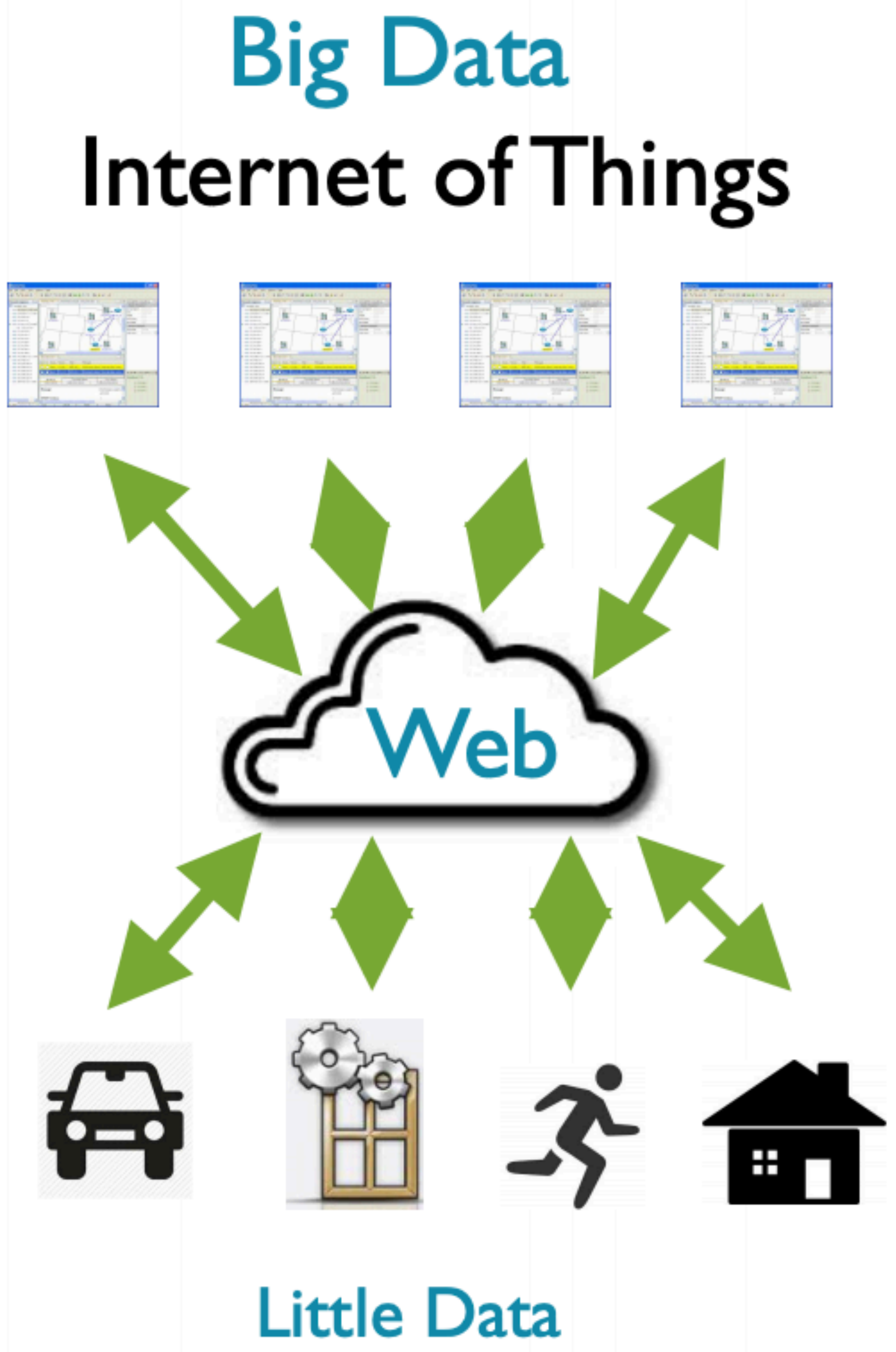
Spring 2024

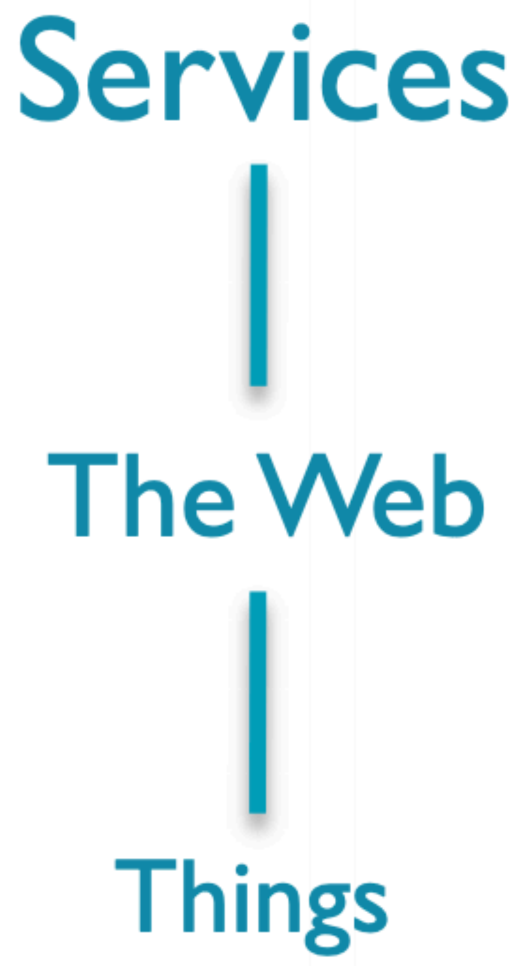
Internet
of people

Internet
of things

M2M

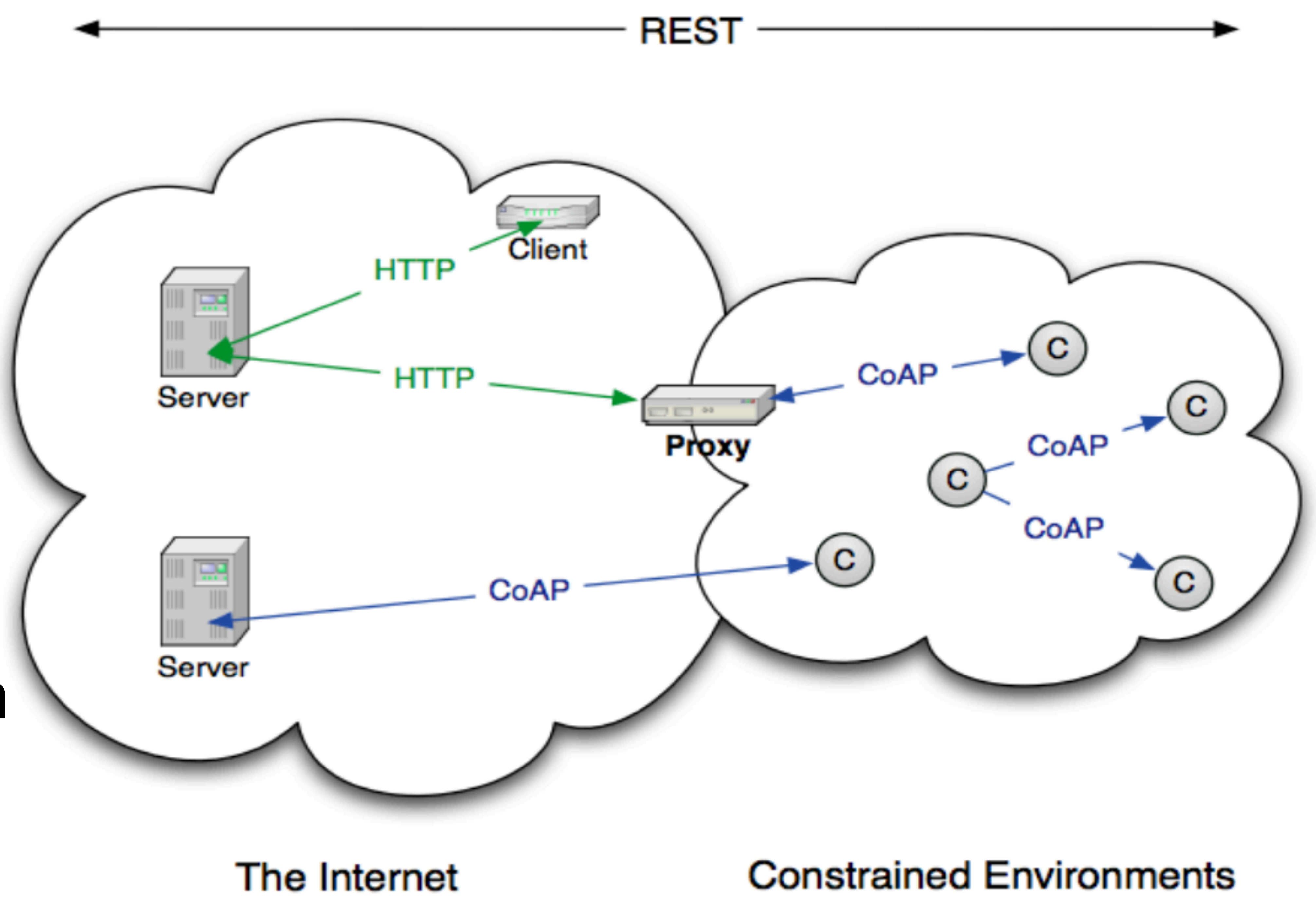



Big Data
Internet of Things
Web
Little Data

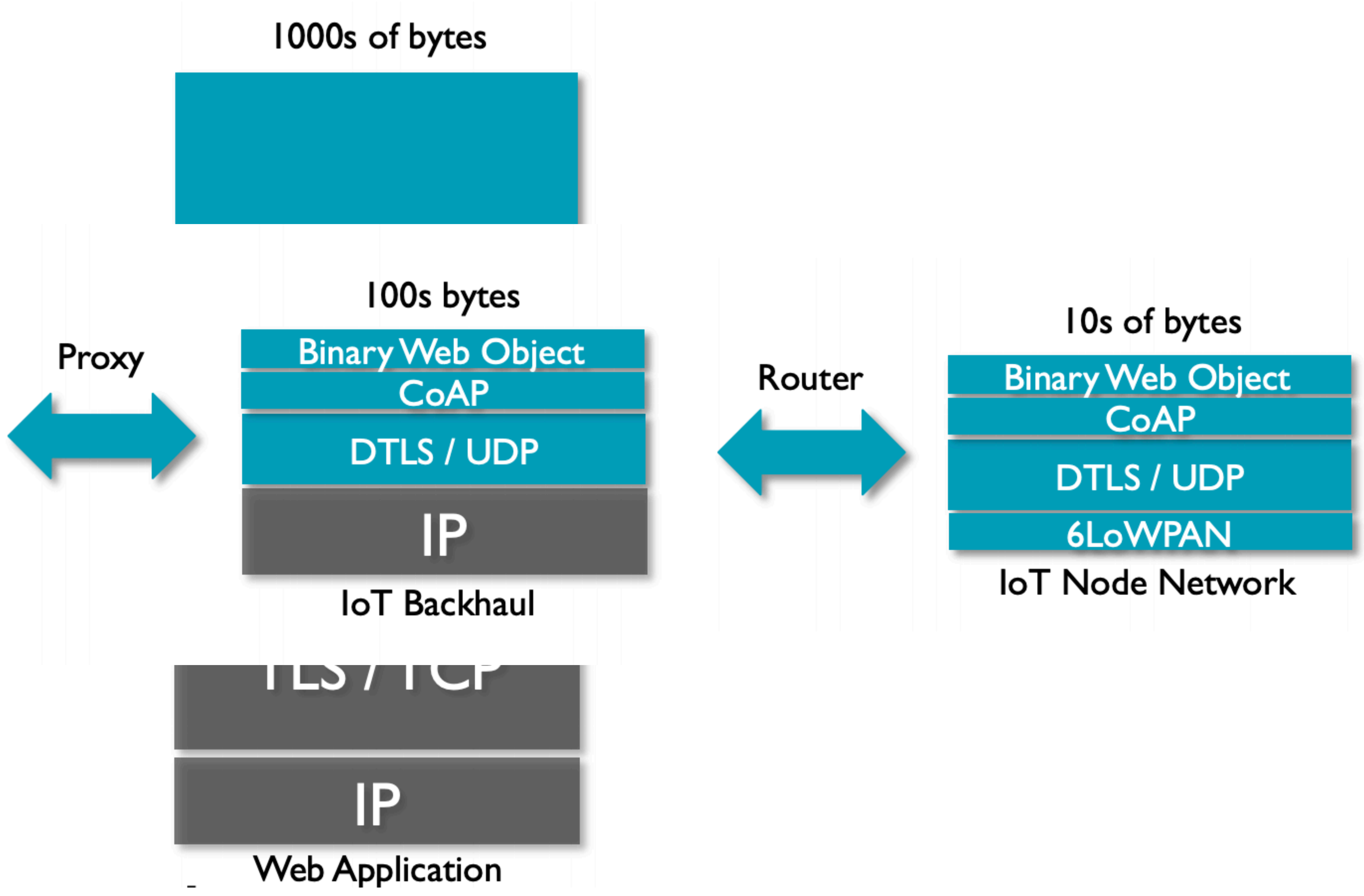

Services
The Web
Things

CoAP

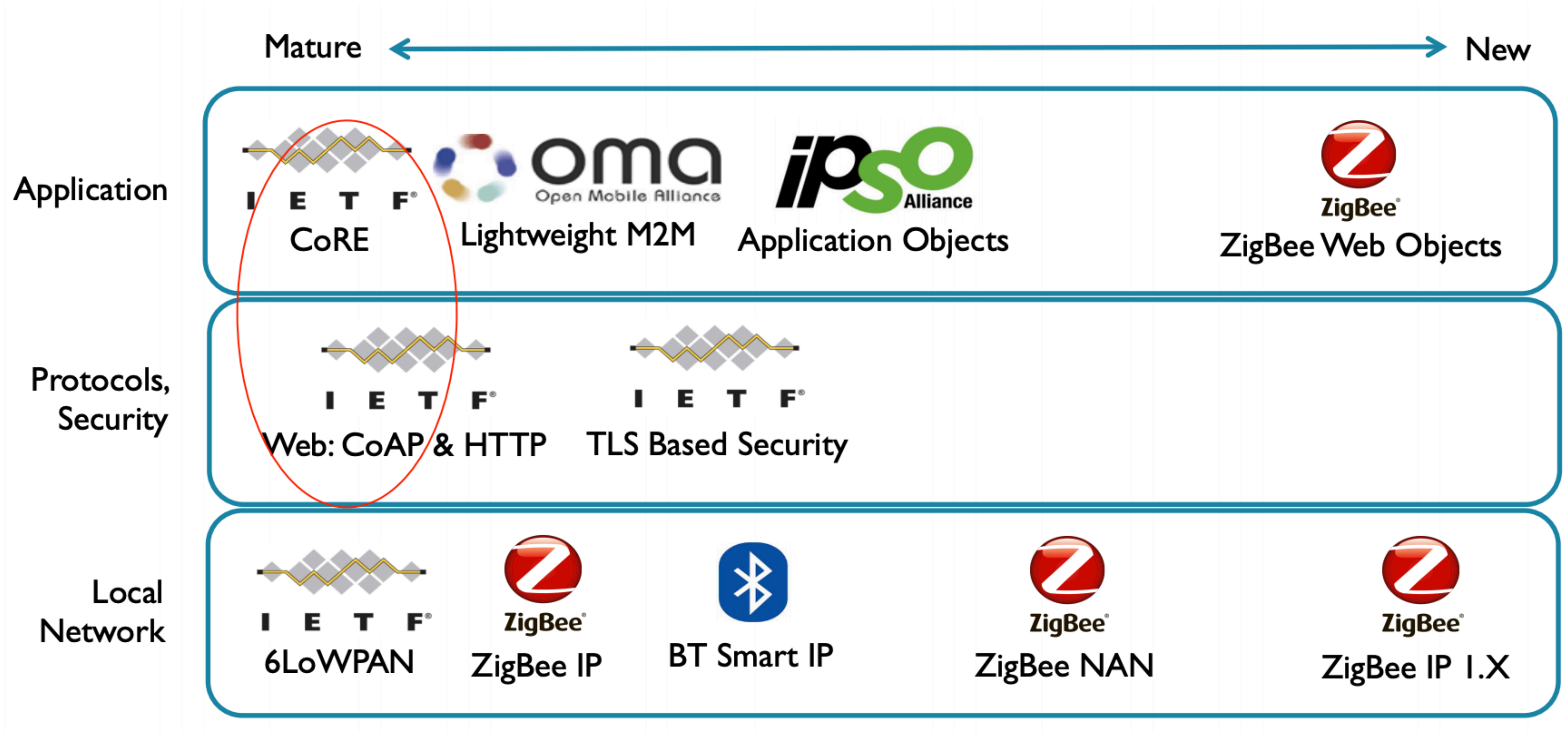
- Open IETF Standard
- Compact 4-byte Header
- UDP, SMS, (TCP) Support
- Strong DTLS Security
- Asynchronous Subscription
- Built-in Discovery



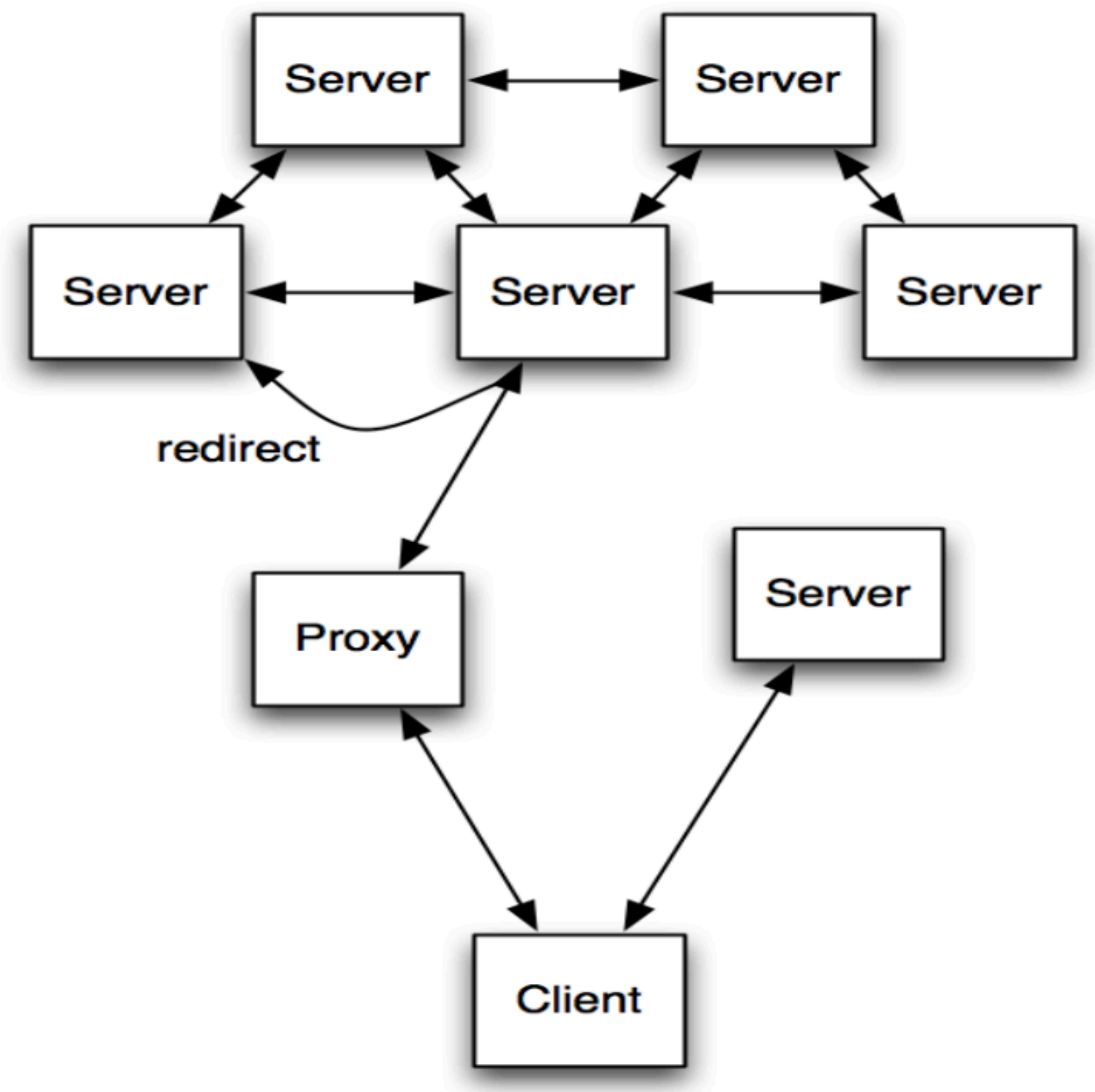
Transitions from Web to IoT



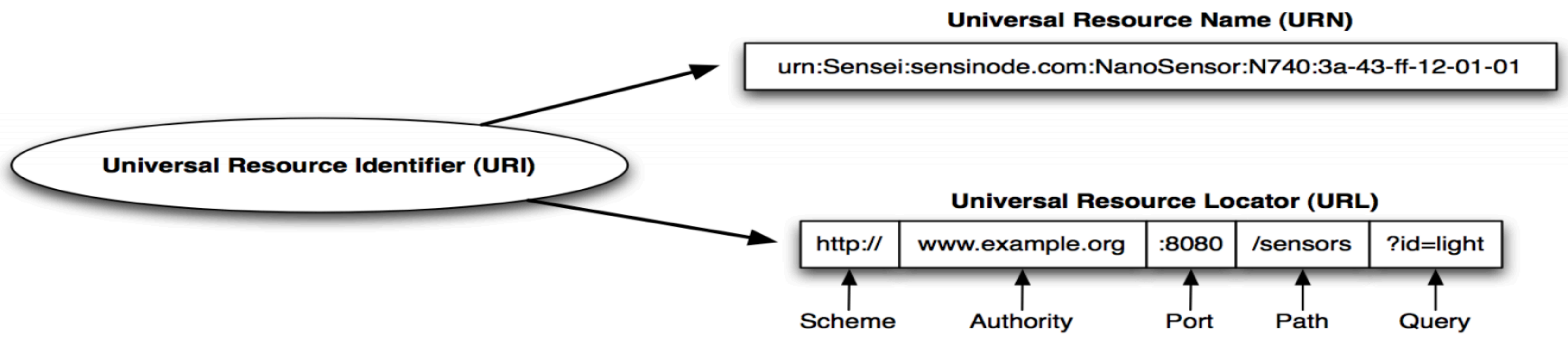
Community


Mature
New
Application
IETF
CoRE
oma Open Mobile Alliance
Lightweight M2M
ipso Alliance
Application Objects
ZigBee
ZigBee Web Objects
Protocols, Security
IETF
Web: CoAP & HTTP
IETF
TLS Based Security
Local Network
IETF
6LoWPAN
ZigBee
ZigBee IP
BT Smart IP
ZigBee
ZigBee NAN
ZigBee
ZigBee IP 1.X

