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CoAP

IoT Protocols

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Overview

- History
- CoAP
- Communication Details
- Tips for the Lab Project

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Constrained Application Protocol (CoAP)

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History

- Devices on the IoT include sensors and actuators
  - Exposing resources (i.e., measurable data, sensors)
  - or enabling interaction with the environment (actuators)
- They have to find ways to
  - Register to services
  - Find each other
  - and interact without much human intervention
- Ideally we would be talking about a decentralized scenario
  - Much like how the web is built up of decentralized web servers

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History

- The Constrained Application Protocol (CoAP)
  - Specialized protocol for constrained device communication
  - Defined in RFC 7252. June 2014
  - Expanded in RFC 7959, 7959, 8323, and 8613
- Efficiency is very important.
  - Is intended for use in resource-constrained IP capable devices
  - Such as low end IoT devices or IoT devices in general
- Works on low throughput networks and devices that run on battery
  - For example Class 1 IoT devices with below:
    - 100KB of Flash
    - 10KB of RAM

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History

- CoAP is a REST-based protocol largely inspired by HTTP
  - However it brings the Web Server concept to the very constrained space where IoT devices are the ones exposing their resources
- CoAP devices are intended to come from multiple manufacturers, much like the World Wide Web enabled anyone to have an HTTP server.
- Like HTTP, CoAP also uses request/response communication
- CoAP is designed to easily translate to HTTP to fit with the web
  - While also meeting specialized requirements
    - Including multicast support
    - Very low overhead and simplicity

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COAP

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CoAP Definitions

- Defined in RFC 7252. June 2014
  - The Constrained Application Protocol (CoAP)
    - All the basic functionality
- Expanded in
  - RFC 7959
    - Block-Wise Transfers in the Constrained Application Protocol
      - For handling large and multiple messages
  - RFC 8323 and RFC 8613
    - CoAP over TCP, TLS, and WebSockets
    - Object Security for Constrained RESTful Environments (OSCORE)
      - For managing and supporting security

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CoAP Terms

- Before going deeper into the CoAP protocol, structure is useful to define some terms that we will use later:
  - **Endpoint**: An entity that participates in the CoAP protocol. Usually, an Endpoint is identified with a host
  - **Sender**: The entity that sends a message
  - **Recipient**: The destination of a message
  - **Client**: The entity that sends a request and the destination of the response (usually an application or platform)
  - **Server**: The entity that receives a request from a client and sends back a response to the client (usually the sensor)

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CoAP Functionality

- Constrained Application Protocol
  - REST-based web transfer protocol
  - Manipulates Web resources using the same methods as HTTP
    - GET, PUT, POST, and DELETE
  - Subset of HTTP functionality re-designed for low power embedded devices such as sensors (for IoT and M2M)
- CoAP provides reliability without using TCP as transport protocol
  - Basically a reliable UDP variant
  - TCP overhead is too high and its flow control is not appropriate for short-lived transactions
- CoAP can also handle asynchronous communication
  - For example, it can first ACKs the reception of the message and then send the response later in an off-line fashion

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Communication Details

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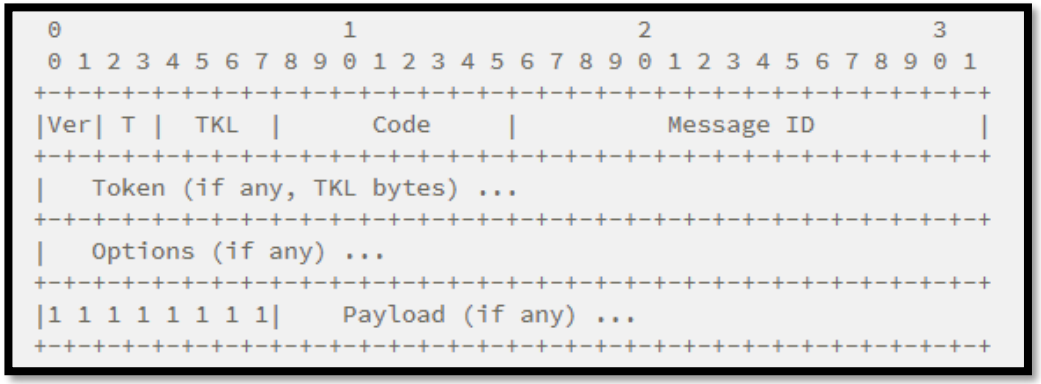
Messsage types

