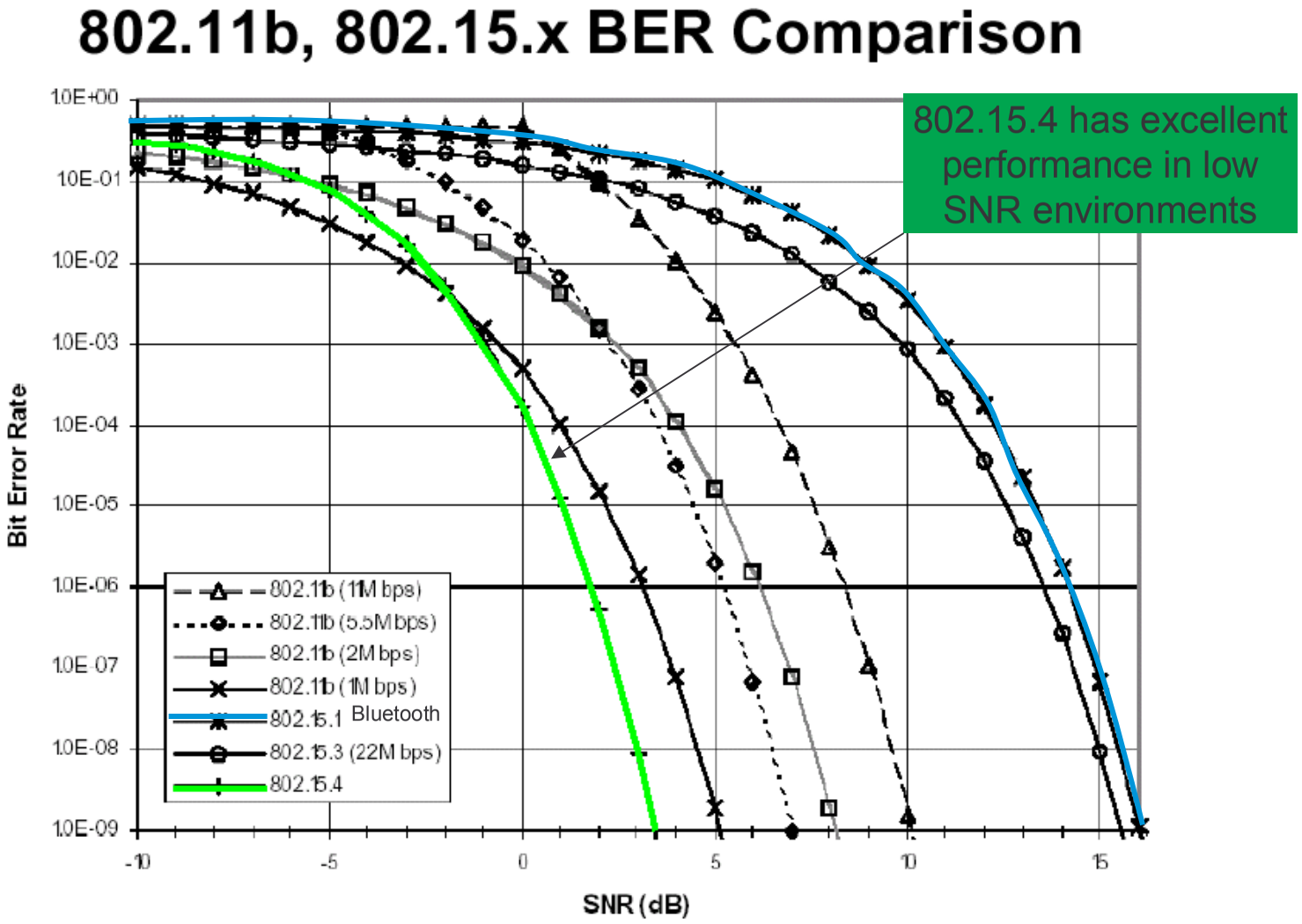
IEEE 802.15.4

- Emerging standard for low-power wireless monitoring and control
  - Scale to many devices
  - Long lifetime is important (contrast to Bluetooth)
  - 10-75m range typical
  - Designed for industrial process monitoring, control, medical devices, etc.
  - High data rate for small packets (~200 Kbps for 75 byte packets)