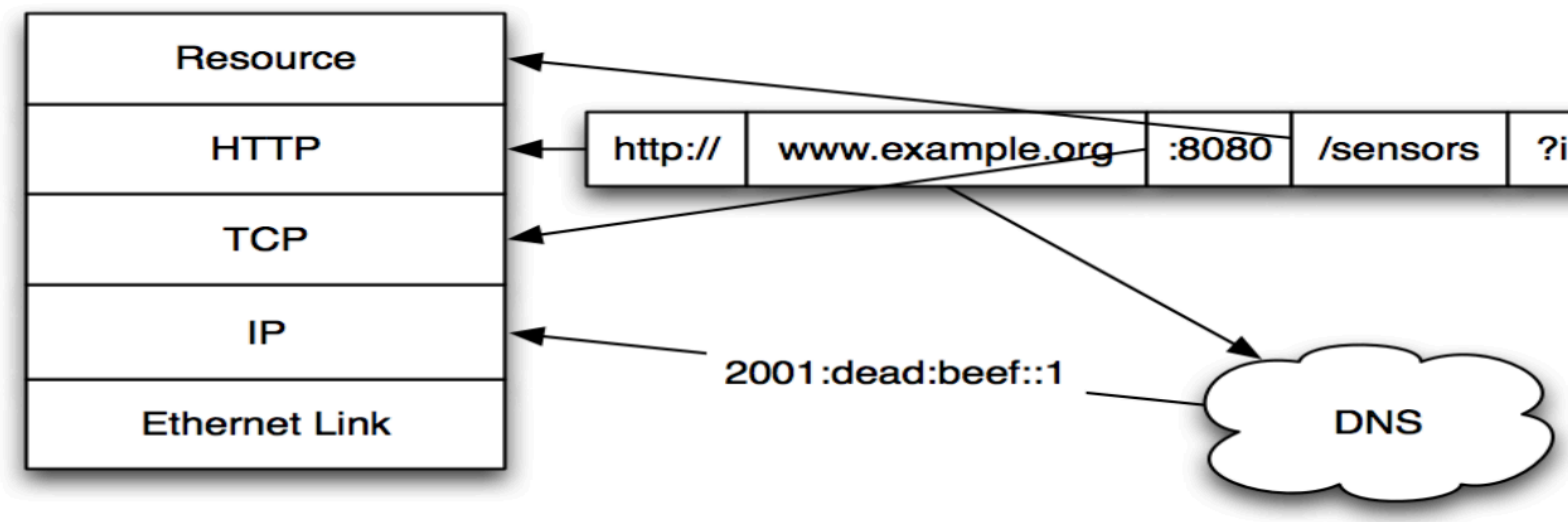
Web Architecture



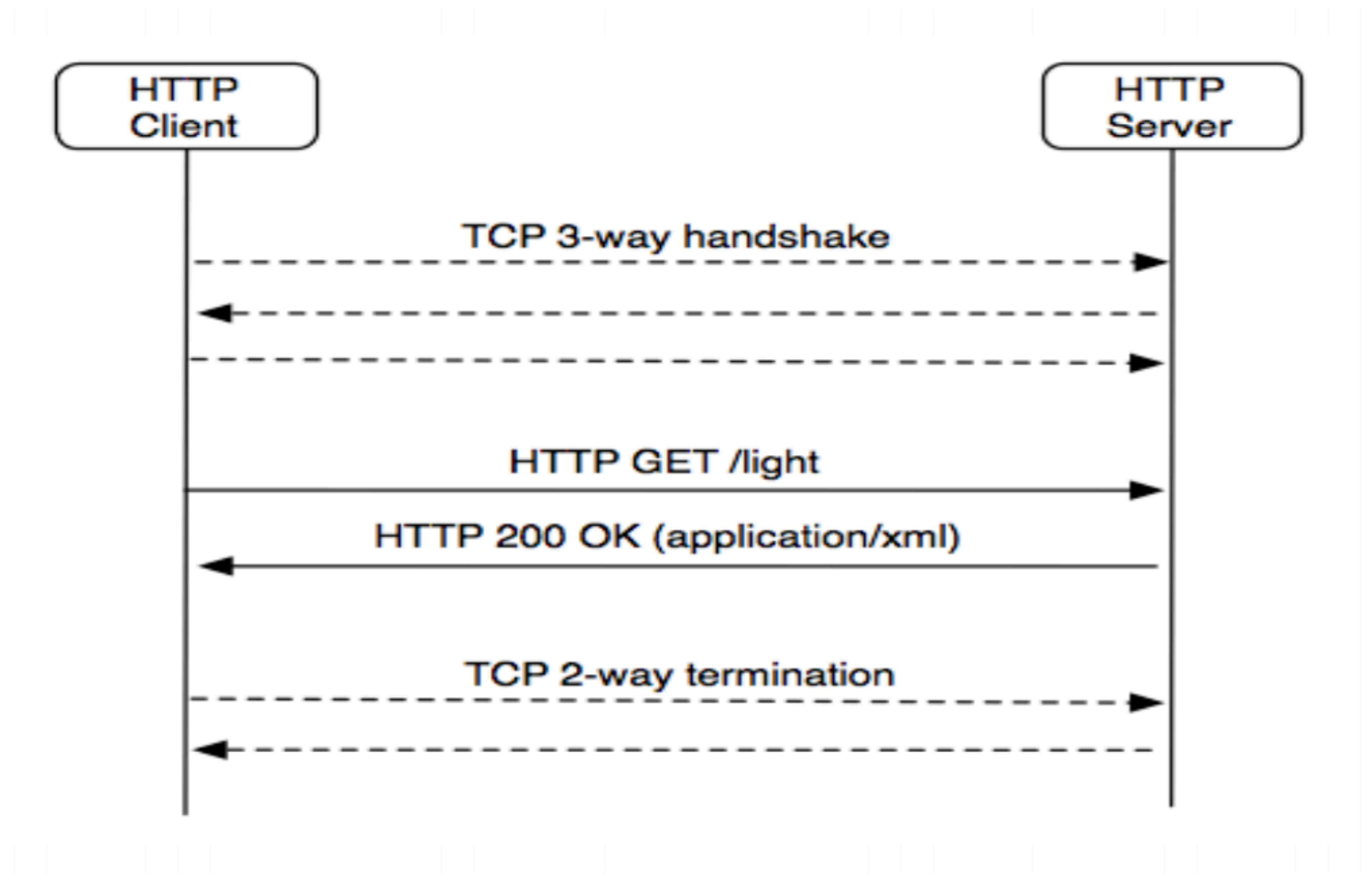
Naming


Universal Resource Identifier (URI)
Universal Resource Name (URN)
urn:Sensei:sensinode.com:NanoSensor:N740:3a-43-ff-12-01-01
Universal Resource Locator (URL)
http://
www.example.org
:8080
/sensors
?id=light
Scheme
Authority
Port
Path
Query

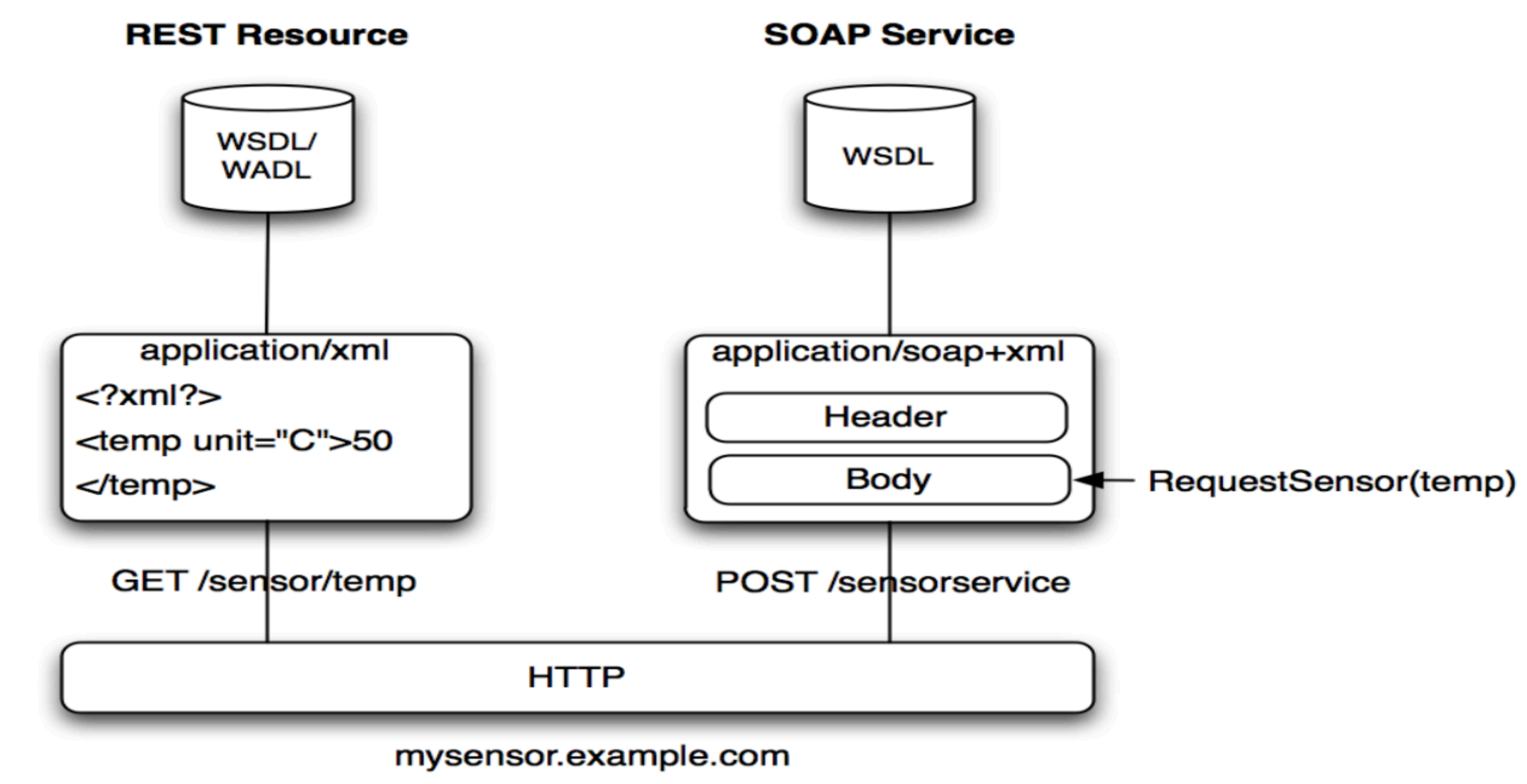
Resolution


Resource
HTTP
TCP
IP
Ethernet Link
http://
www.example.org
:8080
/sensors
?id=light
2001:dead:beef::1
DNS