- Four message types:
  - Confirmable – requires an ACK
  - Non-confirmable – no ACK needed
  - Acknowledgement – ACKs a Confirmable
  - Reset - indicates a Confirmable message has been received but context is missing for processing
- Most common methods are:
  - GET
  - POST
  - PUT
  - DELETE
  - Discover (a GET to .well-known/core to get the tree structure)
  - Observe (a GET variant to add a subscription)

COAP message definition

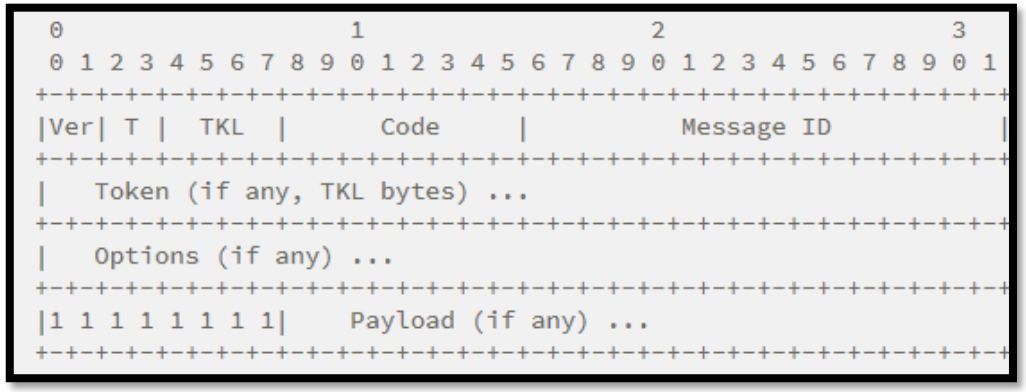
- CoAP messages are very compact and transported over UDP
  - Messages are encoded in a binary format with a header of 4 bytes



CoAP Header

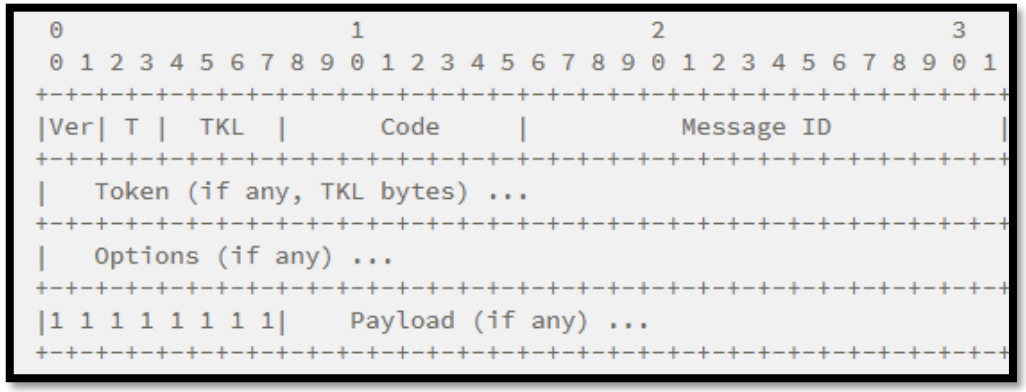
Offsets	Octet	0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
4	32	VER		Type		Token Length				Request/Response Code								Message ID															
8	64	Token (0 - 8 bytes)																															
12	96																																
16	128	Options (If Available)																															
20	160	1	1	1	1	1	1	1	1	Payload (If Available)																							

Message details



- The version field Ver indicates the CoAP version
  - (01) is version 1
- The message type T can be
  - CON (00), NON (01), ACK (10) and RST (11)
    - Use NON (01) for simplicity
- TKL is token length, which specified the length of the token
  - Not needed, (you can it set to 0000) tokens are used to map req/resp
- This is followed by a method- or response-code
  - Method code: Empty (0000 0000), GET (0000 0001), POST (0000 0010), PUT (0000 0011), DELETE (0000 0100)
  - Response code 3+5 bits, Example: 2.00 OK (010 00000) 2.05 Content (010 00101), 4.04 Not Found (100 00100)

