Mobile and Sensor Systems

Lecture 3: Wireless Sensor Systems and IoT

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Acks to Dr A. Gaglione (Digital Catapult) for the slides on IoT

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In this lecture

- We will describe wireless sensor networks in general and the properties of sensor nodes.
- We will introduce sensor network MAC Layer issues and some solutions.
- We will illustrate IoT MAC protocols

Wireless Sensor Networks?

- In many situations, we want to measure things to develop a better understanding of various phenomena.
- With this insight, we can then design novel or improved systems.

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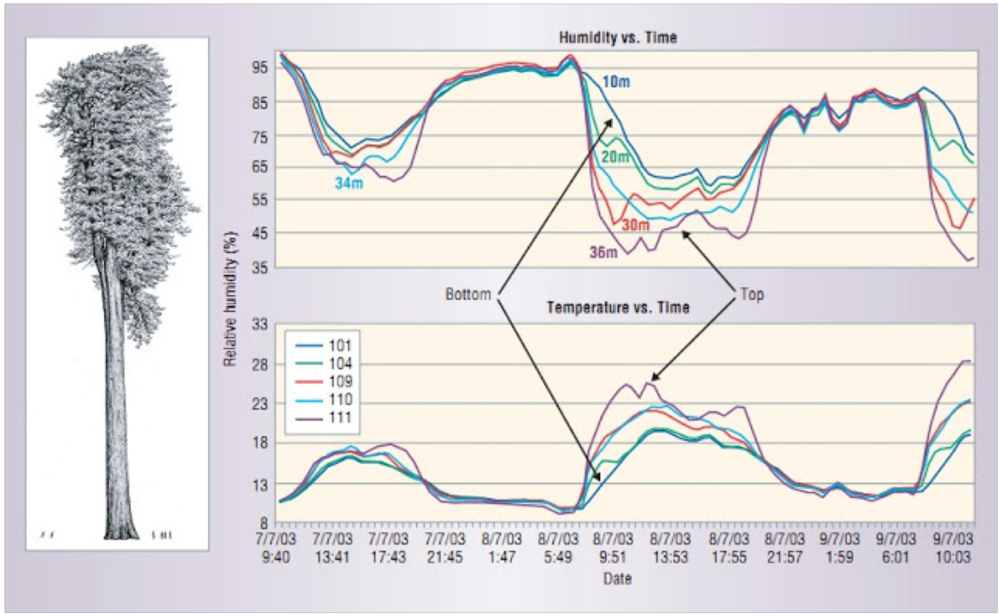
Example: Sensor Network Macroscope

Conventional Manual Monitoring

Long-lived High-density Sensing Networks



Many Applications

- Structural health monitoring
- Environmental monitoring
- Animal behaviour
- Warehouse logistics

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Characteristics

- Farmer wants to cover his entire vineyard
  - Large number of sensing devices.
- He wants to keep the cost down
  - Low cost, resource constrained.
- He cannot run wires to these many devices
  - Battery powered, wireless.

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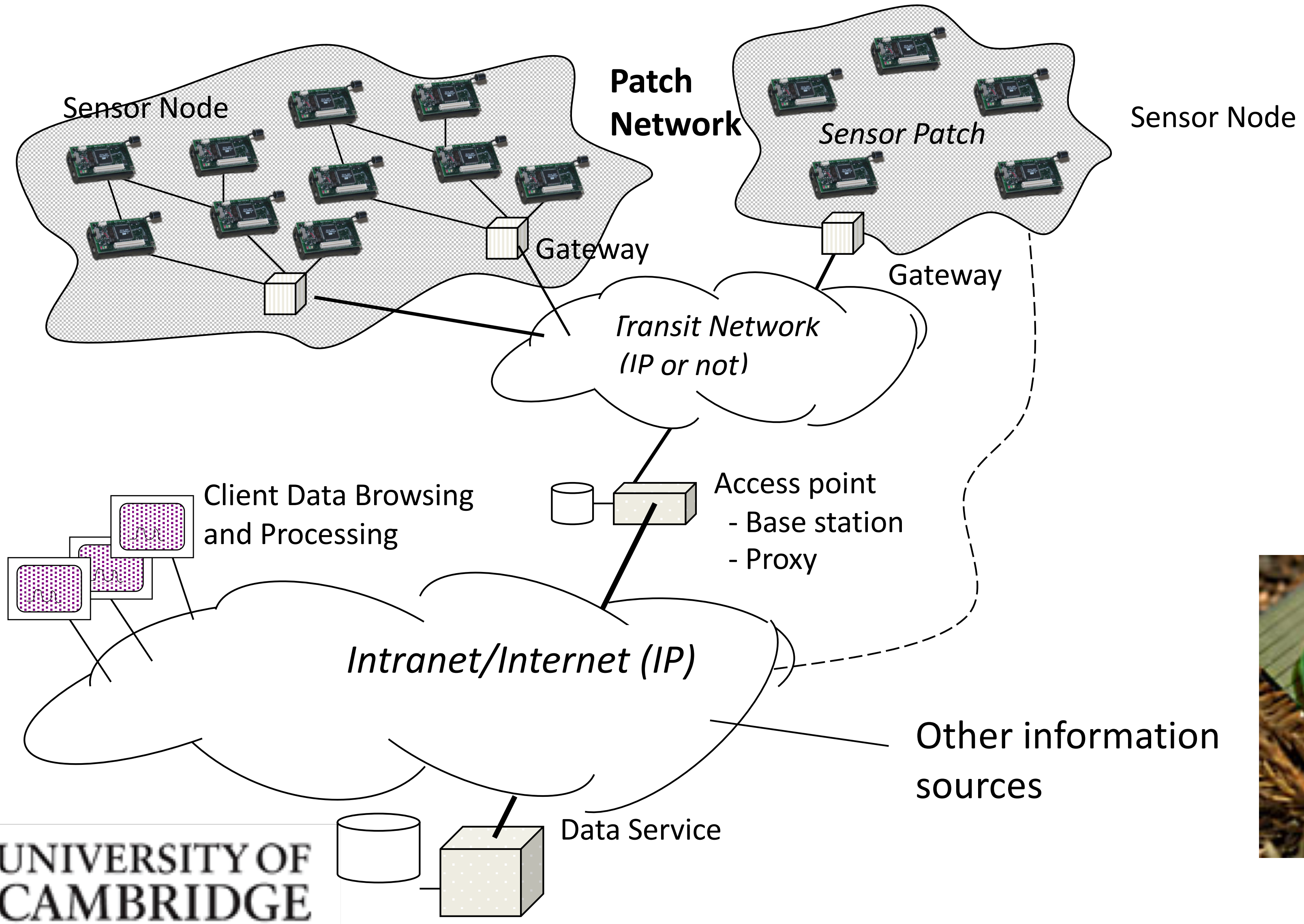
An Example of Sensor Network Architecture



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Sensor Systems vs Standard or Mobile Systems

- Sensor nodes have limited computational resources and energy.
- Sensor nodes are prone to failures (especially because they are often deployed in challenging conditions).
- The topology of a sensor network might not change frequently:
  - Many deployments involve nodes with fixed locations.
  - Some deployments may have mobile sensors.