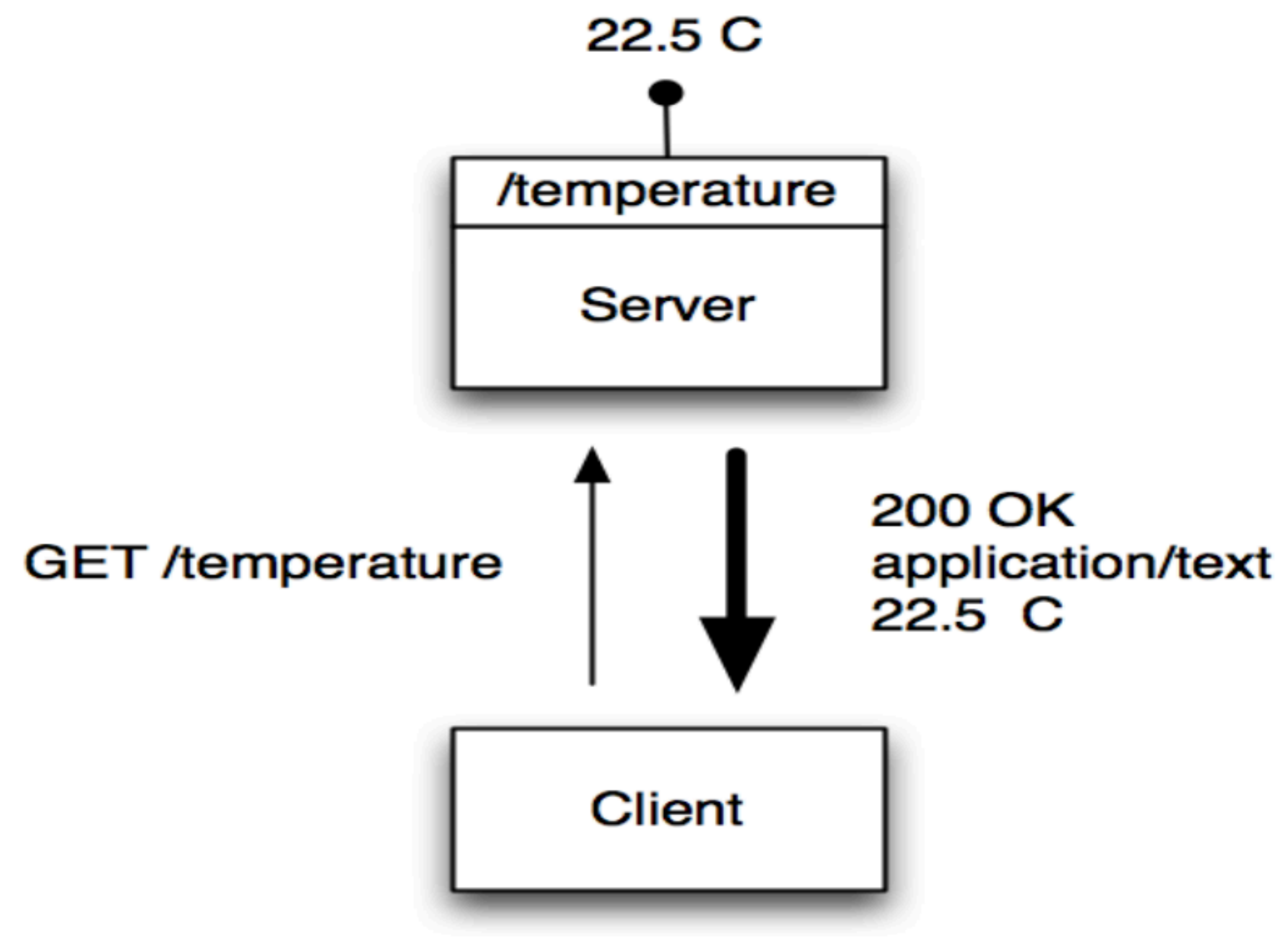
Traditional HTTP



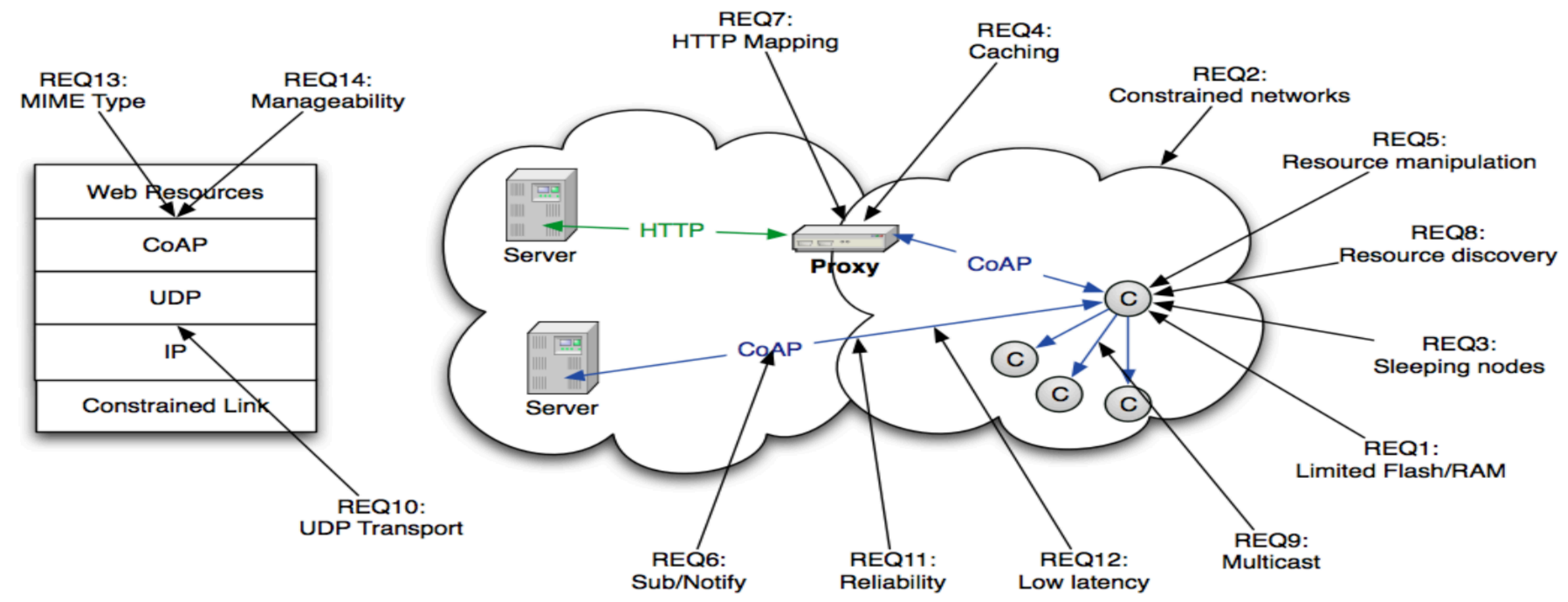
Web Paradigms



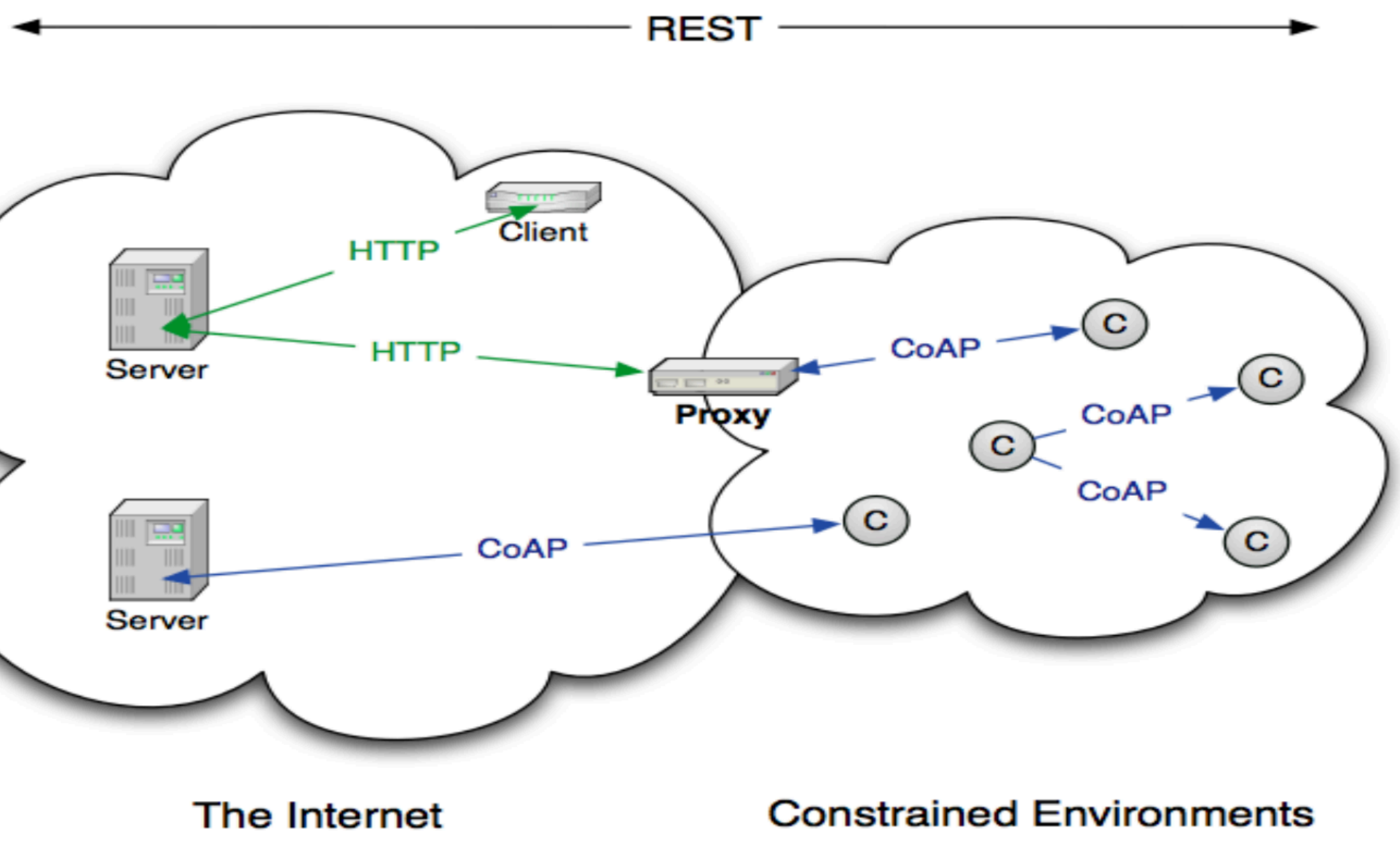
REST Request



CoAP

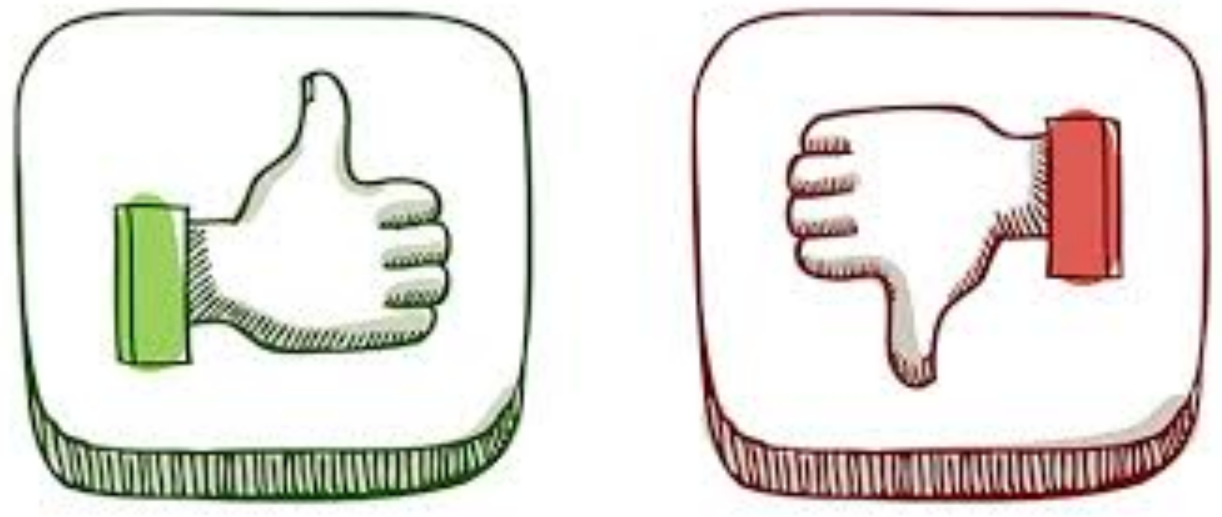

REQ13:
MIME Type
REQ14:
Manageability
Web Resources
CoAP
UDP
IP
Constrained Link
REQ10:
UDP Transport
REQ7:
HTTP Mapping
REQ4:
Caching
REQ2:
Constrained networks
REQ5:
Resource manipulation
REQ8:
Resource discovery
Server
HTTP
Proxy
CoAP
Server
CoAP
C
C
C
C
REQ3:
Sleeping nodes
REQ1:
Limited Flash/RAM
REQ6:
Sub/Notify
REQ11:
Reliability
REQ12:
Low latency
REQ9:
Multicast

Architecture



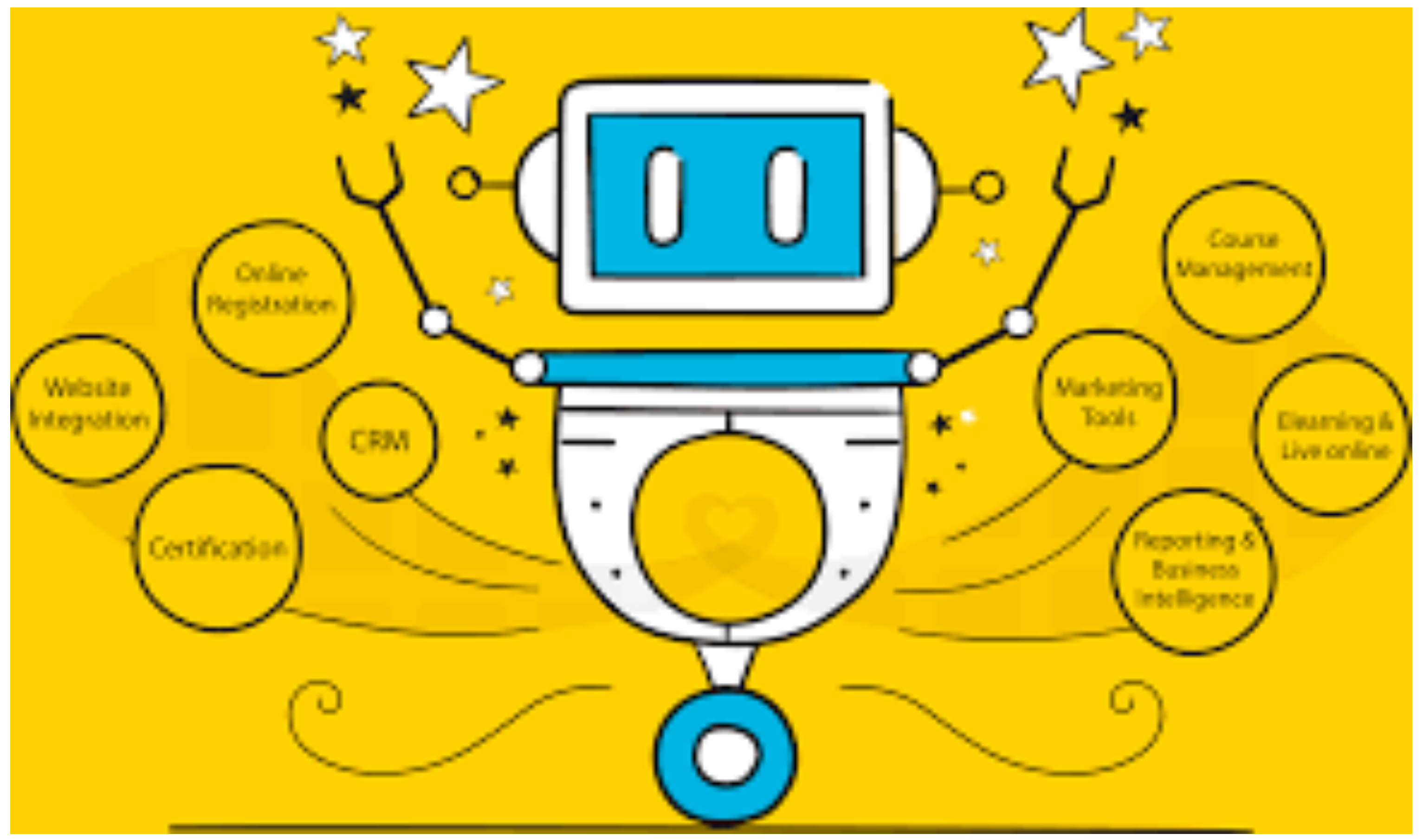
Pro/Cons

- CoAP is:
  - A very efficient RESTful protocol
  - Ideal for constrained devices and networks
  - Specialized for M2M applications
  - Easy to proxy to/from HTTP
- CoAP is not:
  - A general replacement for HTTP
  - HTTP compression
  - Restricted to isolated “automation” networks