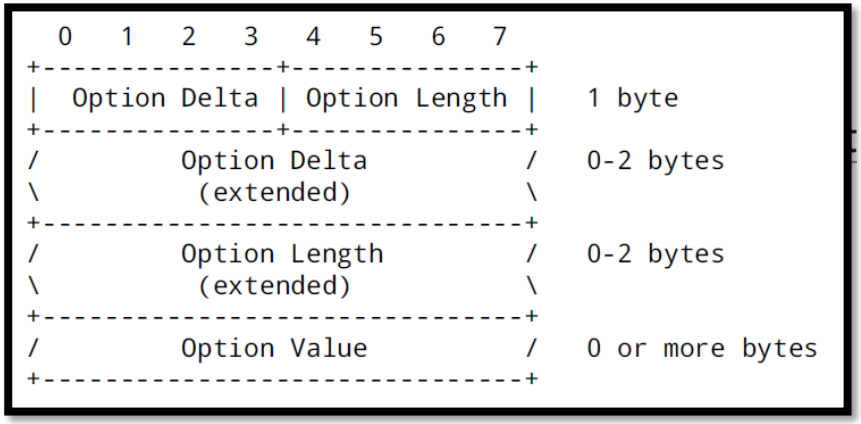
Message details



- Message ID, which is a 16 bit field to detect message duplication
  - Start at random number and then increment
- After the first row, there comes a token which can be ignored if you set the length to 0 before
  - Tokens are used to map a responses to a originating request in asynchronous or bulk responses
- After this, there comes an options field for extensibility
  - Optional, but practically mandatory
  - Since it is what specified the URI path and content format
- The header ends with (1111 1111) 255 in binary to mark the end of the options and beginning of the payload

Message details

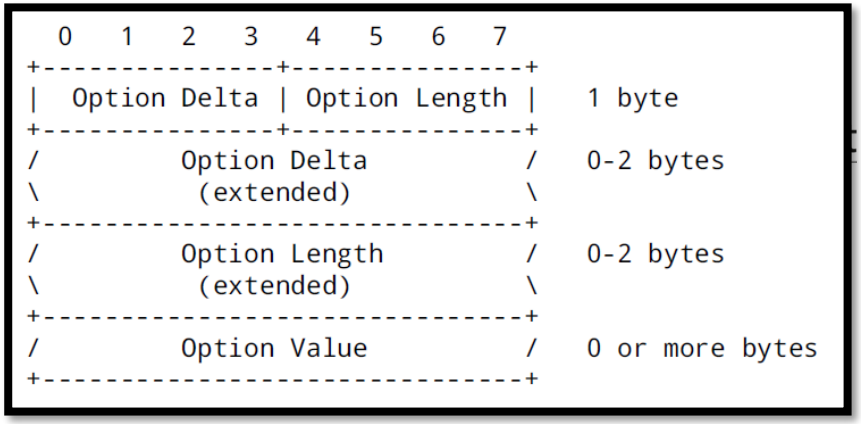
- Options header is 1 byte
  - First four bits indicate which option type it is
  - The remainder four bits are the length of the options value
- The options type are specified as a delta from the previous option (if many)
- Useful example:
  - Header: Uri Path 11 with length 4 (1011 0100)
  - Options value: **sink** (0111 0011, 0110 1001, ..., etc.)
  - Header: text/plain 12 i.e. delta 1 (0001 0000)



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 note 1)
4				x	ETag	opaque	1-8	(none)
5	x				If-None-Match	empty	0	(none)
7	x	x	-		Uri-Port	uint	0-2	(see note 1)
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)
28			x		Size2	uint	0-4	(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)

Media type	Id.
text/plain;charset=utf-8	0
application/link-format	40
application/xml	41
application/octet-stream	42
application/exi	47
application/json	50
application/cbor	60

Extended options



- Sometimes 4 bits are not enough for the options delta or for the option lengths
  - Ex. When there are long path names
- For long option deltas:
  - **For delta between 0 to 12:** set option delta to the real value: **0 to 12**
    - Represents the exact delta value, with no option delta extended value
  - **For delta between 13 to 268:** set options delta to **13**
    - Option delta becomes extended as an 8-bit value that represents the option delta value minus 13
  - **For delta from 269 to 65,804**: set options delta to **14**
    - Option delta extended becomes a 16-bit value that represents the option delta value minus 269
- For long option lengths:
  - **For lengths between 0 to 12:** set length to the real value: **0 to 12**
    - Represents the exact length value, with no option length extended value
  - **For option length from 13 to 268**: set option length to **13**
    - Option length extended is then aa 8-bit value that represents the option length value minus 13
  - **For option length from 269 to 65,804**: set option length to **14**
    - Option length extended is then a 16-bit value that represents the option length value minus 269