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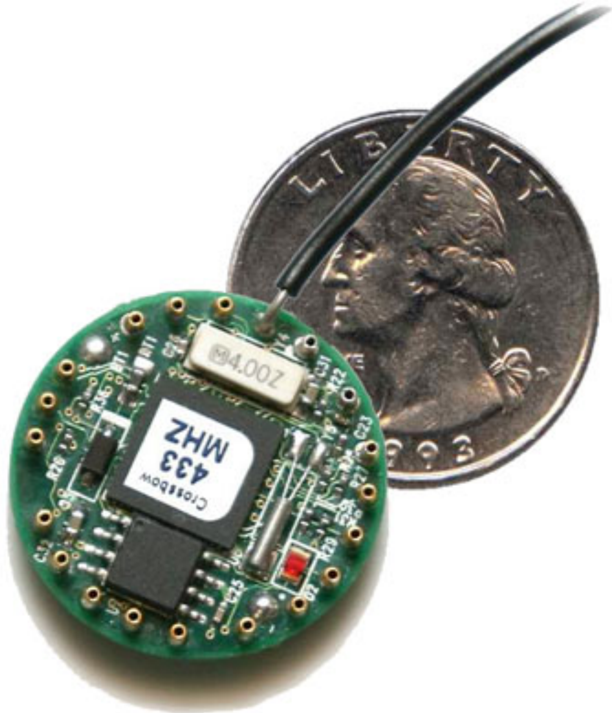
Sensor Node

- A typical sensor node is composed of,
  - Sensing device
  - Low power radio
  - Small storage



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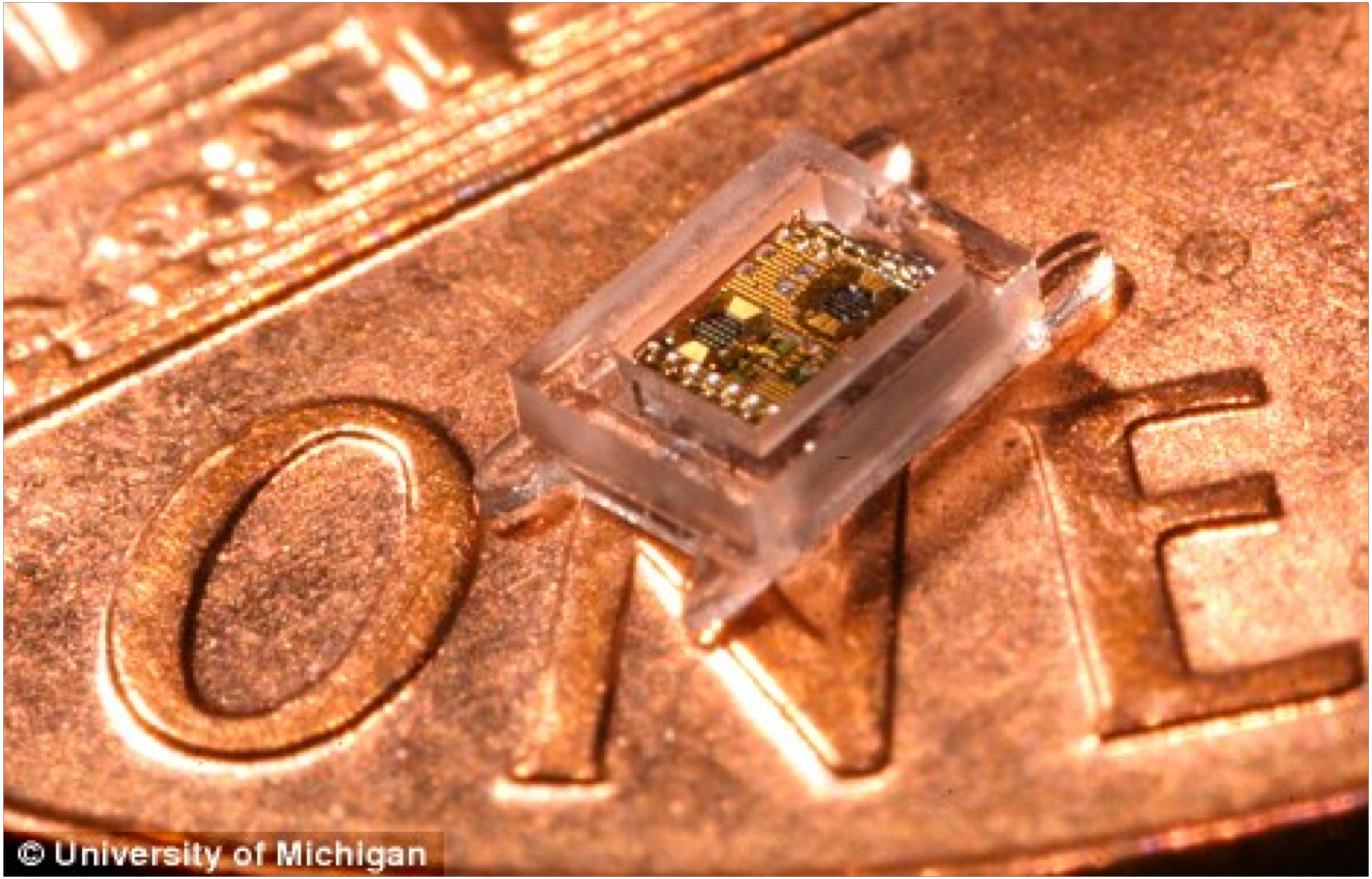

Michigan Micro Mote

What Operating System runs on a sensor?

- Operating system useful to simplify programming tasks and to allow more control over operations of the system
- But what can we do with such a constrained device?
- Given the kind of applications needed it is important to support concurrency…[frequent and parallel collection from different sensors]

Energy Management

- Local computation does not consume significant amount of energy.
- **The main source of energy consumption is the radio.**
- Current draw on Telosb,
  - Microcontroller ON, Radio OFF 1.8mA
  - Microcontroller ON, Radio ON 21mA

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Energy Management

- In order to save energy, limit the number of radio transmissions.
- Idle listening consumes as much power as transmission.
- Current draw on Telosb,
  - Idle listening 23mA
  - Transmitting 21mA
- Idle listening is wasteful when average data rate is low.
- Switch off the radio when idle.
- Transmissions from other sensor nodes are lost.

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Radio Duty Cycling

- Switch off the radio of all sensors at specific intervals:
  - Very precise synchronization.
  - Still probable idle time for sensors which do not communicate.
- More refined strategy:
  - Wave of switch off time depending on topology.
  - Still an overestimate of the communication needs of some sensors (traffic might be varying across the network).