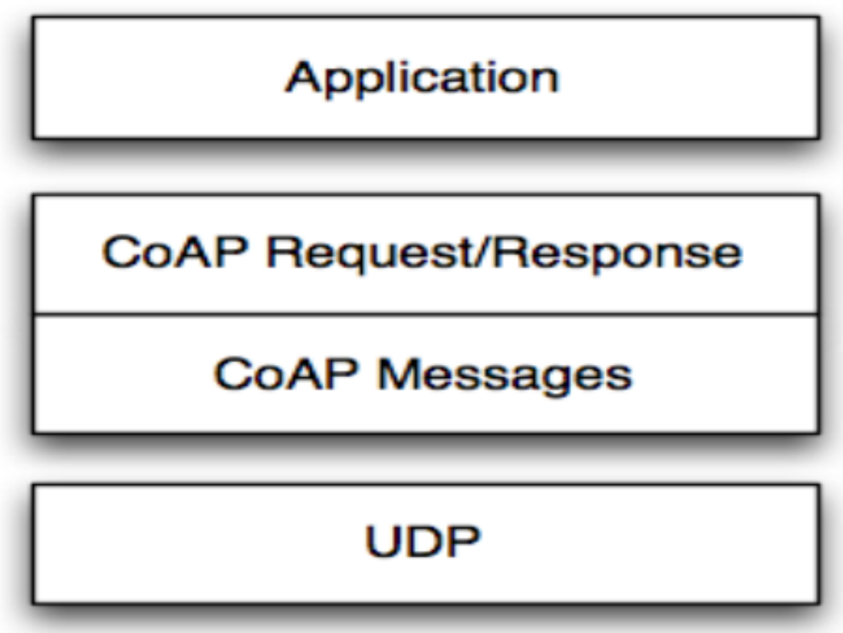
Features

- Embedded web transfer protocol (coap://)
- Asynchronous transaction model
- UDP binding with reliability and multicast support
- GET, POST, PUT, DELETE methods
- URI support
- Small, simple 4 byte header
- DTLS based PSK, RPK and Certificate security
- Subset of MIME types and HTTP response codes
- Built-in discovery
- Optional observation and block transfer



Transactional Model

- Transport
  - CoAP currently defines:
    - UDP binding with DTLS security
    - CoAP over SMS or TCP possible
  - Base Messaging
    - Simple message exchange between endpoints
    - Confirmable or Non-Confirmable Message answered by Acknowledgement or Reset Message
  - REST Semantics
    - REST Request/Response piggybacked on CoAP Messages
    - Method, Response Code and Options (URI, content-type etc.)