IEEE 802.15.4

- IEEE802.15.4
  - Physical and MAC layer
  - Channel Access is via Carrier Sense Multiple Access with collision avoidance and optional time slotting
  - Message acknowledgement and an optional beacon structure
  - Multi-level security
  - Configured for maximum battery life, has the potential to last as long as the shelf life of most batteries

IEEE 802.15.4 PHY Performance



ZigBee

- ZigBee
  - Network and application layer on top of 802.15.4
  - Still emerging, standard not yet available outside of ZigBee Alliance
  - Finalised Dec 2004

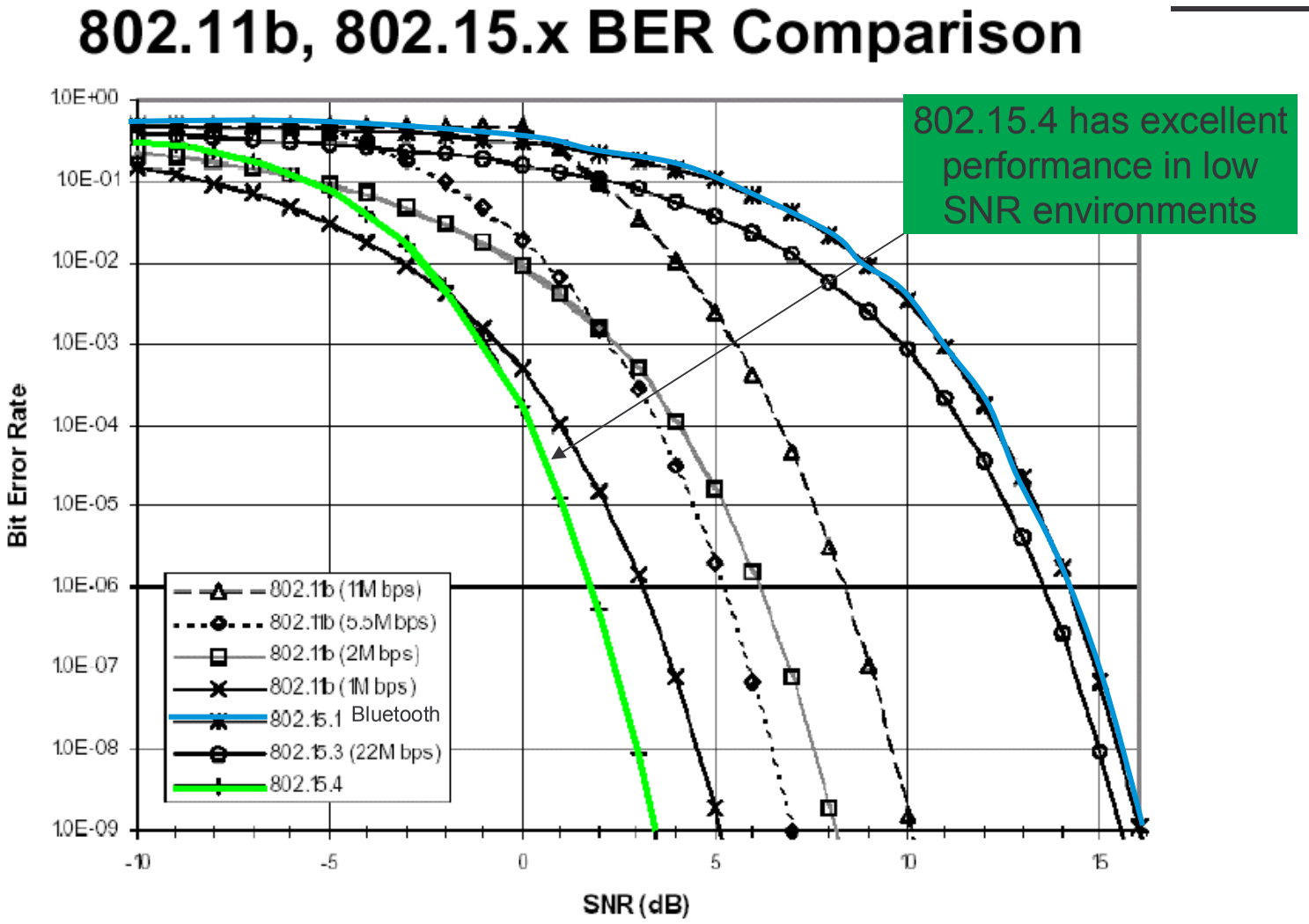
Chips

- Single-chip 802.15.4 radio transceiver, $5.
  - Incorporated into some motes e.g. Telos
  - 1.8V supply, consumes 19.7 mA receiving, 17.4 mA transmit
  - Easy to integrate: Open source software drivers
  - Support 802.15.4 PHY and encryption in hardware
    - MAC still implemented in software

