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IPv6 Protocol Stack for IoT

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University of Macedonia (UoM), Greece

Lefteris Mamatas, Tryfon Theodorou, George Violettas

	IETF IoT Protocol Stack	*TCP/IP Protocol Stack*
Application Layer	IETF COAP	HTTP, FTP, DNS, SSH, SMTP, NTP, …
Transport Layer	UDP	TCP, UDP
Network Layer	IPv6, IETF RPL	IPv4, IPv6
Adaption Layer	IETF 6LoWPAN	N/A
MAC Layer	IEEE 802.15.4 MAC	Network Access
Physical Layer	IEEE 802.15.4 PHY	

IETF and IoT

- Internet Engineering Task Force (IETF) leads standardization of communication protocols for Low Power and Lossy Networks (LLNs) [1][2]
- Develops a number of Internet protocols, including the:
  - Routing Protocol for LLNs (RPL) and
  - Constrained Application Protocol (CoAP)
- There are open challenges due to:
  - complex deployment characteristics of such systems
  - stringent requirements imposed by various services wishing to make use of such complex systems
- How current approaches can be improved?
- What are the opportunities for the research community to contribute to the IoT field?

IoT

- TCP/IP is the de facto standard for computer communications in today's networked world
- IP offers a flexible architecture and could be the future for IoT networks
- Main challenge of IPv6 sensor devices:
  - Efficient usage of low power and bandwidth

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Internet vs IoT Network Stack