Header

```
 0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |Ver| T |  TKL  |      Code     |          Message ID           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Token (if any, TKL bytes) ...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Options (if any) ...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |1 1 1 1 1 1 1 1|    Payload (if any) ...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Ver - Version (1)

T - Message Type (Confirmable, Non-Confirmable, Acknowledgement, Reset)

TKL- Token Length, if any, the number of Token bytes after this header

Code - Request Method (1-10) or Response Code (40-255)

Message ID - 16-bit identifier for matching responses

Token - Optional response matching token

Options Field

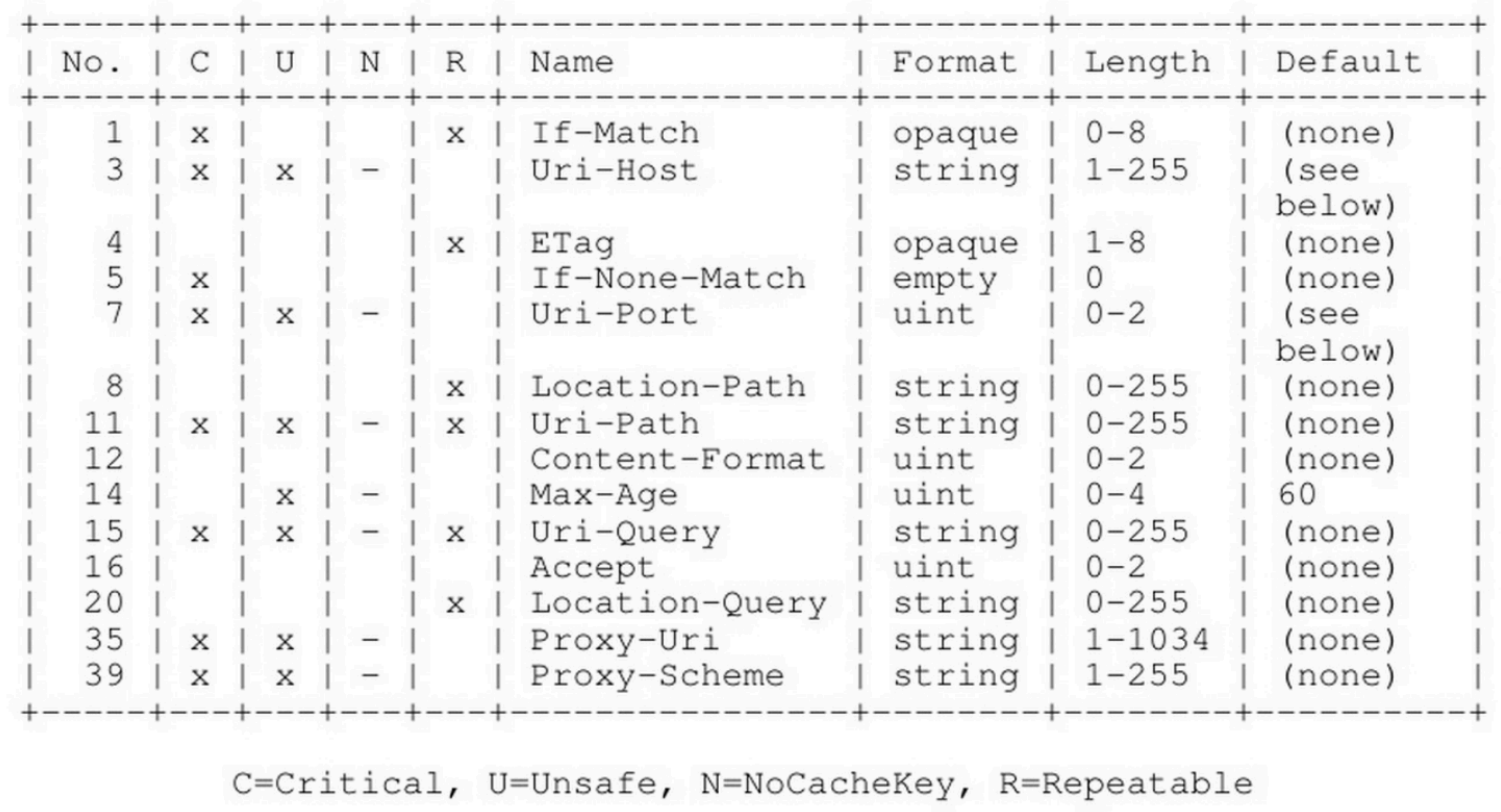
```
  0   1   2   3   4   5   6   7
+---------------+---------------+
|               |               |
|  Option Delta | Option Length |   1 byte
|               |               |
+---------------+---------------+
\                               \
/         Option Delta          /   0-2 bytes
\          (extended)           \
+-------------------------------+
\                               \
/         Option Length         /   0-2 bytes
\          (extended)           \
+-------------------------------+
\                               \
/                               /
\                               \
/         Option Value          /   0 or more bytes
\                               \
/                               /
\                               \
+-------------------------------+
```

Option Delta - Difference between this option type and the previous

Length - Length of the option value

Value - The value of Length bytes immediately follows Length

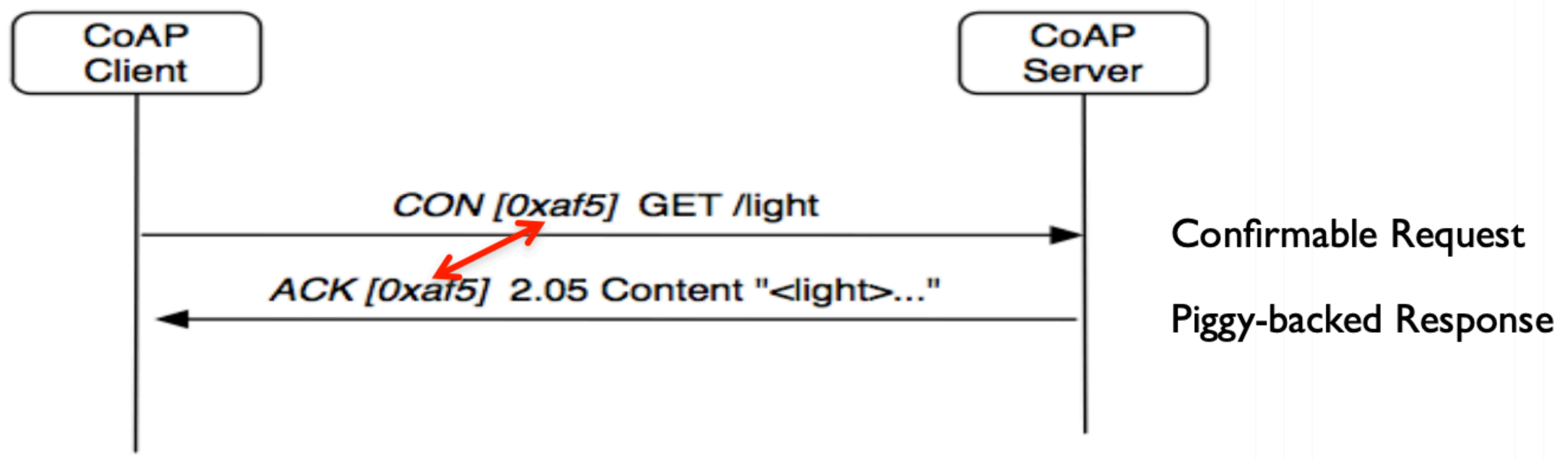
Base Specification



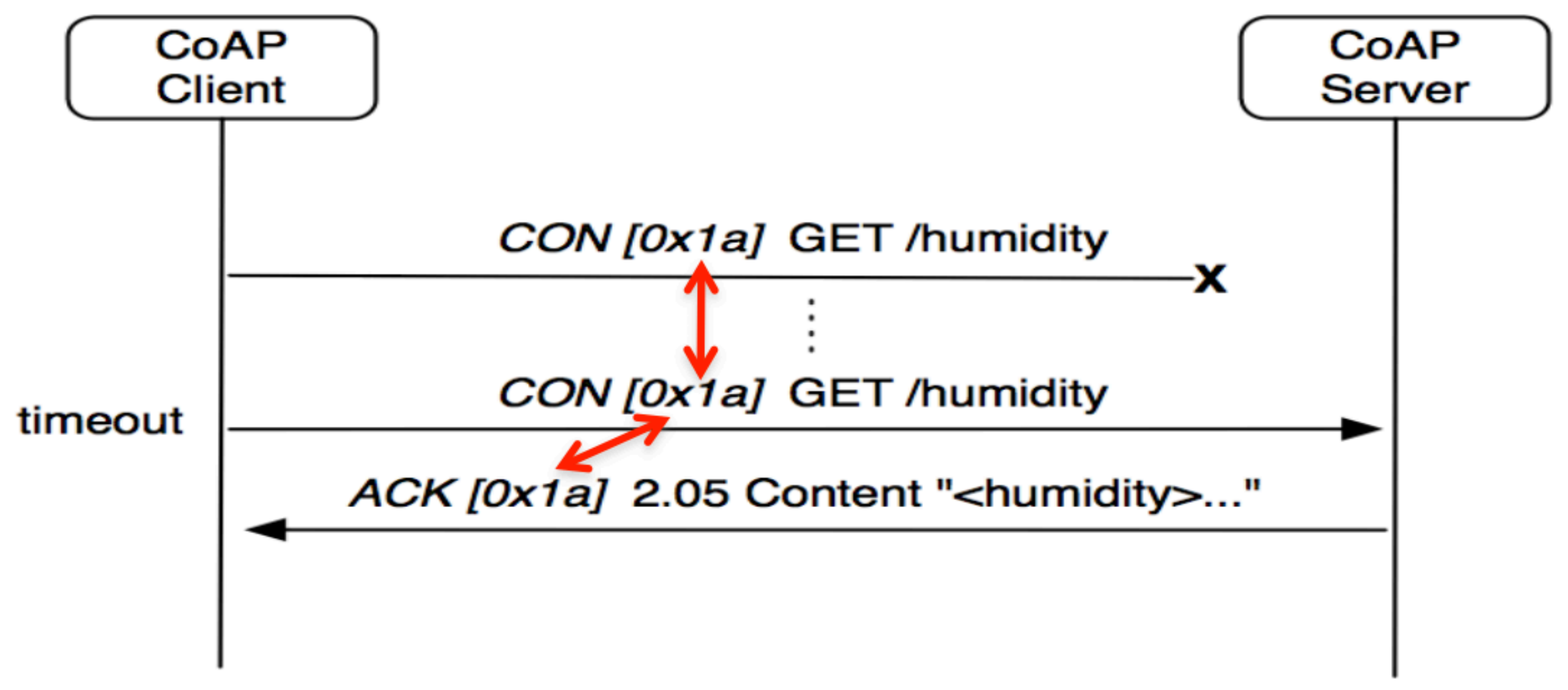
No.	C	U	N	R	Name	Format	Length	Default