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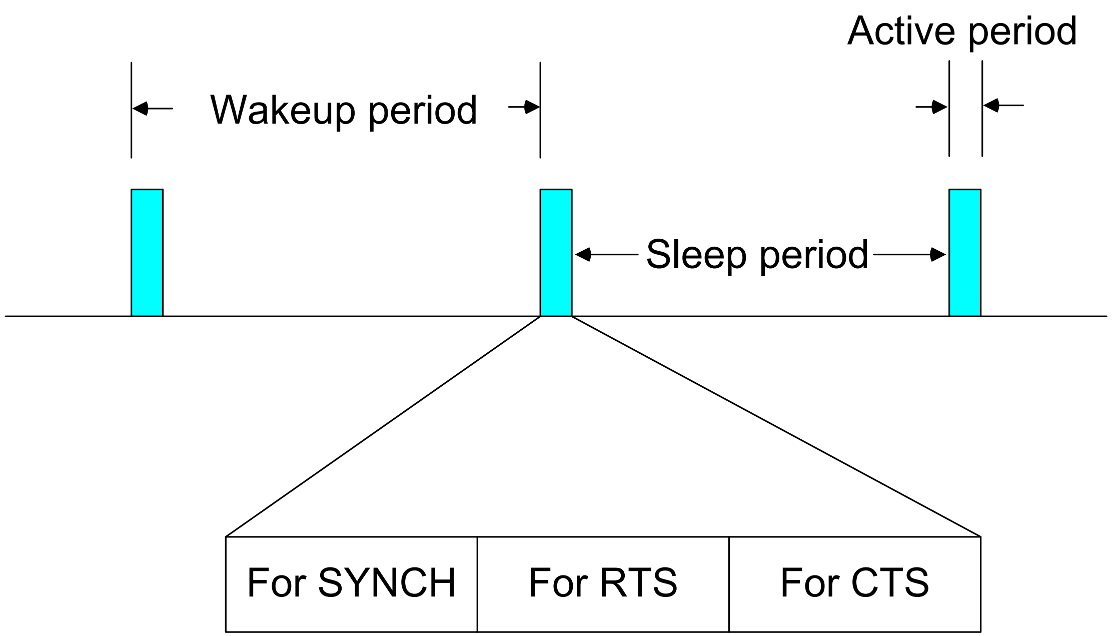
Dynamic duty cycling

- More refined strategies have been proposed which aim to allow sensors with more packets to stay awake longer and others to sleep more.
  - Synchronized (e.g. S-MAC)
  - Asynchronous (e.g. B-MAC, X-MAC)

- Synchronized protocols try to **negotiate a schedule** among neighboring nodes.
- Asynchronous protocols rely on **preamble sampling** to connect a transmitter to receivers.

Sensor-MAC (S-MAC)

- Idea: Switch nodes off, ensure that neighboring nodes turn on simultaneously to allow packet exchange (rendez-vous)
  - Packet exchange occurs only in these ***active periods***
  - Need to also exchange wakeup schedule between neighbors
  - When awake, essentially perform RTS/CTS
  - Use SYNCH, RTS, CTS phases



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S-MAC

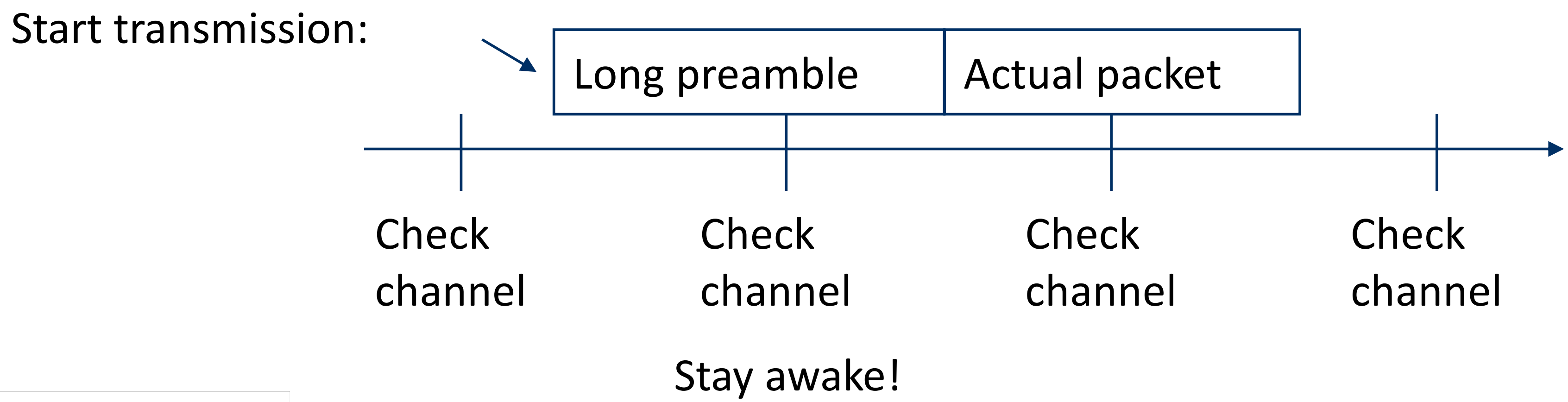
- SYNC phase divided into time slots with CSMA and backoffs to send schedule to neighbours.
- Y chooses a slot and if no signal is received in this slot, it will transmit its schedule to X otherwise it will wait for next wake up of X.
- RTS phase: X listens for RTS packets (CSMA contention).
- CTS phase: X sends one and extends its wake up time.

S-MAC synchronized islands

- Nodes try to pick up schedule synchronization from neighboring nodes.
- If no neighbor found, nodes pick some schedule to start with.
- If additional nodes join, some node might learn about two different schedules from different nodes
  - “Synchronized islands”.
- To bridge this gap, it has to follow both schemes and use more energy.

Preamble Sampling (Low Power Listening, LPL)

- So far: Periodic sleeping supported by some means to synchronize wake up of nodes to ensure rendez-vous between sender and receiver.
- Alternative option: Don't try to explicitly synchronize nodes:
  – Have receiver sleep and only periodically sample the channel.
- Use ***long preambles*** to ensure that receiver stays awake to catch actual packet. Example: B-MAC and WiseMAC.



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Problems with this technique

- Overhearing
  - All receivers listening to the preamble have to stay awake to find out who is the intended receiver.
- Energy Consumption
  - Long preamble causes increased energy consumption at both the transmitter and the receiver.
- Latency
  - Long preamble introduces per-hop latency.