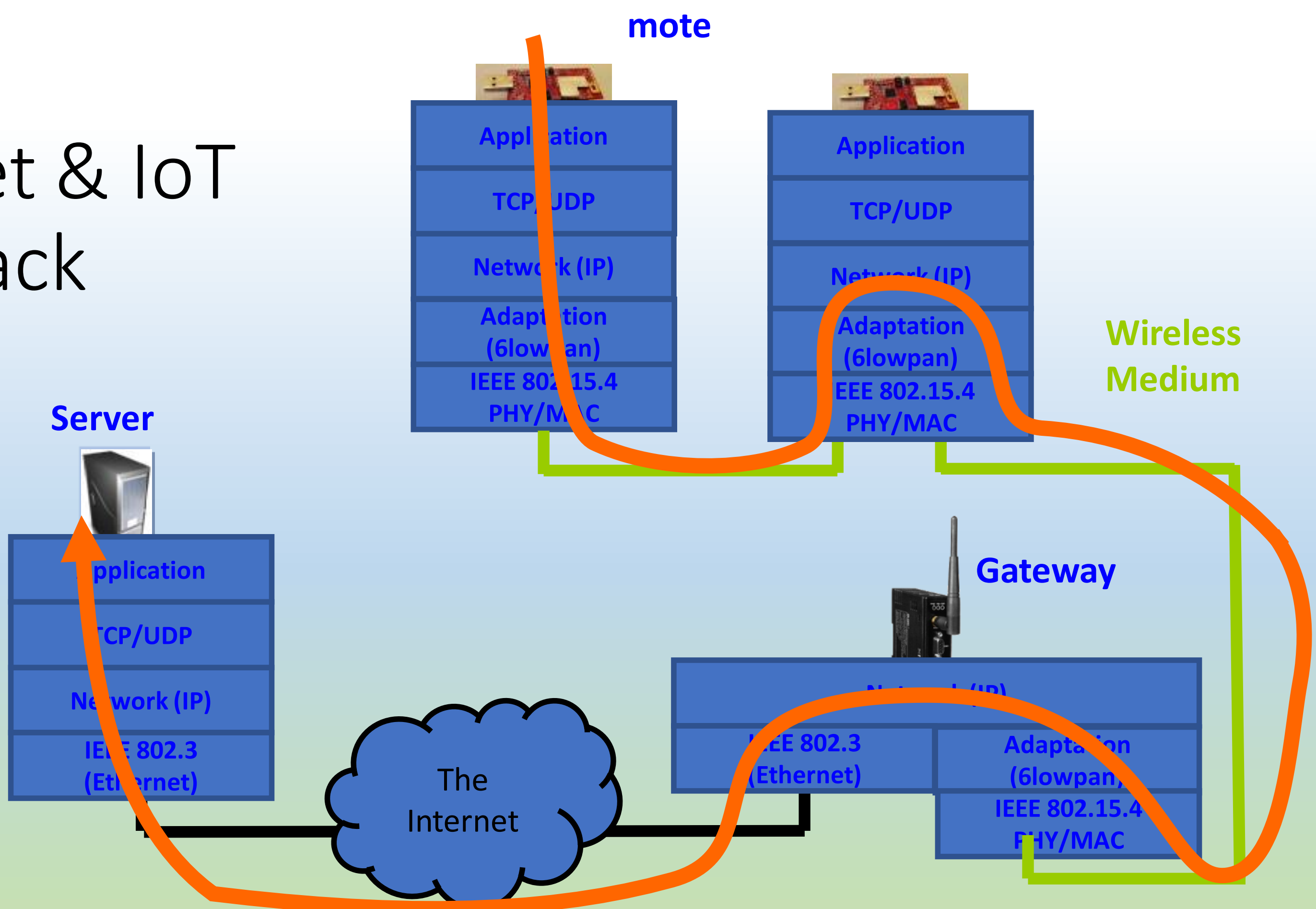
Internet Network Stack

- Applications layer
- Transport layer
- Network layer
- Datalink layer
- Physical layer

Internet of Things Network Stack [3]

Applications layer	HTTP, MQTT, CoAP …
Transport layer	TCP / UDP
Network layer	IPv6
Adaptation layer	6LoWPAN
Datalink layer	IEEE 802.15.4 MAC
Physical layer (Wirel	IEEE 802.15.4 868/915 MHz / IEEE 802.15.4 2.4 GHz

Internet & IoT Stack



http://personal.ee.surrey.ac.uk/Personal/P.Barnaghi/teaching/EEEM048/2015/EEEM048_Lecture1_Introduction.pdf

Contiki IPv6 Network Stack

Network Layers	Contiki IoT/IP Protocols Stack	Contiki IPv6 protocols
Application	HTTP, WebSockets, CoAP, MQTT	websocket.c, http-socket.c, coap.c, mqtt.c
Transport	TCP, UDP	udp-socket.c, tcp-socket.c
Network, routing	IPv6, IPv4, RPL	uip6.c, rpl.c
Adaptation	6lowpan	sicslowpan.c
MAC	CSMA/CA	csma.c
Duty cycling	ContikiMAC, CSL	nullrdc.c, contikimac.c
Radio	802.15.4	cc2538-rf.c

Contiki also supports **IPv4** and **RIME** protocol stacks

https://www.slideshare.net/ADunkels/building-day-2-upload-1

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Physical Layer Protocols

- **IEEE 802.15.4** is a radio technology standard for low-power and low-datarate applications with a radio coverage of only a few meters.
- Developed within the IEEE 802.15 Personal Area Network (PAN) Working Group.
- Because it is low power and low complexity, an number of IoT devices have been built as IEEE 802.15.4-compliant devices.
- Frequency bands: 2.4GHz, 915MHz, and 868MHz
- Maximum data rate of 250 kb/s and a maximum output power of 1 mW
- Modulation & encodings, Bitrate and bit errors
- Other standardization organizations are also developing low-power protocol stacks based on IEEE 802.15.4:
  - WirelessHART and
  - ZigBee.

Data Link Layer [4]

Adaptation layer

Datalink layer
- Media Access Control Layer (MAC)
- Radio Duty Cycling Layer (RDC)
- Framer

Physical layer (Wireless)

http://anrg.usc.edu/contiki/index.php/MAC_protocols_in_ContikiOS

Framer

- A *Framer* consists of a collection of auxiliary functions that are called before transmitting a packet and after their reception

- Contiki *Framer* types:
  - ***framer-802154*** it creates and parses frames compatible with standard IEEE 802.15.4 (2003).
  - ***framer-nullmac*** it should be used together with *nullmac* (MAC layer).