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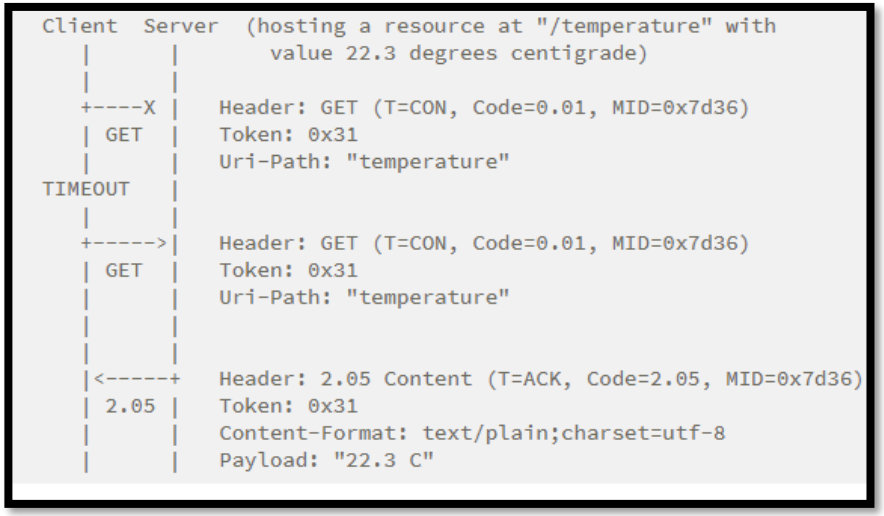
COAP Reliable Transmission

- CoAP was intended for UDP transmission, which is unreliable
  - This means that CoAP request and response messages may arrive out of order, appear duplicated, or go missing without notice.
- CoAP implements a lightweight reliability mechanism
  - Including "confirmable" and "non-confirmable" messages
  - If the messages is confirmable (CON), that means that either the request or the response require an acknowledgement (ACK).
- To ensure retransmission in case of loss
  - Endpoints sending a CON message keeps track of the timeout and number of resends for each message

COAP message definition

- This figure shows how a simple CoAP Request
  - With timeout and resends
- I.E. the first message gets lost due to the unreliable nature of UDP
  - So the client needs to retransmit the message after waiting for an acknowledgement until timeout
- Client sends a **confirmable** request
  - GET /temperature
  - This requires an acknowledgment from the server
  - The message ID is 0x7d36, which will be returned
  - Without the ID, a client could receive duplicated



Observing Resources

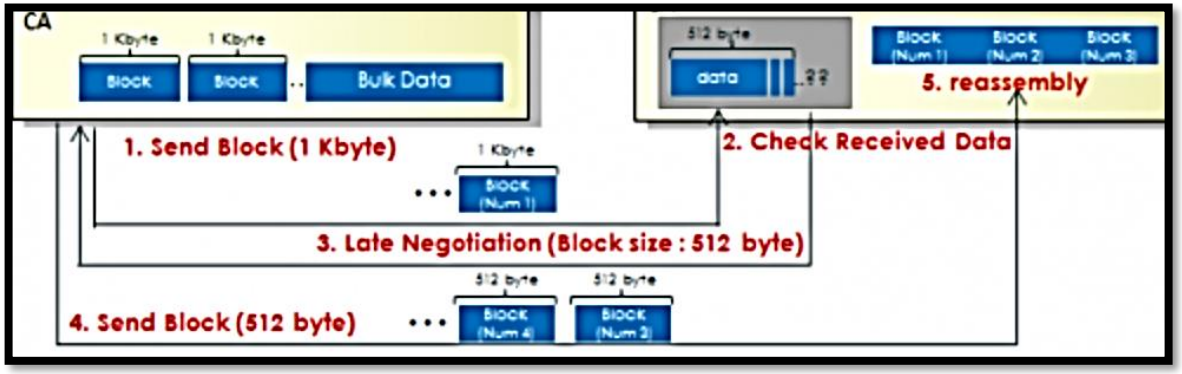
- Basic CoAP functions as a simple resource retrieve system (GET)
  - However, in CoAP one might want to observe a resource and get events upon changes instead. (Pub/Sub)
- In CoAP, this has been solved by using the Observe option.
  - Basically, we add the Observe functionality to the GET as an option (Nr. 6)

No.	C	U	N	R	Name	Format	Length	Default
6		x	-		Observe	uint	0-3 B	(none)