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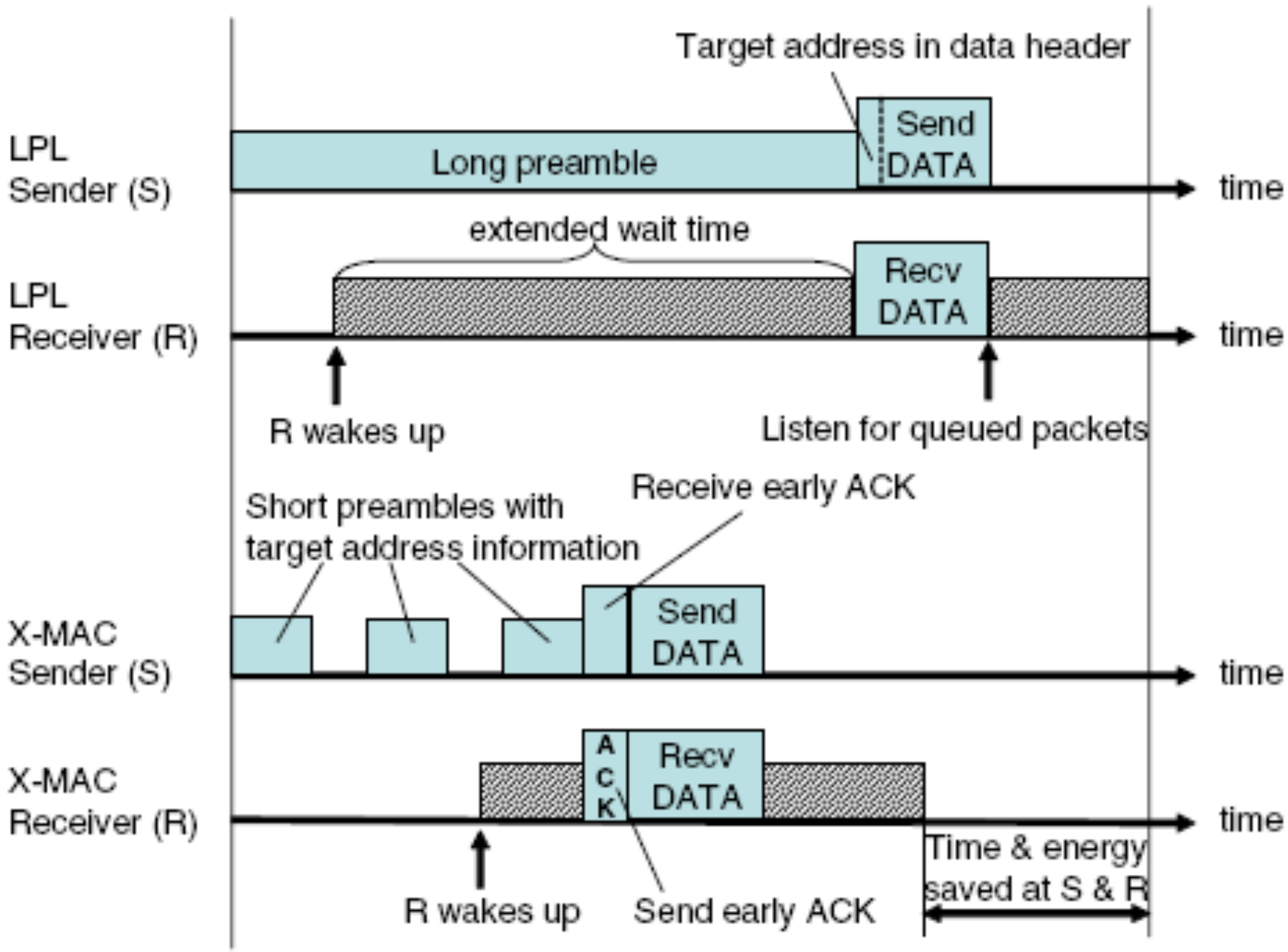
X-MAC

- Short preamble
  - Reduce latency and reduce energy consumption
- Target in preamble
  - Minimize overhearing problem.
- Adding wait time between preambles
  - Reduces latency for the case where destination is awake before preamble completes.

X-MAC



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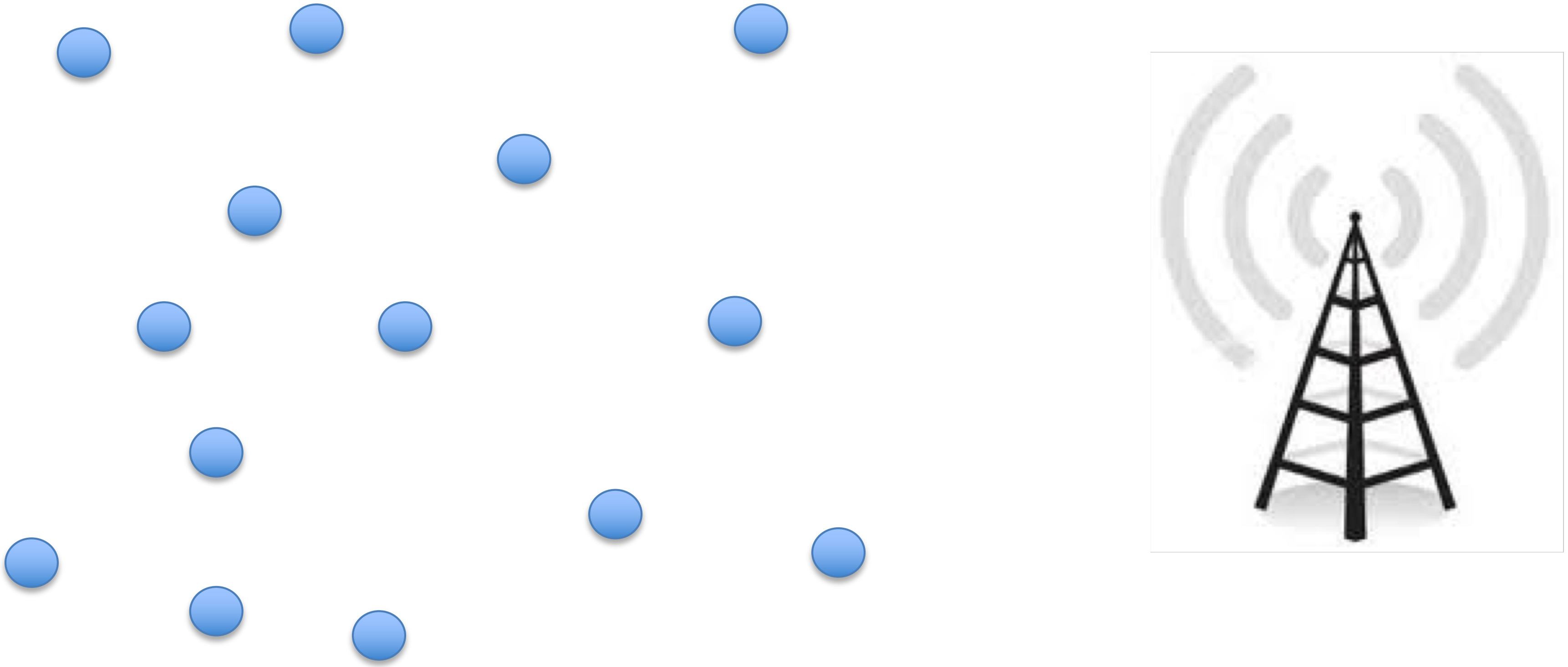
Low-Energy Adaptive Clustering Hierarchy (LEACH)



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Low-Energy Adaptive Clustering Hierarchy (LEACH)

- Assumption: dense network of nodes, reporting to a central sink, each node can reach sink **directly**.
- Idea: Group nodes into "***clusters***", controlled by ***clusterhead:***
  - Setup phase; details: later.
  - About 5% of nodes become clusterhead (depends on scenario).
  - Role of clusterhead is rotated to share the burden.
  - Clusterheads advertise themselves, ordinary nodes join CH with strongest signal.
  - Clusterheads organize: CDMA code for all member transmission. TDMA schedule to be used within a cluster
- In steady state operation:
  - CHs collect & aggregate data from all cluster members.
  - Report aggregated data to sink using CSMA.