Radio Duty Cycling Layer

- Turn on/off the radio to save power (radio is a power consuming device compare to other components). Make sure nodes are awake to hear messages from other devices
- Non-Energy saving:
  - ***nullrdc-noframer*** does not use Framer functions and transmits/receives data directly to Radio layer (Physical). The developer can take total control over the format of the packets being transmitted.
  - ***Nullrdc*** uses the Framer functions for header creation/parsing. It does not save energy and works as a pass-through layer that only transmits a packet and returns the results of such transmission (success or collision).
  - ***Sicslowmac*** is a RDC layer with no energy savings and that uses IEEE 8021.5.4 frames.
- Energy saving:
  - **X-MAC** is a short-preamble protocol from 2006 that was ported to ContikiOS.
  - **ContikiMac** is a protocol that proposes enhancement over X-MAC.
  - **LPP** (Low Power Probing) is a receiver-initiated low power protocol from 2008 that was also ported to ContikiOS

MAC Layer

- Do not transmit when others are transmiting
- Back-off exponentially when there is too much traffic
- **nullmac** is a simple pass-through protocol that simply calls the appropriate RDC functions
- **CSMA** implements addressing, sequence number and retransmissions.
- CSMA protocol keeps a list of packets to each of the neighbors and calculate statistics:
  - retransmissions, collisions, deferrals, etc.

Adaptation Layer

- To enable IP connectivity in resource constrained sensor networks:
  - the IPv6 over LowPower WPAN (6LowPAN) Working Group has been established
- The 6LoWPAN protocol applies IPv6 optimization over the MAC and PHY layers of IEEE 802.15.4
- Transmits network packets over the radio
- Compresses headers, fragment packets

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6LoWPAN – characteristics

1. **Small packet size**:
   - Given that the maximum physical layer frame is **127 bytes**
2. Several **addressing modes**:
   - It allows the use of either IEEE **64-bit** extended addresses or (after an association event) **16-bit** addresses unique within the PAN (Personal Area Network)
3. **Low bandwidth**:
   - Data rates of **250 kbps, 40 kbps, and 20 kbps** for each of the currently defined physical layers (2.4GHz, 915MHz, and 868MHz, respectively)
4. Topologies including **star** and **mesh**
5. **Large number of devices** expected to be deployed during the lifetime of the technology
6. **Unreliable** due to uncertain radio connectivity, battery drain, device lockups, physical tampering, etc.
7. **Sleeping mode**:
   - Devices may sleep for long periods of time in order to conserve energy

Network Layer

- Decides how to send a packet from node1 to node3, through node2
- The IETF Routing over Lossy and Low-Power Networks (RoLL) working group focuses on:
  - routing protocol design and is committed to the standardization of the IPv6 routing protocol for lossy and lowpower networks (LLNs)
- In IoT two main protocols are involved:
  - IPv6 (out of the tutorials scope)
  - RPL (ripple)

RPL

- RPL is a distance vector IPv6 routing protocol for LLNs
- RPL is an IPv6 routing protocol for low power and lossy networks
  - designed by the IETF Routing Over Low power and Lossy network (**ROLL**) group
- RPL is a proactive distance vector protocol:
  - it begins finding the routes as soon as the RPL network is initialized
- In Contiki the default IPv6 routing protocol is RPL