1	x			x	If-Match	opaque	0-8	(none)
3	x	x	-		Uri-Host	string	1-255	(see below)
4				x	ETag	opaque	1-8	(none)
5	x				If-None-Match	empty	0	(none)
7	x	x	-		Uri-Port	uint	0-2	(see below)
8				x	Location-Path	string	0-255	(none)
11	x	x	-	x	Uri-Path	string	0-255	(none)
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)
16					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)

C=Critical, U=Unsafe, N=NoCacheKey, R=Repeatable

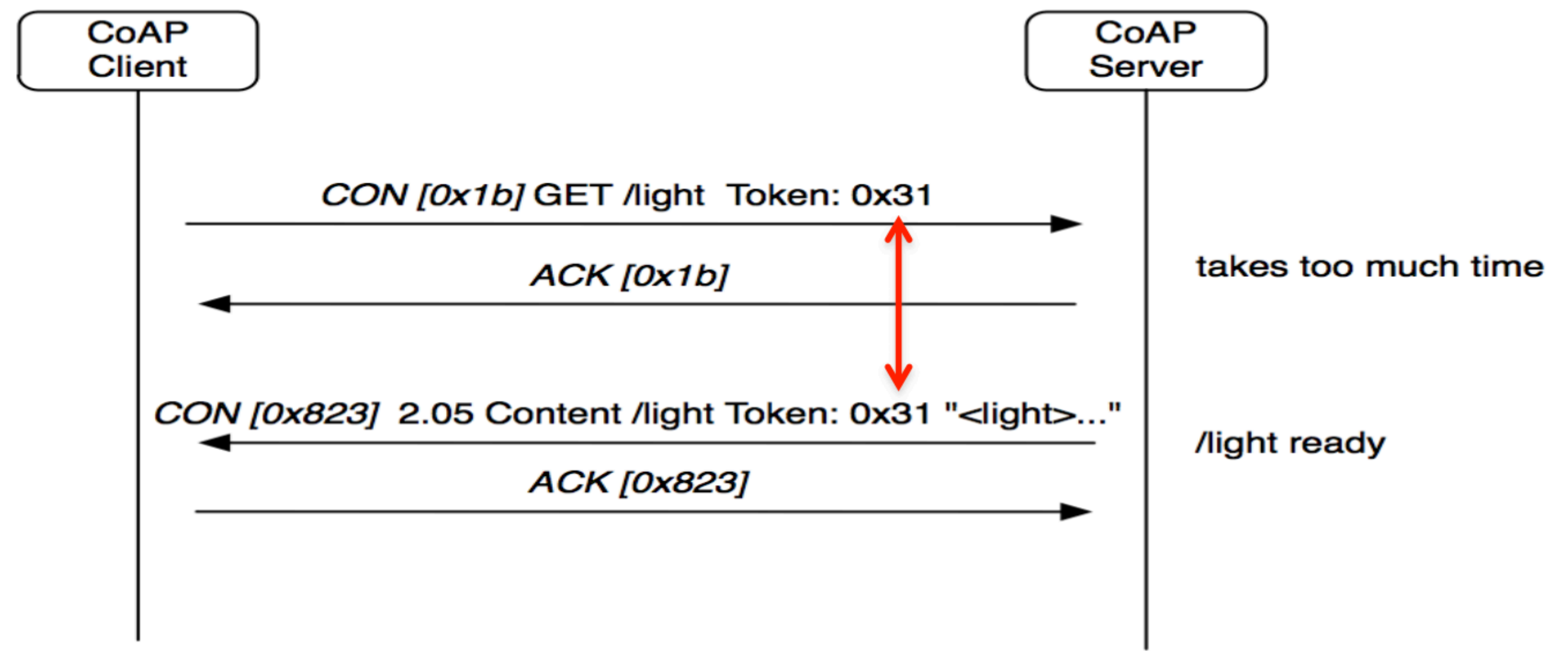
Simple Request



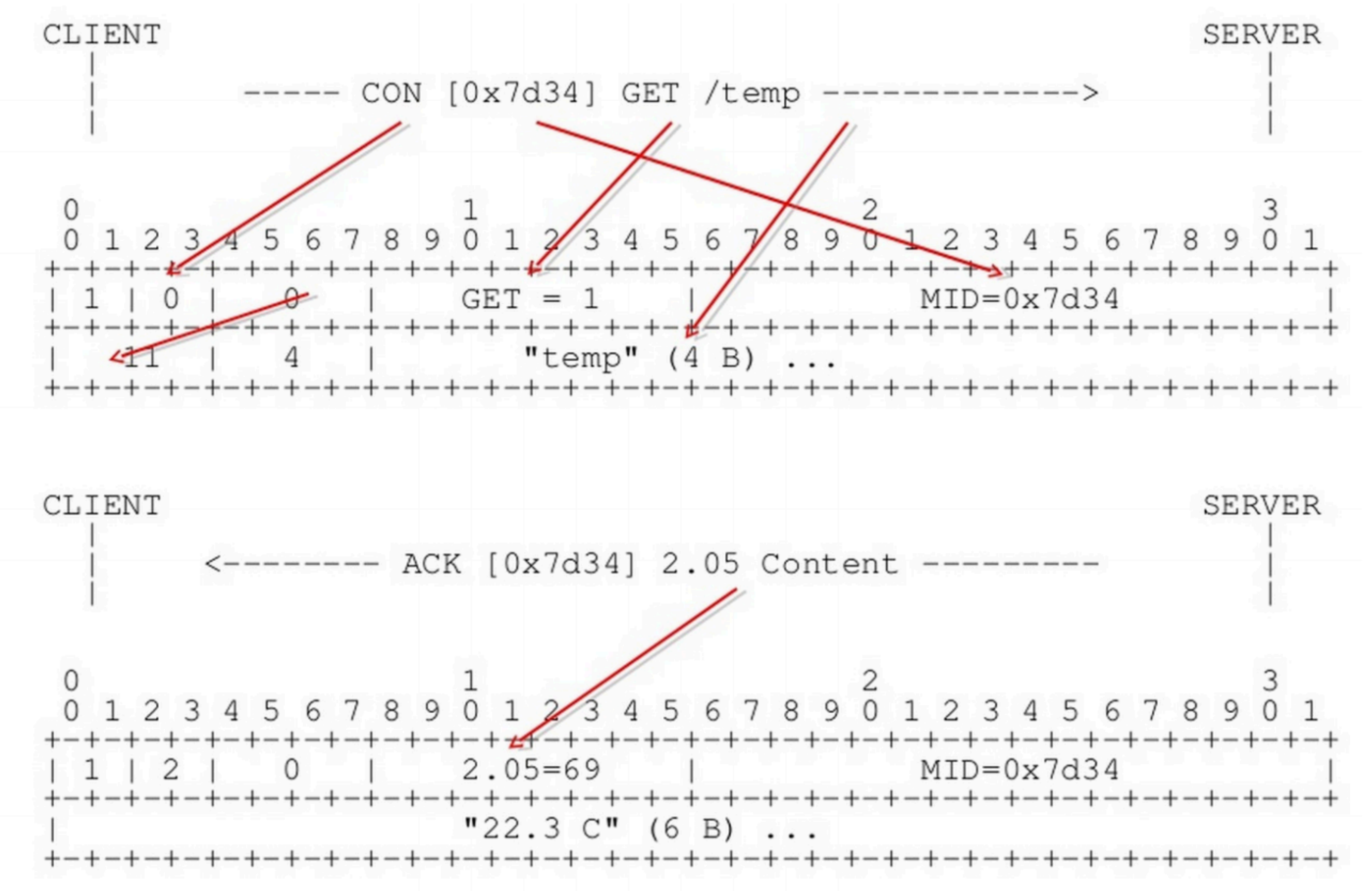
Data Loss


CoAP Client
CoAP Server
CON [0x1a] GET /humidity
x
timeout
CON [0x1a] GET /humidity
ACK [0x1a] 2.05 Content "<humidity>..."

Separate Response


CoAP Client
CoAP Server
CON [0x1b] GET /light Token: 0x31
ACK [0x1b]
takes too much time
CON [0x823] 2.05 Content /light Token: 0x31 "<light>..."
/light ready
ACK [0x823]

Bits & Bytes

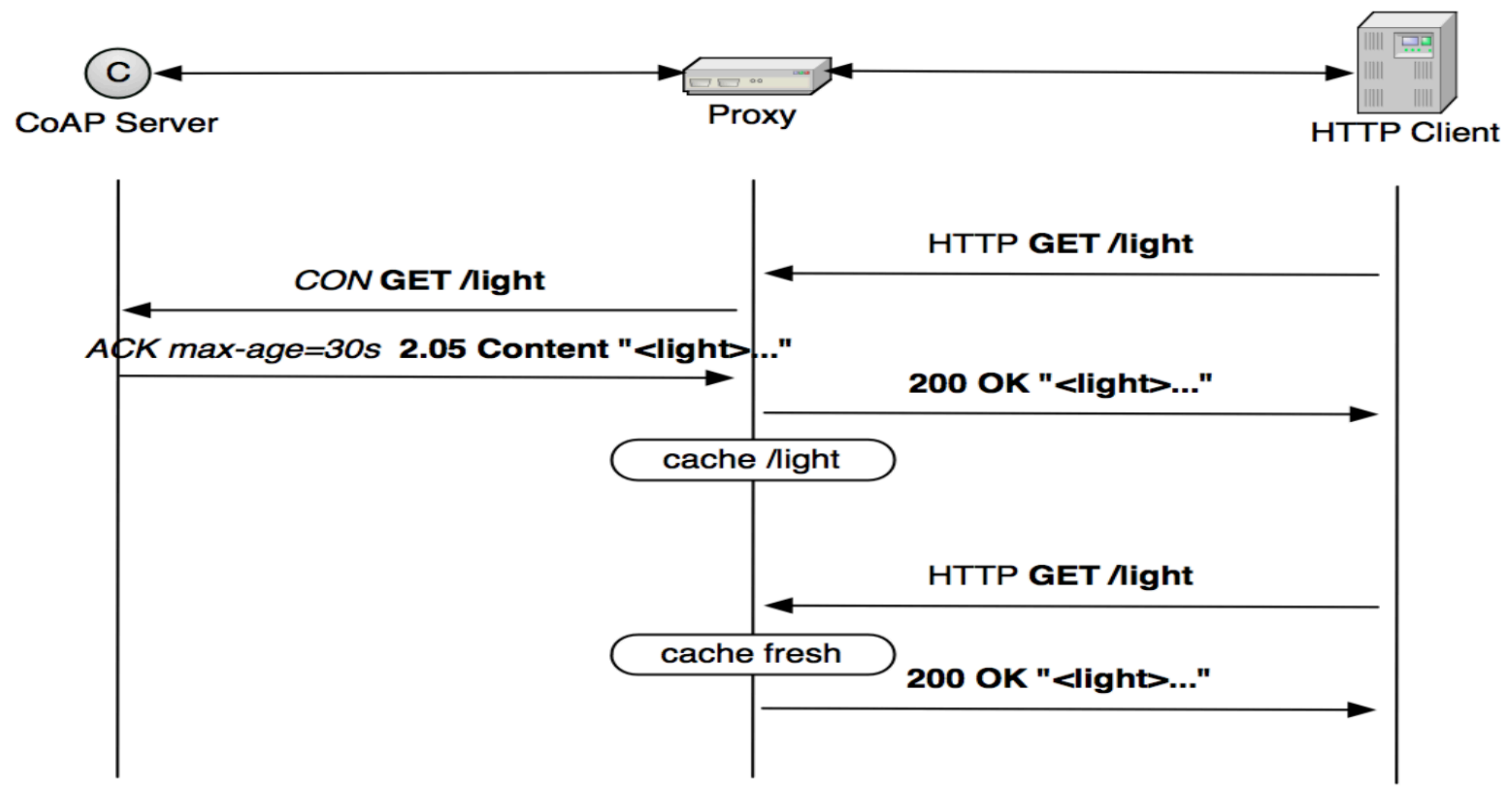


```
CLIENT                                                     SERVER
  |                                                           |
  |       ----- CON [0x7d34] GET /temp ------------->         |
  |                                                           |

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| 1 | 0 |   0   |     GET = 1     |          MID=0x7d34           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  11   |   4   |      "temp" (4 B) ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

CLIENT                                                     SERVER
  |                                                           |
  |     <-------- ACK [0x7d34] 2.05 Content ---------         |
  |                                                           |

 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| 1 | 2 |   0   |    2.05=69      |          MID=0x7d34           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     "22.3 C" (6 B) ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