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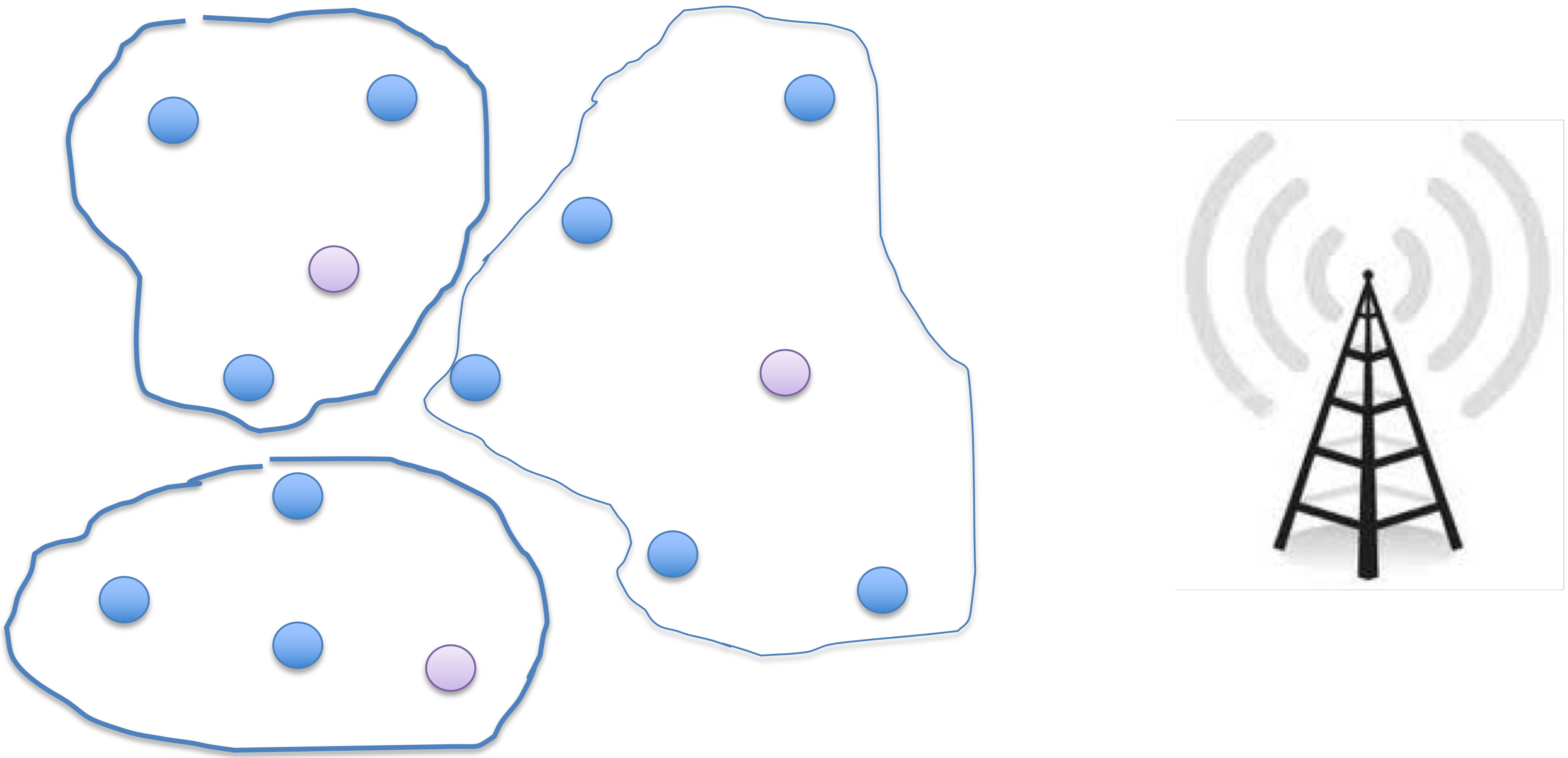
Low-Energy Adaptive Clustering Hierarchy (LEACH)



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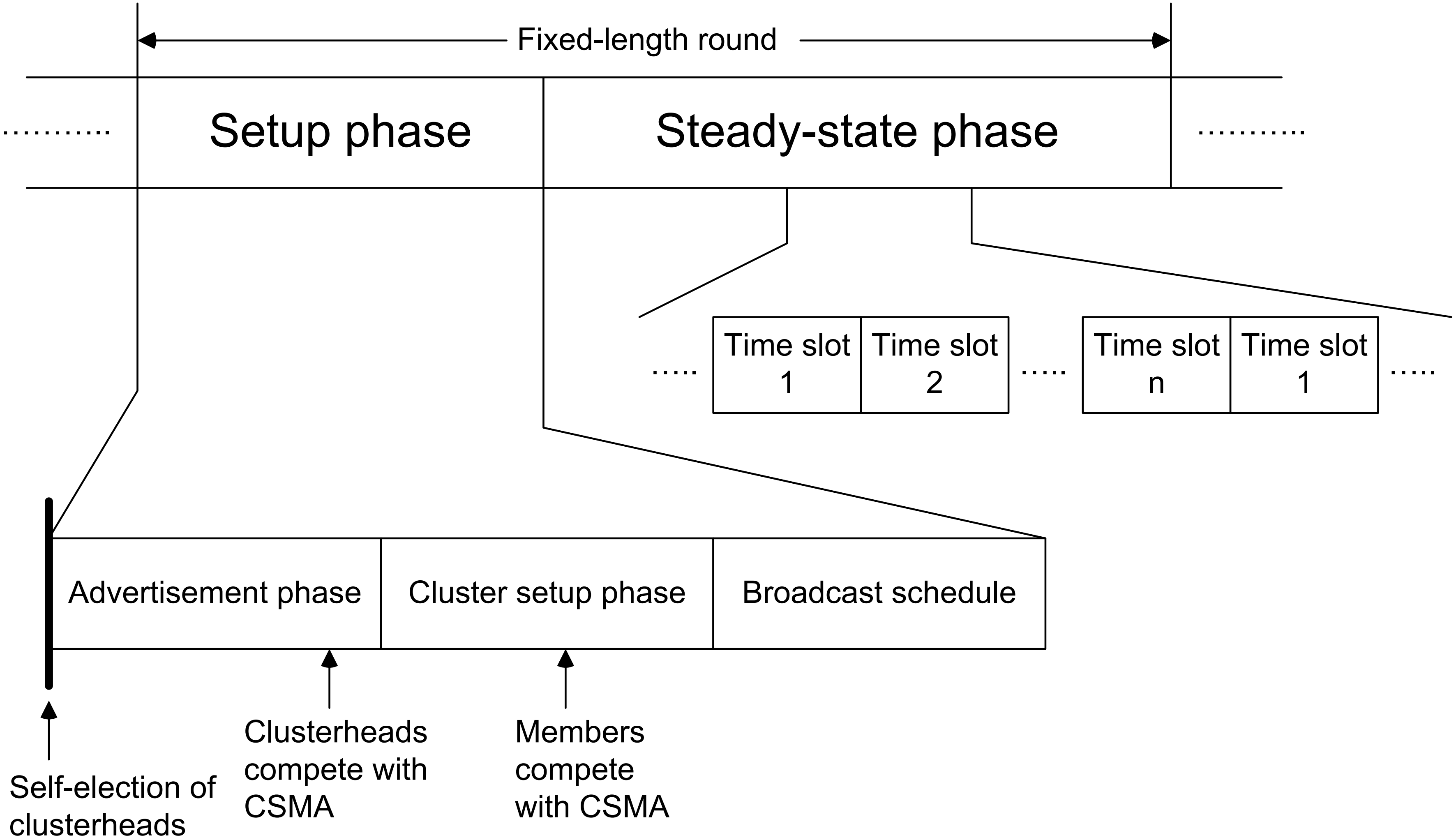
LEACH rounds