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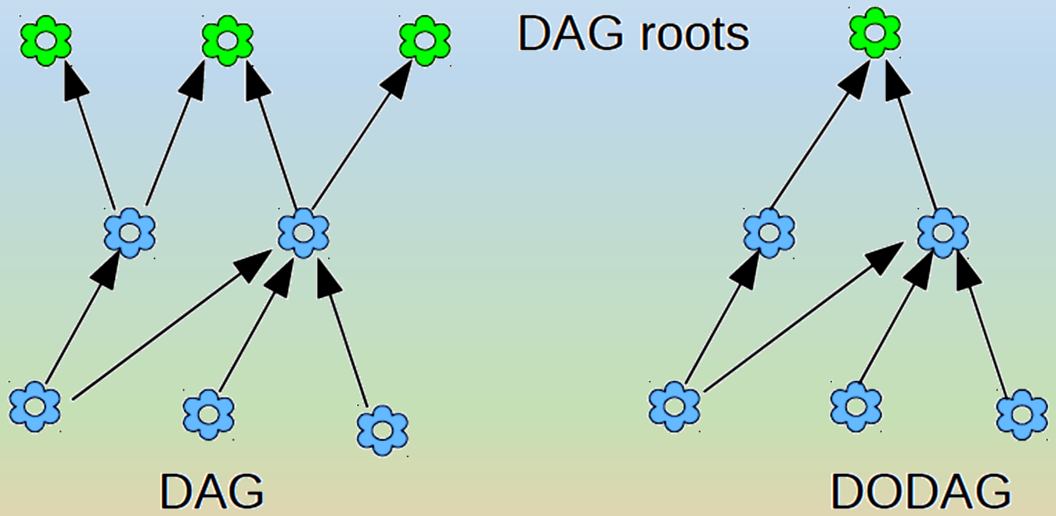
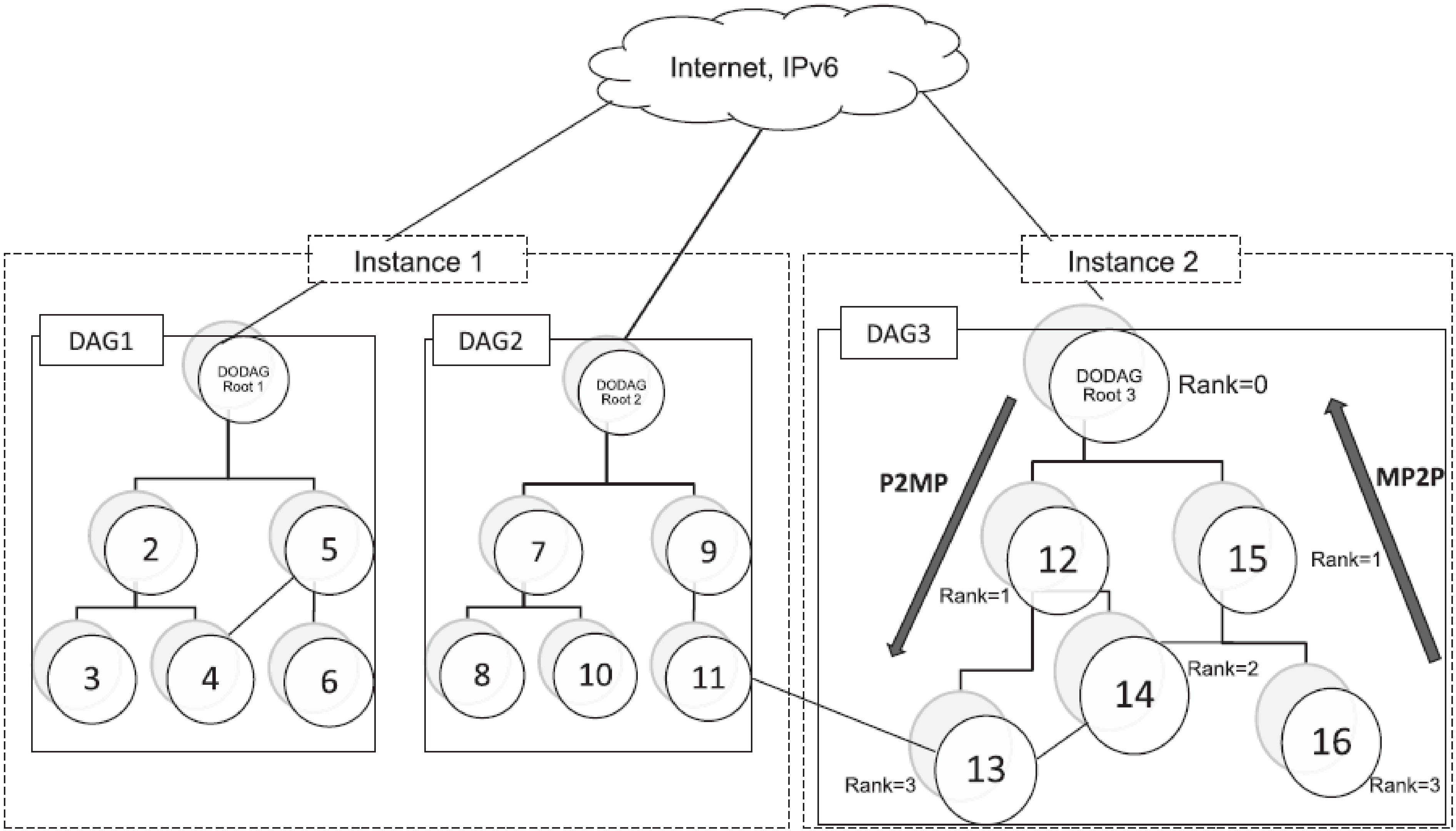
RPL routing