- If observe is added to the GET method
  - The server will add/remove a client from a list of observers of a resource.
  - The value of the Observe option is either 0 for register or 1 for deregister.
- If the servers returns a successful response (2.xx)
  - With the observe option included, that means that the client has been added
  - You can also add more options to the observe, for example Max age

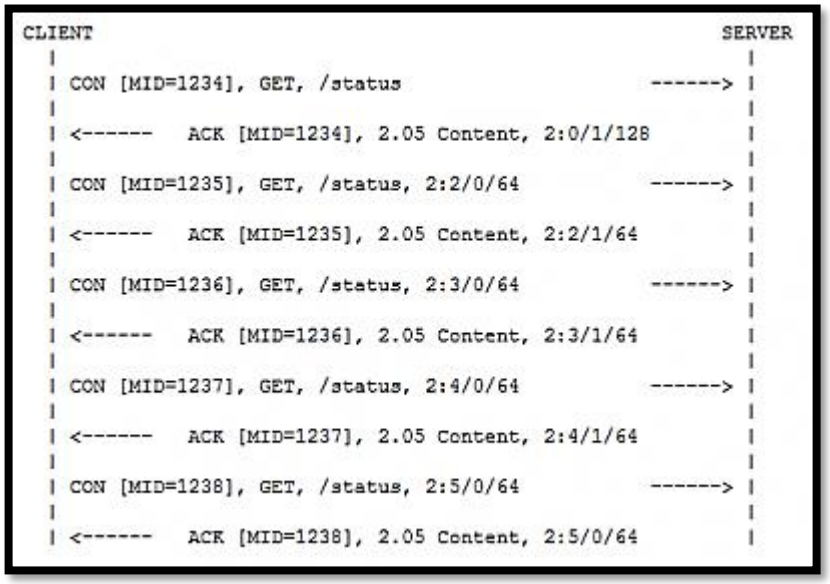
Block Transfer

- There is a hard limit on the size of an UDP packet
  - Which will be problematic when sending or retrieving large data
- Bulk transfer was made in RFC 7959 to solve this
  - Two variants but quite similar (Block1 and Block2)
  - Block1 is useful with the payload-bearing POST and PUT requests
  - Block2 is useful with payload-bearing GET, POST, PUT responses
- General Example



Block Transfer

- Three items of information needs to be communicated
  - The block number(NUM) within the sequence
  - The size of the block (SZX)
  - Whether more blocks are following (M)
- Example: **NUM / M / SZX**
  - With renegotiated size
    - From 128 to 64
  - Meaning, first block is both 1 and 2 (128 bytes)



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Tips for the Lab Project

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Tips for the Lab Project

- Start by using a normal Coap Client, connect to coap.me and observe the messages in wireshark (udp.port == 5683)
- Then create your own UDP socket connecting to coap.me on port 5683
  - And listening to incoming packets back
- Try to send a very simple GET message
  - Byte 1: (0101 0000) Coap version 1, NON, no token
  - Byte 2: (0000 0001) GET
  - Byte 3: (1010 1010) Random msg id number part 1
  - Byte 4: (0101 0101) Random msg id number part 2
- Upon receiving incoming packets
  - Split on (1111 1111) 255/ff
  - Print header and payload

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Tips for the Lab Project

- Remember that you can use bitwise operators
  - For example:
    - **And &** to mask out bits and find if a bit is set
      - 1010 1111 & 0010 0000 = 0010 0000 = true
      - 1010 1111 & 0001 0000 = 0000 0000 = false
    - **Or |** to join bytes, for example two half bytes
      - 1010 0000 | 0000 1111 = 1010 1111
  - You also have:
    - ~ (bitwise NOT)
    - ^ (bitwise XOR)
    - << (bitwise left shift)
    - >> (bitwise right shift)

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Tips for the Lab Project

- The actual client program does not need to be fancy
  - Just make a simple console application with multiple choices and that reads keyboard inputs for host, path, etc.
- Remember that the options are specified as delta values
  - Meaning that they need to come in numerical order
- The content length is very important in CoAP
  - The URI length needs to be correctly specified in the packet/header
    - Before it is written out. As there is only a delimiter for the payload (ff)
- Wireshark is your friend
  - To see how other CoAP clients messages looks like is very good for you to learn, debug and compare to yourself to them
- Discover requires you to implement block transfer and handle long path names, so it is not mandatory for the lab

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