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Internet of Things

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What is the IoT?

"A global infrastructure for the information society, enabling advanced services by interconnecting **things** based on existing and evolving interoperable information and communication technologies" [1].

"A system of **physical objects** that can be discovered, monitored, controlled, or interacted with by electronic devices that communicate over various networking interfaces and eventually can be connected to the wider internet" [2].

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[1] ITU-T Recommendation Y.2060. Overview of the Internet of Things. 2012.
[2] D. Guinard, V. Trifa. Building the Web of Things. 2016.

IoT landscape

Devices (tags, sensor nodes, mobile and wearable devices)

Machines (home appliances, security systems, vehicles, etc.)

Environments (smart homes, buildings, cities)

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Typical IoT system architecture

IoT Cloud	Service hosting Visualisations Advanced analytics Data storage
IoT Gateway	Edge analytics Local storage
IoT Device	Basic processing Short/wide comms Sensing/actuation

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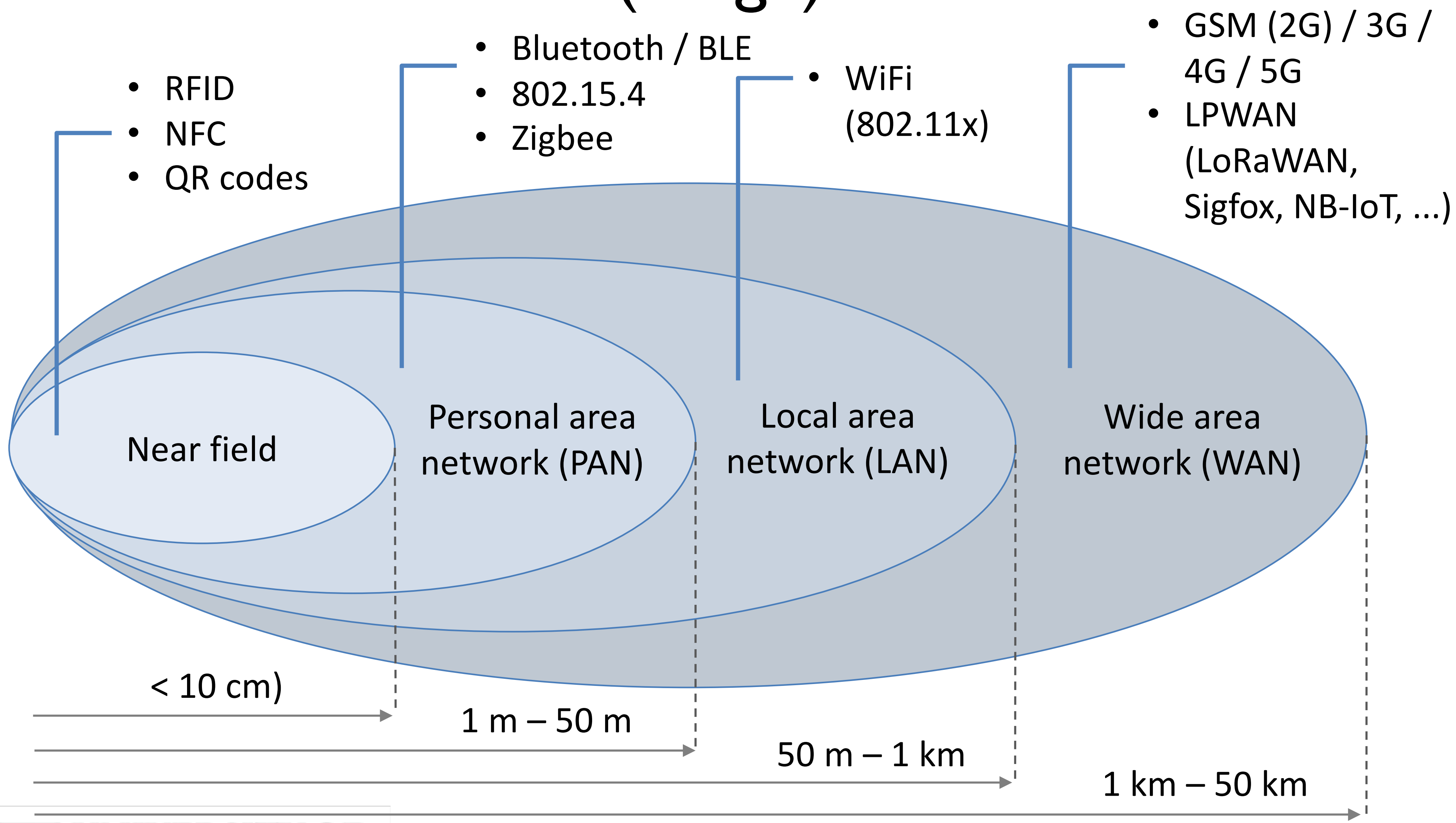
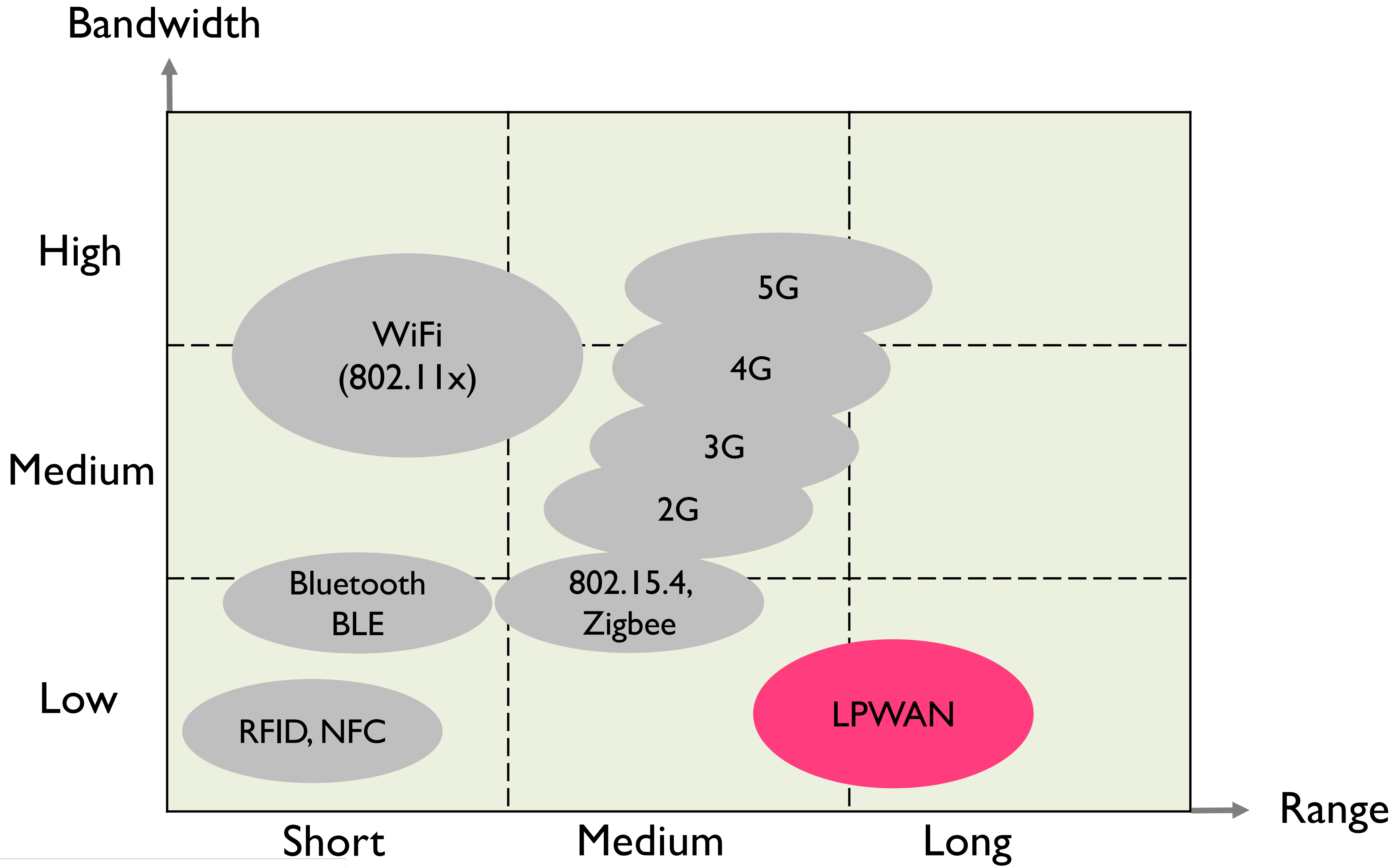
Classification of communication technologies (range)