- Directed Acyclic Graph (DAG) - a directed graph with no cycles exist
- Destination Oriented DAG (DODAG) - a DAG rooted at a single destination



RPL instances



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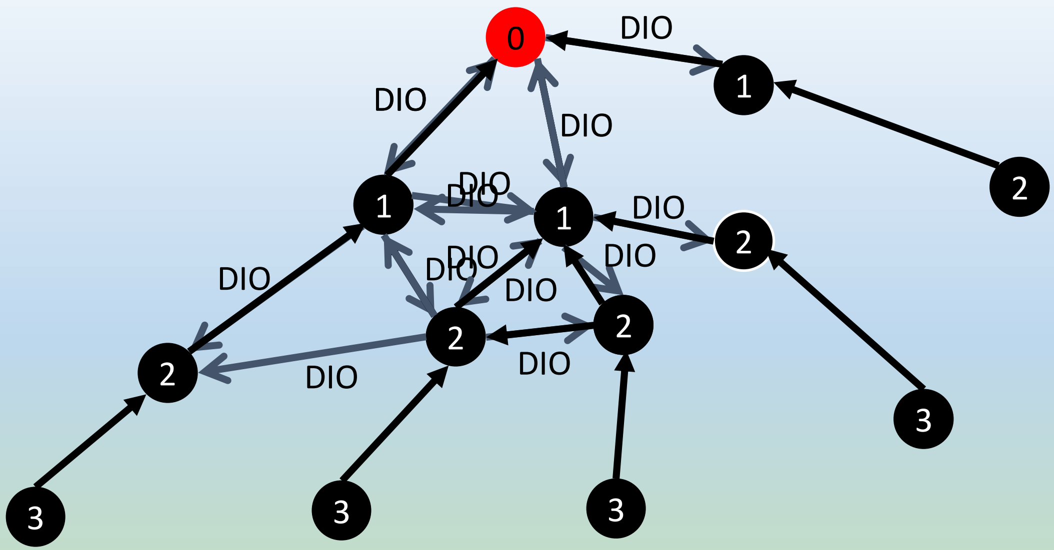
RPL control messages

RPL defines new ICMPv6 message with three possible types:

- DAG Information Object (DIO) - advertises the characteristics of the graph such as the **objective function** in use, the **node rank** and the **graph version**, and allows the creation and maintenance of DODAGs
  - broadcast, point-to-multipoint
- DAG Information Solicitation (DIS) - solicit a DODAG Information Object (DIO) from an RPL node
  - a node willing to connect to a graph can request the transmission of DIO from nodes attached to the graph by sending DIS
- Destination Advertisement Object (DAO) - used to propagate destination information upwards along the DODAG
  - unicast, multipoint-to-point, point-to-point

DODAG construction



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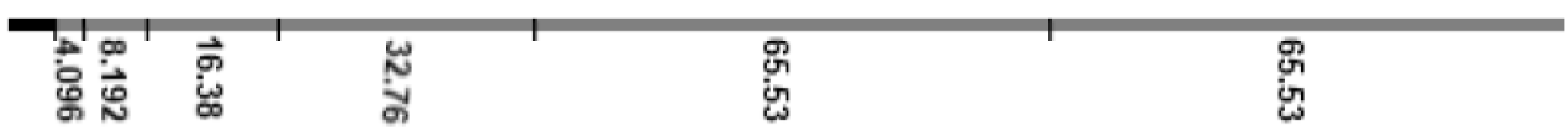
RPL objective function