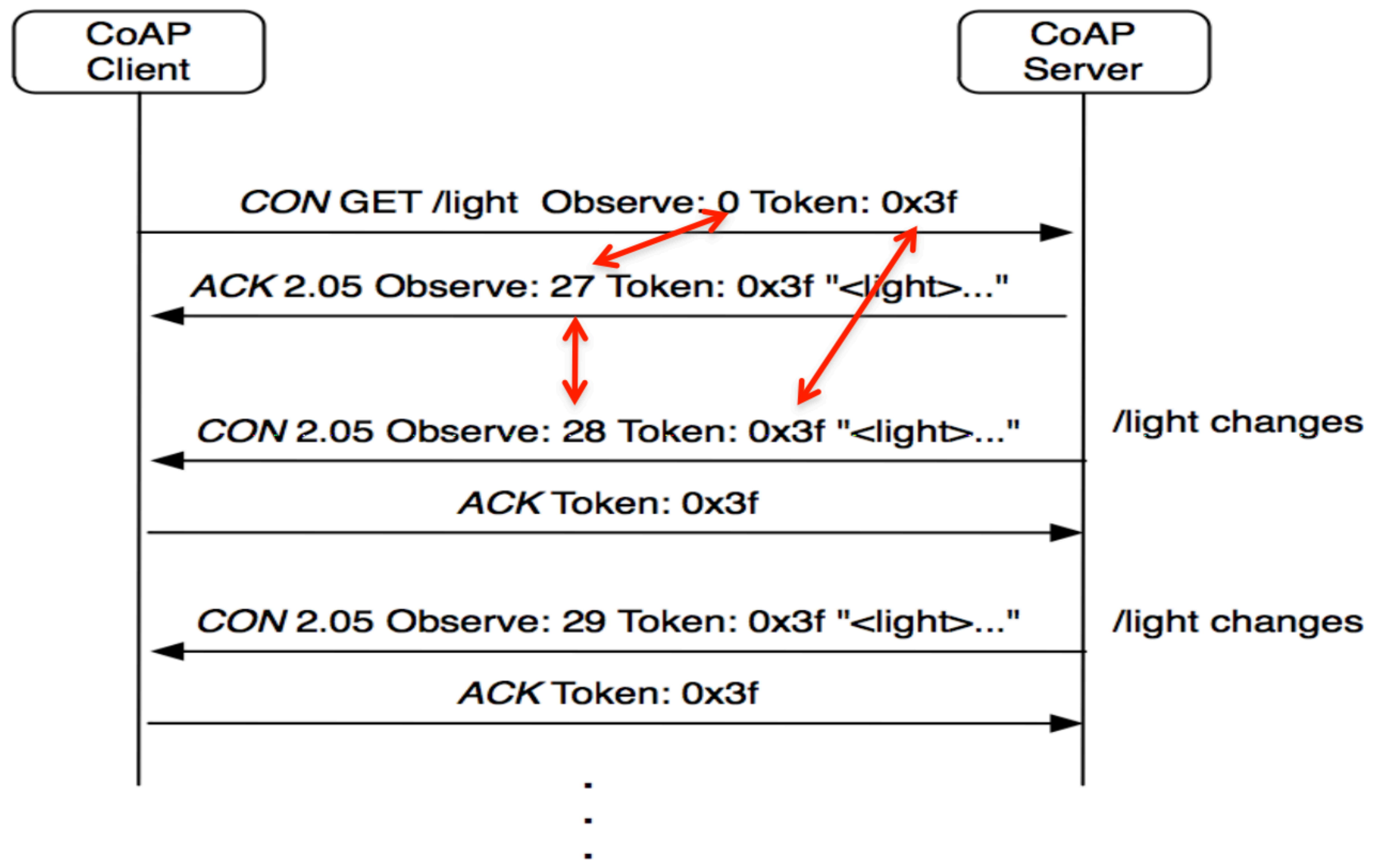
Caching

- CoAP includes a simple caching model
  - Determined by response code
  - An option number mask determines if it is a cache key
- Freshness model
  - Max-Age option indicates cache lifetime
- Validation model
  - Validity checked using the Etag Option
- A proxy often supports caching
  - Usually on behalf of a constrained node,
    - a sleeping node,
    - or to reduce network load.

Proxy

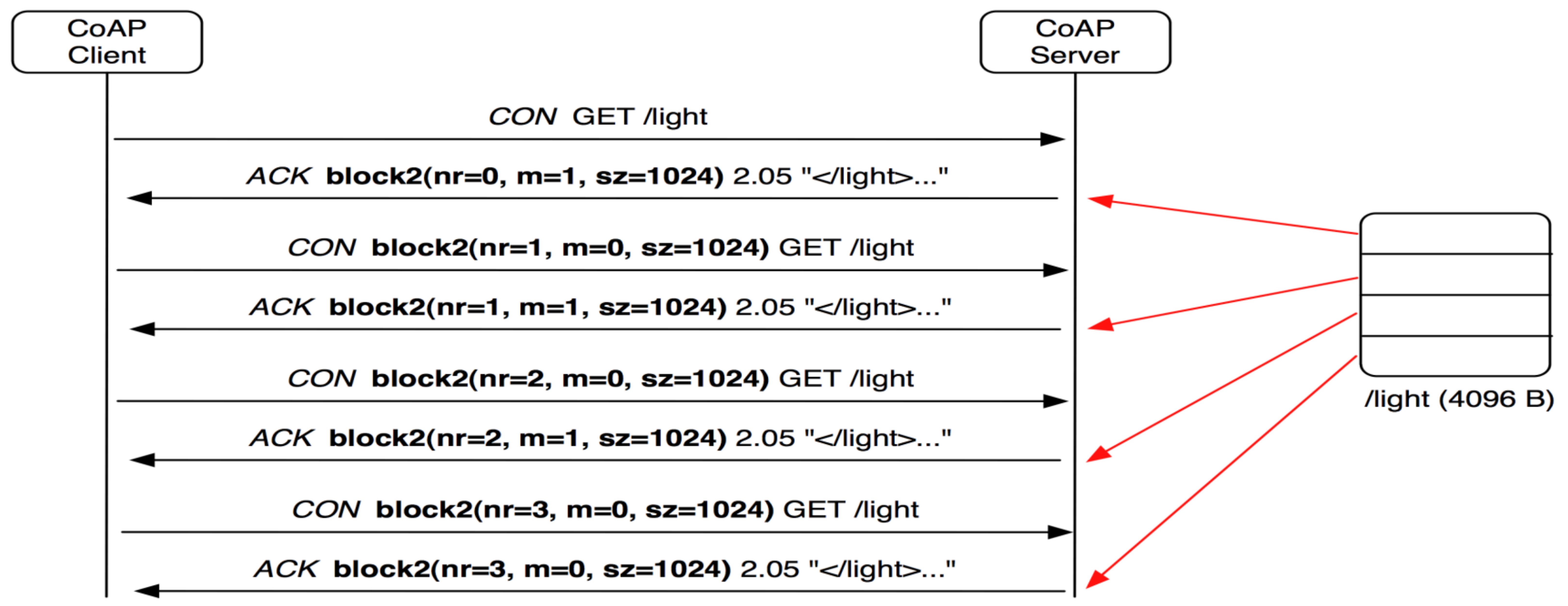

C
CoAP Server
Proxy
HTTP Client
HTTP **GET /light**
CON **GET /light**
ACK max-age=30s **2.05 Content "<light>..."**
200 OK "<light>..."
cache /light
HTTP **GET /light**
cache fresh
200 OK "<light>..."

Subscription


CoAP Client
CoAP Server
CON GET /light Observe: 0 Token: 0x3f
ACK 2.05 Observe: 27 Token: 0x3f "<light>..."
CON 2.05 Observe: 28 Token: 0x3f "<light>..."
/light changes
ACK Token: 0x3f
CON 2.05 Observe: 29 Token: 0x3f "<light>..."
/light changes
ACK Token: 0x3f

See draft-ietf-core-observe

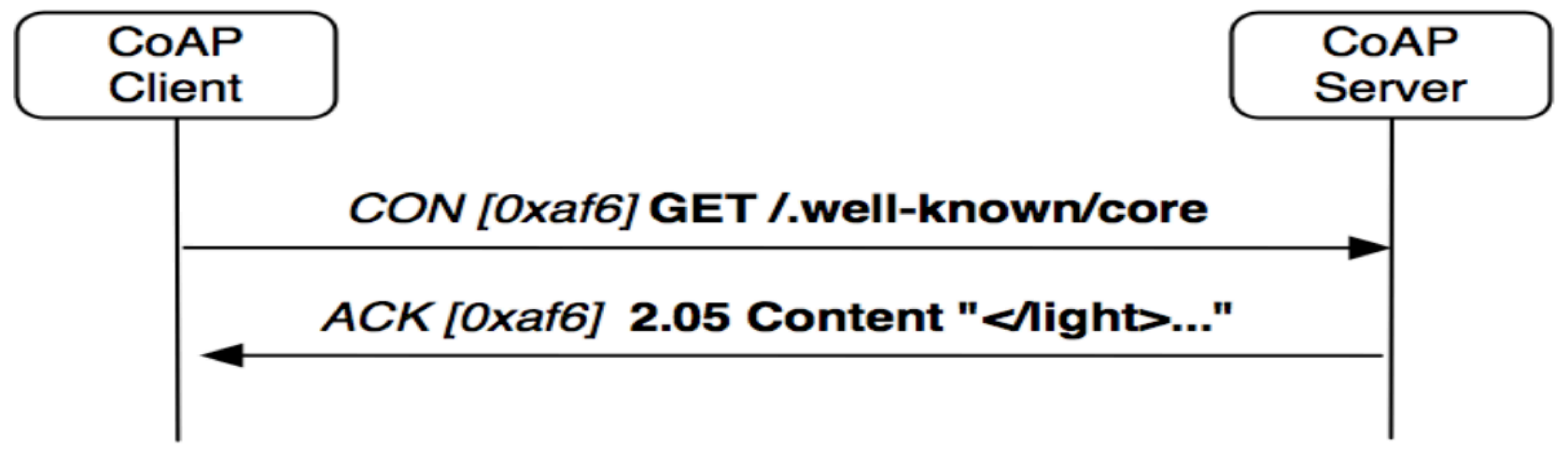
Block Transfer


CoAP Client
CoAP Server
CON GET /light
ACK block2(nr=0, m=1, sz=1024) 2.05 "</light>..."
CON block2(nr=1, m=0, sz=1024) GET /light
ACK block2(nr=1, m=1, sz=1024) 2.05 "</light>..."
CON block2(nr=2, m=0, sz=1024) GET /light
ACK block2(nr=2, m=1, sz=1024) 2.05 "</light>..."
CON block2(nr=3, m=0, sz=1024) GET /light
ACK block2(nr=3, m=0, sz=1024) 2.05 "</light>..."
/light (4096 B)

Community & Open Source

- There are many open source implementations available
  - mbed includes CoAP support
  - Java CoAP Library Californium
  - C CoAP Library Erbium
  - libCoAP C Library
  - jCoAP Java Library
  - OpenCoAP C Library
  - TinyOS and Contiki include CoAP support
- CoAP is already part of many commercial products/systems
  - ARM Sensinode NanoService
  - RTX 4100 WiFi Module
- Firefox has a CoAP plugin called Copper
- Wireshark has CoAP dissector support
- Implement CoAP yourself, it is not that hard!