Classification of communication technologies (range vs bandwidth)



Main characteristics

- Long range communication links
- Low bandwidth, low power
- Deep indoor penetration
- Very cheap radio modules

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Typical LPWAN applications

- Smart metering
- Air quality monitoring
- Smart lighting
- Asset tracking (not real-time)
- Tank monitoring
- Waste management

These applications are typically delay tolerant and require the transmission of only a few packets per hours

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LoRaWAN

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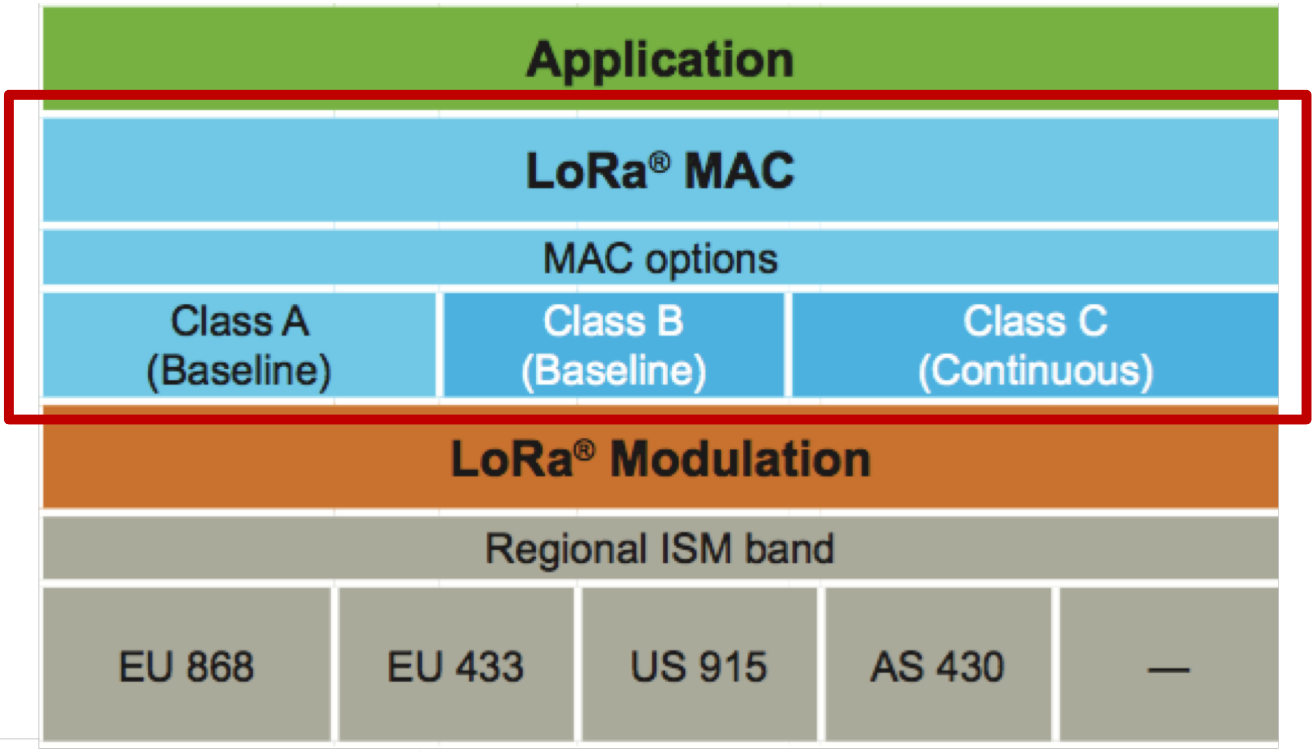
What is LoRaWAN?