- The construction of the DODAG is governed by the metric advertised in the objective function
  - the metric expresses the link quality (open issue)
  - several metrics have been proposed: ETX and OF0
  - ETX is the default metric used in the WSN RPL implementation e.g., TinyOS and Continki
- ETX is defined as the predicted number of transmissions required to successfully send a packet over a link
  - enables high throughput as it is based on the Packet Delivery Ratio (PDR) between the source and destination
  - PDR is evaluated actively from every sent or received packet and gives an instantaneous quality evaluation of the link

RPL trickle algorithm

- The trickle timer mechanism regulates DODAG Information Object (DIO) message transmissions
  - limit the number of control packets sent
- Two important parameters
  - DIO Interval Minimum
  - DIO Interval Doublings

Imin = 2 ^ DIO Interval Minimum	Imax = Imin * 2 ^ DIO Interval Doublings
Imin = 2 ^ 12	Imax = 4096 * 2 ^ 4
Imin = 4096 ms	Imax = 65636 ms
Imin = 4.096 s	Imax = 65.536 s



Transport Layer

- Allows program A to send data to program B
  - Even though the network may drop packets
- Receive packets in order, despite them being reordered on the way
- UDP – Best-effort simple datagram delivery, no ordering
- TCP – Reliable byte stream delivery, in order
  - TCP reduces sending rate significantly when we have packet loss, or packets are not in order
  - Unnecessary for some applications
  - Does not support multicast/broadcast operation (point-to-point)

Application Layer

Application Layer Protocols for the IoT:

- HTTP (TCP)
- WebSockets (TCP)
- CoAP (UDP)
- MQTT (TCP)
- SMQTT (UDP)

CoAP

- The Constrained Application Protocol (CoAP) is specified by the IETF CoRE Working Group
- Specialized web transfer protocol for resource constrained nodes and networks
- CoAP conforms to the REST style
- Abstracts all the objects in the network as resources
- Each resource corresponds to a unique universal resource identifier (URI),
  - from which the resources can be operated stateless, including GET, PUT, POST, DELETE, and so on
- Unlike HTTP, CoAP adopts datagram-oriented transport protocols, such as UDP.
  - CoAP introduces a two-layer structure to ensure reliable transmission over UDP

MQTT (1)