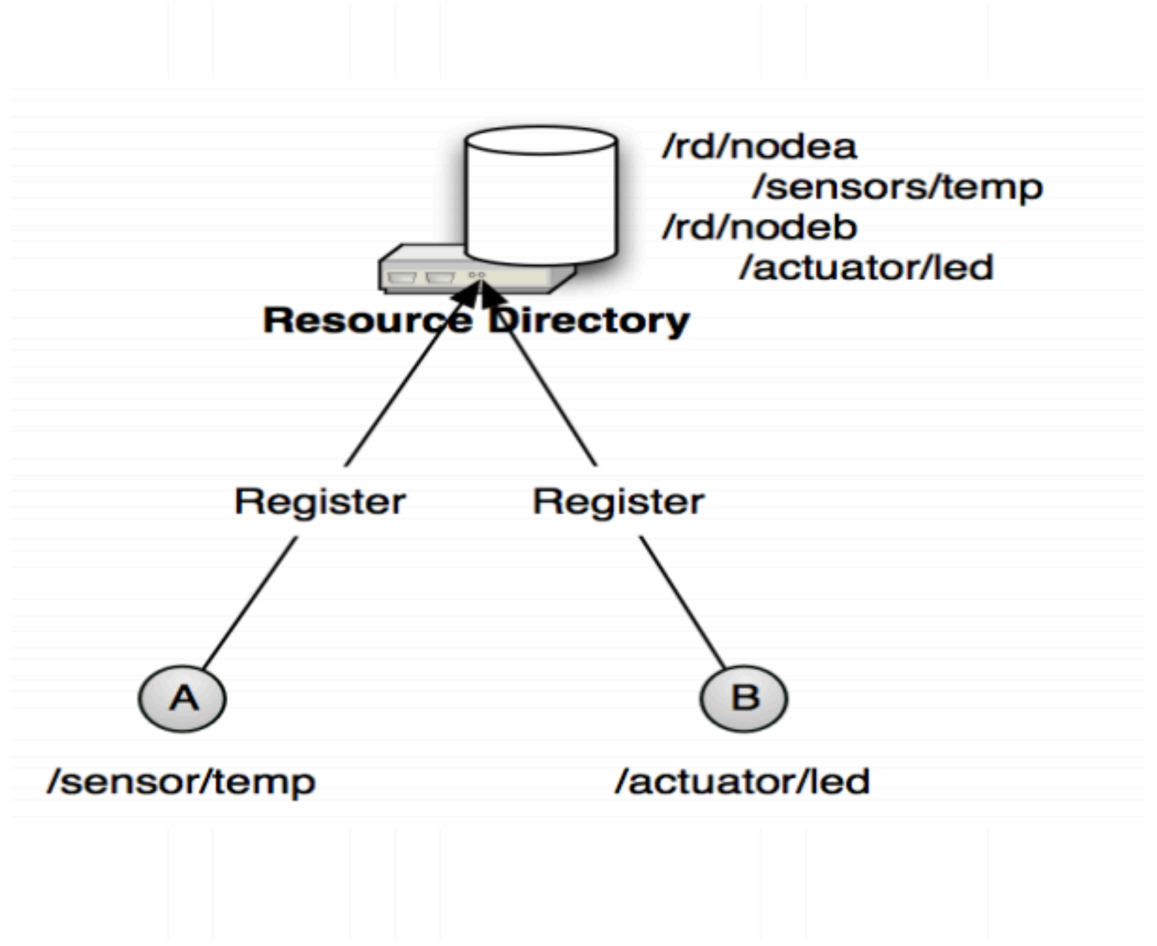
Resource Discovery


CoAP Client
CoAP Server
CON [0xaf6] GET /.well-known/core
ACK [0xaf6] 2.05 Content "</light>..."

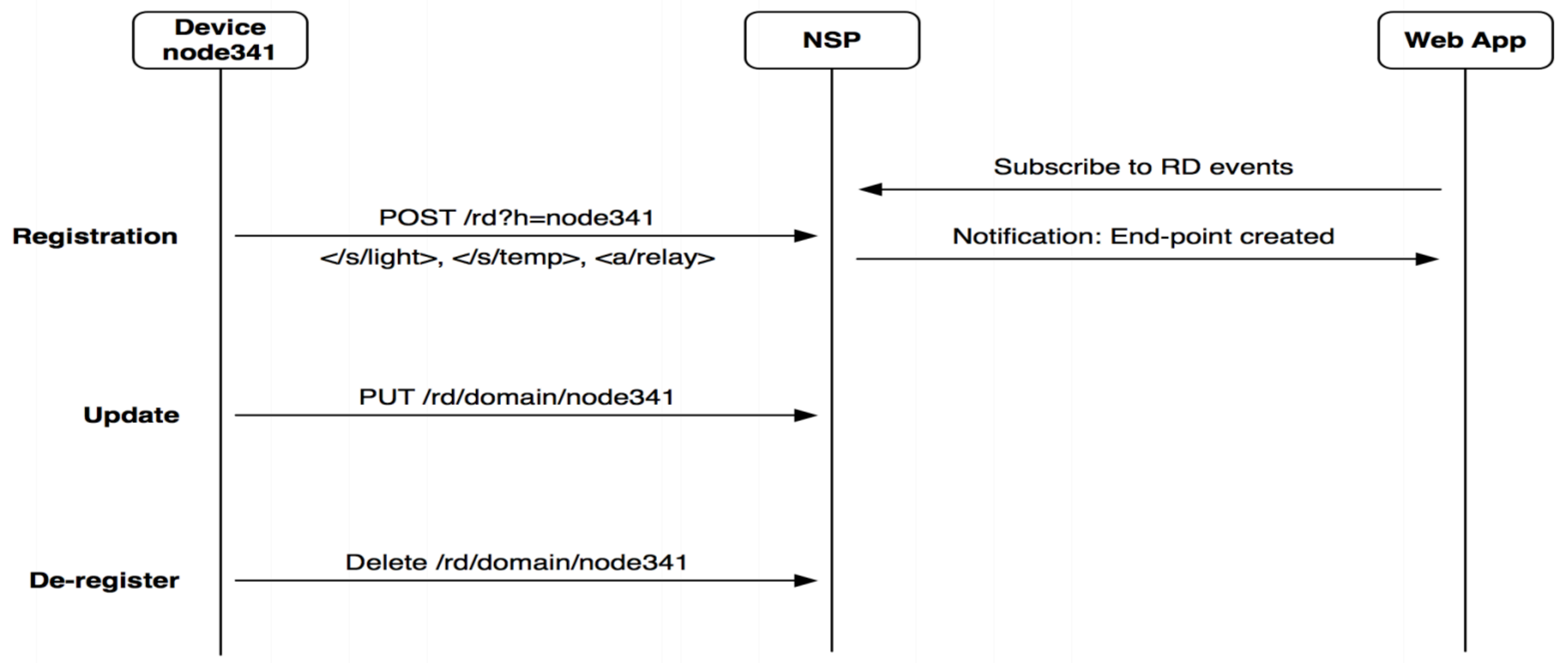
```
</dev/bat>;obs;rt="ipso:dev-bat";ct="0",
</dev/mdl>;rt="ipso:dev-mdl";ct="0",
</dev/mfg>;rt="ipso:dev-mfg";ct="0”,
</pwr/0/rel>;obs;rt="ipso:pwr-rel";ct="0",
</pwr/0/w>;obs;rt="ipso:pwr-w";ct="0",
</sen/temp>;obs;rt="ucum:Cel";ct="0"
```

Resource Directory

- Link Format only defines
  - The link format
  - Peer-to-peer discovery
- A directory approach is also useful
  - Supports sleeping nodes
  - No multicast traffic, longer battery life
  - Remote lookup, hierarchical and federated distribution
- The CoRE Link Format can be used to build Resource Directories
  - Nodes POST (register) their link-format to an RD
  - Nodes PUT (refresh) to the RD periodically
  - Nodes may DELETE (remove) their RD entry
  - Nodes may GET (lookup) the RD or resource of other nodes



Resource Directory



Client Sample

```go
package main

import (
  "context"
  "log"
  "os"
  "time"

  "github.com/plgd-dev/go-coap/v2/udp"
)

func main() {
  co, err := udp.Dial("localhost:5683")
  if err != nil {
    log.Fatalf("Error dialing: %v", err)
  }
  path := "/a"
  if len(os.Args) > 1 {
    path = os.Args[1]
  }
```

```go
import (
  "context"
  "log"
  "os"
  "time"

  "github.com/plgd-dev/go-coap/v2/udp"
)

func main() {
  co, err := udp.Dial("localhost:5683")
  if err != nil {
    log.Fatalf("Error dialing: %v", err)
  }
  path := "/a"
  if len(os.Args) > 1 {
    path = os.Args[1]
  }

  ctx, cancel := context.WithTimeout(context.Background(), time.Second)
  defer cancel()
  resp, err := co.Get(ctx, path)
  if err != nil {
    log.Fatalf("Error sending request: %v", err)
  }
  log.Printf("Response payload: %v", resp.String())
}
```

Server Sample

```go
package main

import (
  "bytes"
  "log"

  coap "github.com/plgd-dev/go-coap/v2"
  "github.com/plgd-dev/go-coap/v2/message"
  "github.com/plgd-dev/go-coap/v2/message/codes"
  "github.com/plgd-dev/go-coap/v2/mux"
)

func handleA(w mux.ResponseWriter, r *mux.Message) {
  err := w.SetResponse(codes.Content, message.TextPlain, bytes.NewReader([]byte("hello world")))
  if err != nil {
    log.Printf("cannot set response: %v", err)
  }
}

func main() {
  r := mux.NewRouter()
```

```go
package main

import (
  "bytes"
  "log"

  coap "github.com/plgd-dev/go-coap/v2"
  "github.com/plgd-dev/go-coap/v2/message"
  "github.com/plgd-dev/go-coap/v2/message/codes"
  "github.com/plgd-dev/go-coap/v2/mux"
)

func handleA(w mux.ResponseWriter, r *mux.Message) {
  err := w.SetResponse(codes.Content, message.TextPlain, bytes.NewReader([]byte("hello world")))
  if err != nil {
    log.Printf("cannot set response: %v", err)
  }
}

func main() {
  r := mux.NewRouter()
  r.Handle("/a", mux.HandlerFunc(handleA))

  log.Fatal(coap.ListenAndServe("udp", ":5683", r))
}
```

Java Server Sample

```
import org.eclipse.californium.core.CoapResource;
import org.eclipse.californium.core.CoapServer;
import org.eclipse.californium.core.server.resources.CoapExchange;

import static org.eclipse.californium.core.coap.CoAP.ResponseCode.*;

public class JavaCoapServer {

    public static void main(String[] args) {

        // binds on UDP port 5683
        CoapServer server = new CoapServer();

        // "hello"
        server.add(new HelloResource());

        // "subpath/Another"
        CoapResource path = new CoapResource("subpath");
        path.add(new AnotherResource());
        server.add(path);

        // "removeme!, "time", "writeme!"
        server.add(new RemovableResource(), new TimeResource(), new WritableResource());
```

```
public class JavaCoapServer {

    public static void main(String[] args) {

        // binds on UDP port 5683
        CoapServer server = new CoapServer();

        // "hello"
        server.add(new HelloResource());

        // "subpath/Another"
        CoapResource path = new CoapResource("subpath");
        path.add(new AnotherResource());
        server.add(path);

        // "removeme!, "time", "writeme!"
        server.add(new RemovableResource(), new TimeResource(), new WritableResource());

        server.start();
    }

    public static class HelloResource extends CoapResource {
        public HelloResource() {

            // resource identifier
            super("Hello");

            // set display name
```

```
public static class HelloResource extends CoapResource {
    public HelloResource() {

        // resource identifier
        super("Hello");

        // set display name
        getAttributes().setTitle("Hello-World Resource");
    }

    @Override
    public void handleGET(CoapExchange exchange) {
        exchange.respond("Hello world!");
    }
}

public static class AnotherResource extends CoapResource {
    public AnotherResource() {

        // resource identifier
        super("Another");

        // set display name
        getAttributes().setTitle("Another Hello-World Resource");
    }

    @Override
    public void handleGET(CoapExchange exchange) {
```

```
public static class AnotherResource extends CoapResource {
    public AnotherResource() {

        // resource identifier
        super("Another");

        // set display name
        getAttributes().setTitle("Another Hello-World Resource");
    }

    @Override
    public void handleGET(CoapExchange exchange) {
        exchange.respond("Fun with CoAP!");
    }
}

public static class RemovableResource extends CoapResource {
    public RemovableResource() {
        super("removeme!");
    }

    @Override
    public void handleDELETE(CoapExchange exchange) {
        delete();
        exchange.respond(DELETED);
    }
}
```

```
public static class TimeResource extends CoapResource {

    public TimeResource() {
        super("time");
    }

    @Override
    public void handleGET(CoapExchange exchange) {
        exchange.respond(String.valueOf(System.currentTimeMillis()));
    }
}

public static class WritableResource extends CoapResource {

    public String value = "to be replaced";

    public WritableResource() {
        super("writeme!");
    }

    @Override
    public void handleGET(CoapExchange exchange) {
        exchange.respond(value);
    }

    @Override
    public void handlePUT(CoapExchange exchange) {
        byte[] payload = exchange.getRequestPayload();
    public static class WritableResource extends CoapResource {

        public String value = "to be replaced";

        public WritableResource() {
            super("writeme!");
        }

        @Override
        public void handleGET(CoapExchange exchange) {
            exchange.respond(value);
        }

        @Override
        public void handlePUT(CoapExchange exchange) {
            byte[] payload = exchange.getRequestPayload();

            try {
                value = new String(payload, "UTF-8");
                exchange.respond(CHANGED, value);
            } catch (Exception e) {
                e.printStackTrace();
                exchange.respond(BAD_REQUEST, "Invalid String");
            }
        }
    }
}
```

Java Client Sample

```java
import org.eclipse.californium.core.CoapClient;
import org.eclipse.californium.core.CoapResponse;

public class HelloClient {
    public static void main(String[] args) {
        CoapClient client = new CoapClient("coap://localhost/Hello");
        CoapResponse response = client.get();
        if (response!=null) {
          System.out.println( response.getCode() );
          System.out.println( response.getOptions() );
          System.out.println( response.getResponseText() );
        } else {
          System.out.println("Request failed");
        }
    }
}
```

Lecture outcomes

- CoAP Protocol.
- Practice using a sample.