- LoRaWAN is the MAC/network layer which uses LoRa as the underlying radio modulation



3 classes of devices

A. Battery powered devices, bi-directional comm.
B. Battery powered devices, bi-directional comm., extra receive windows
C. Main powered devices

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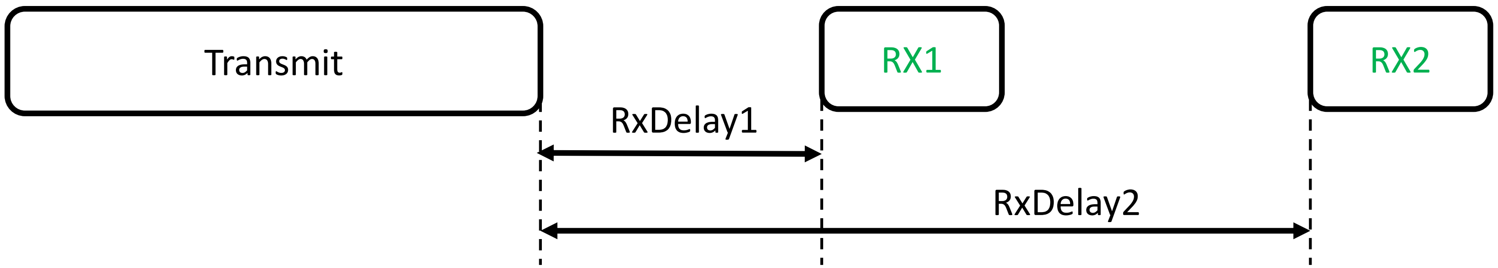
End-device classes

- Battery powered – Class A
  - Bidirectional communications
  - End-device initiates communication (uplink)
  - Server communicates with end-device (downlink) during predetermined response windows
  - For every uplink, there are two possible downlink slots
  - Low power consumption, high latency



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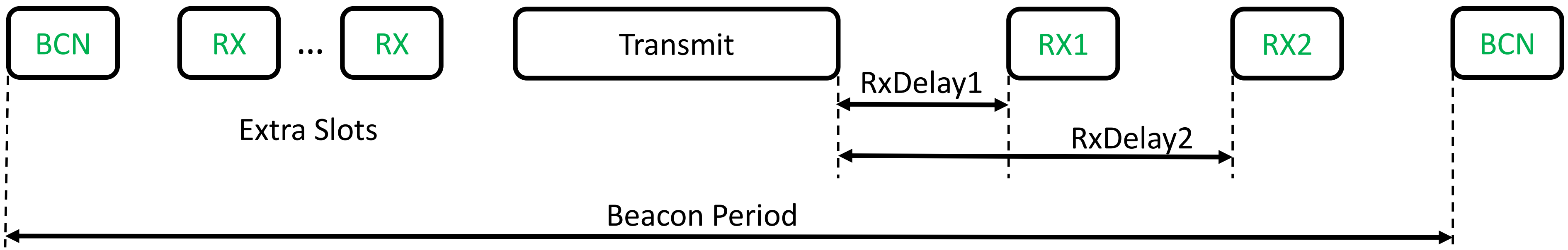
End-device classes

- Low latency – Class B
  - Bidirectional with scheduled receive slots
  - There are pre-programmed downlink slots. Downlink is possible at these times
  - Periodic beacon from gateway to synchronize downlink slots
  - High power consumption, low latency



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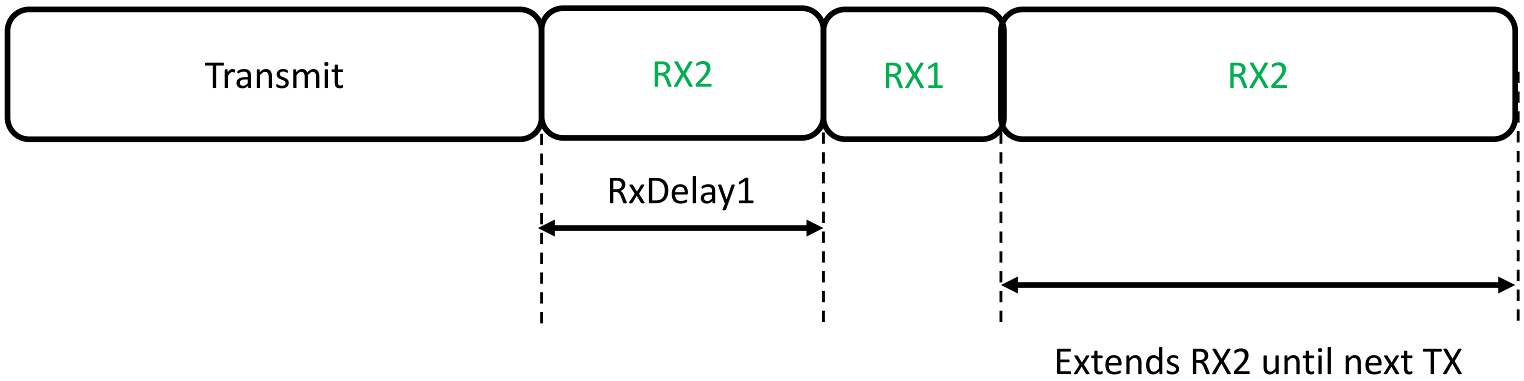
End-device classes

- No latency – Class C
  - Bidirectional communications
  - Server can initiate transmission at any time
  - End-device is constantly receiving
  - Main-powered devices, no latency



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Summary

- We have described the characteristics of sensor systems and their challenges
- We have introduced MAC protocols for sensor systems
- We have illustrated the IoT protocols

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Suggested Readings

- TinyOS tutorial: http://www.tinyos.net/tinyos-1.x/doc/tutorial/
- SMAC: Ye, W., Heidemann, J., and Estrin, D. 2004. Medium access control with coordinated adaptive sleeping for wireless sensor networks. IEEE/ACM Trans. Netw. 12, 3 (Jun. 2004), 493-506.
- WISEMAC: El-Hoiydi, A. and Decotignie, J. 2004. WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks. In Proceedings of the Ninth international Symposium on Computers and Communications 2004 Volume 2 (Iscc"04) - Volume 02 (June 28 - July 01, 2004). ISCC. IEEE Computer Society, Washington, DC, 244-251.
- X-MAC: M. Buettner, G.V. Yee, E. Anderson, and R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks," in *Proceedings of the 4th international conference on Embedded networked sensor systems* Boulder, Colorado, USA: ACM, 2006.
- LEACH: Energy-Efficient Communication Protocols for Wireless Microsensor Networks. Wendi Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan,, Proc. Hawaaian Int'l Conf. on Systems Science, January 2000.

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Suggested readings

- O. Vermesan and P. Friess (eds.). Internet of Things – From Research and Innovation to Market Deployment. River Publishers Series in Communication. 2014
- ITU-T Recommendation Y.2060. Overview of the Internet of Things. June 2012.
- Z. Shelby and C. Bormann. 6LoWPAN: The Wireless Embedded Internet. Wiley Publishing. 2010.
- N. Sornin, M. Luis, T. Eirich, T. Kramp, O. Hersent. LoRaWAN Specification. Version V1.0. Lora Alliance. January 2015.

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