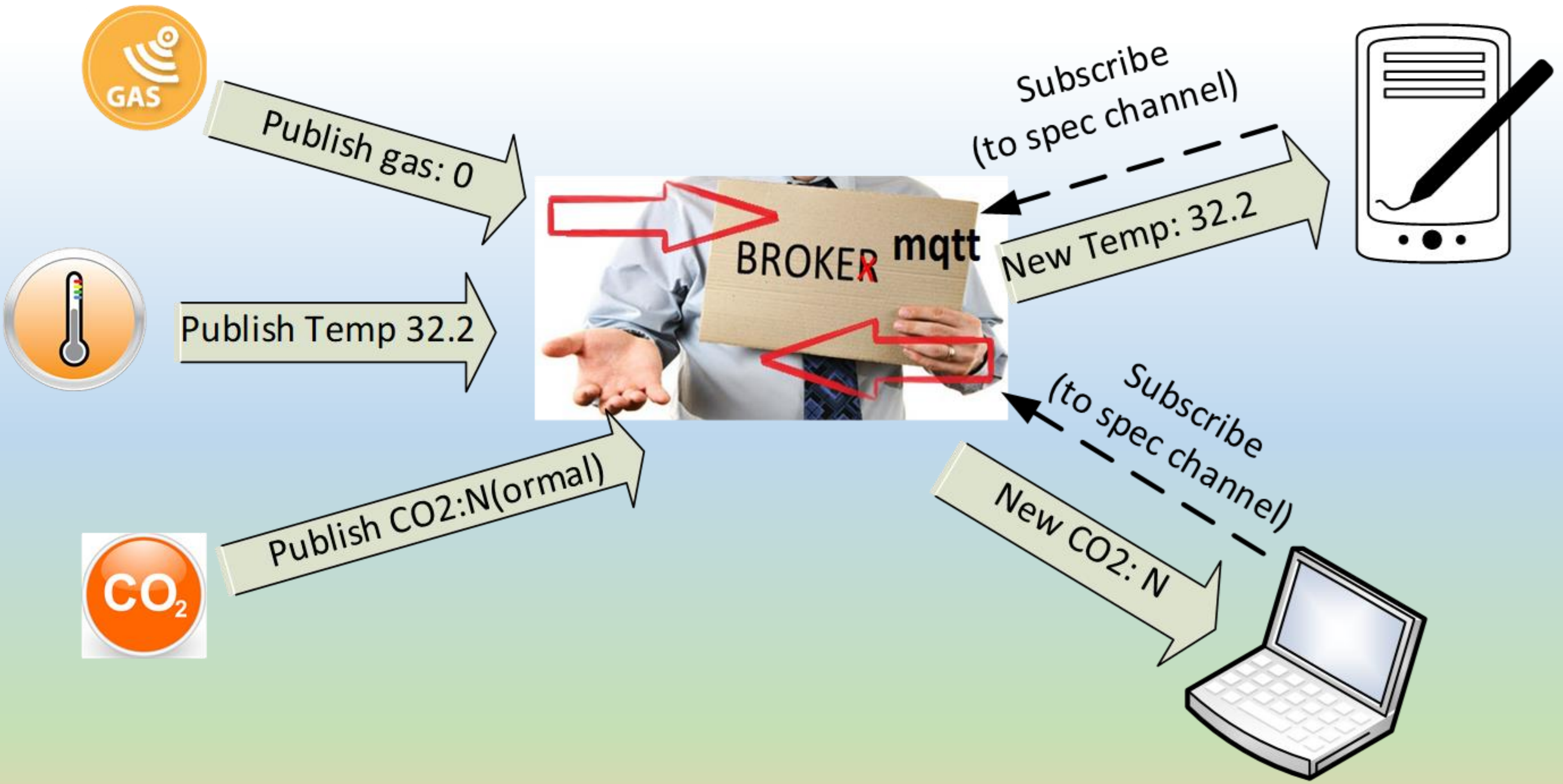
MQTT (Message Queue Telemetry Transport) is:

- a lightweight publish-subscribe protocol
- suitable for machine-to-machine (M2M)/"Internet of Things" connectivity
- useful for connections with remote locations
  - where a small code footprint is required and/or network bandwidth is at a premium
- used on top of TCP/IP
- uses a message broker that dispatches messages:
  - between senders that publish them, and
  - receivers that are interested in these messages

MQTT (2)

- Same client can both publish and subscribe for messages
- Each message is published to a specific topic
- The topic is the message routing information
  - string with slash separated hierarchy levels
  - *"office/floor1/temperature"*
- Clients subscribe to topics
- broker delivers all messages sent with matching topics
- Use wildcards to subscribe to multiple topics:
  - *"office/floor1/*"*

MQTT



GAS
Publish gas: 0
Publish Temp 32.2
CO_2
Publish CO2:N(ormal)
BROKER mqtt
Subscribe
(to spec channel)
New Temp: 32.2
Subscribe
(to spec channel)
New CO2: N

Contiki IoT
Hands-on 1-2 (a)

Broadcast Temperature example

Contiki IoT
Hands-on 1-2 (b)

Multihop example

References

[1] Z. Sheng, S. Yang, Y. Yu, A. V. Vasilakos, J. A. Mccann, and K. K. Leung, “A survey on the ietf protocol suite for the internet of things: standards, challenges, and opportunities,” *IEEE Wirel. Commun.*, vol. 20, no. 6, pp. 91–98, Dec. 2013.

[2] L. Atzori, A. Iera, and G. Morabito, “The Internet of Things: A survey,” *Comput. Netw.*, vol. 54, no. 15, pp. 2787–2805, Oct. 2010.

[3] Antonio Liñán Colina, Alvaro Vives, Marco Zennaro, Antoine Bagula, and Ermanno Pietrosemoli, *Internet of Things in 5 days*.

[4] “MAC protocols in ContikiOS - Contiki.” http://anrg.usc.edu/contiki/index.php/MAC_protocols_in_ContikiOS. [Accessed: 08-Oct-2017].