802.15.4 PHY

- 802.15.4 defines several frequency ranges:
  - 16 channels in the 2.4GHz band
    - » 5 MHz per channel, 250 kbps
  - 10 channels in the 902-928MHz band
    - » 2 MHz per channel, 40 kbps
  - 1 channel in the 868 MHz band
    - » 20kbps

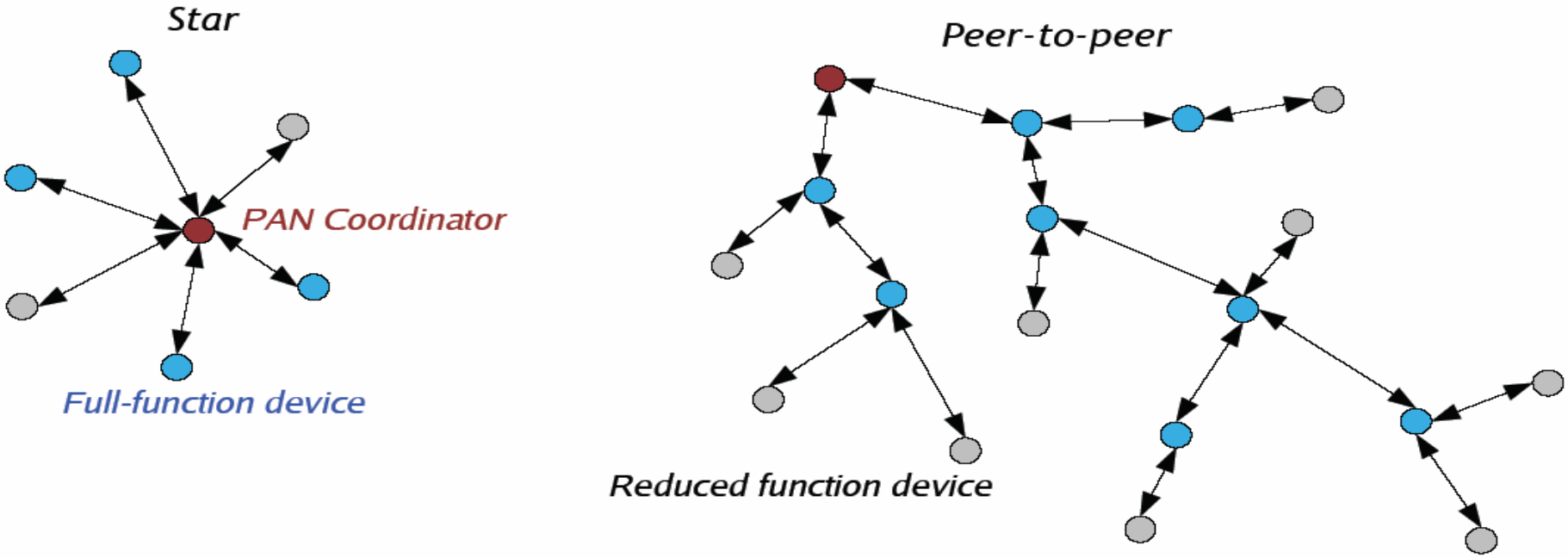
PHY Performance



PHY

- Direct Sequence spreading used for 2.4GHz band
  - Each 4-bit nibble mapped onto quasi-orthogonal 32-bit chipping code
  - Modulated using offset-QPSK
- Data transmitted at a rate of 2 million chips/sec
  - 32-bit chip maps onto 4-bit raw data symbol
  - So, effective data rate is (2,000,000)/(32) *4 = 250,000 bits/sec
    - (Note that this is only 244 Kbps if 1 Kbit = 1024 bits)

IEEE 802.15.4 Network Topologies



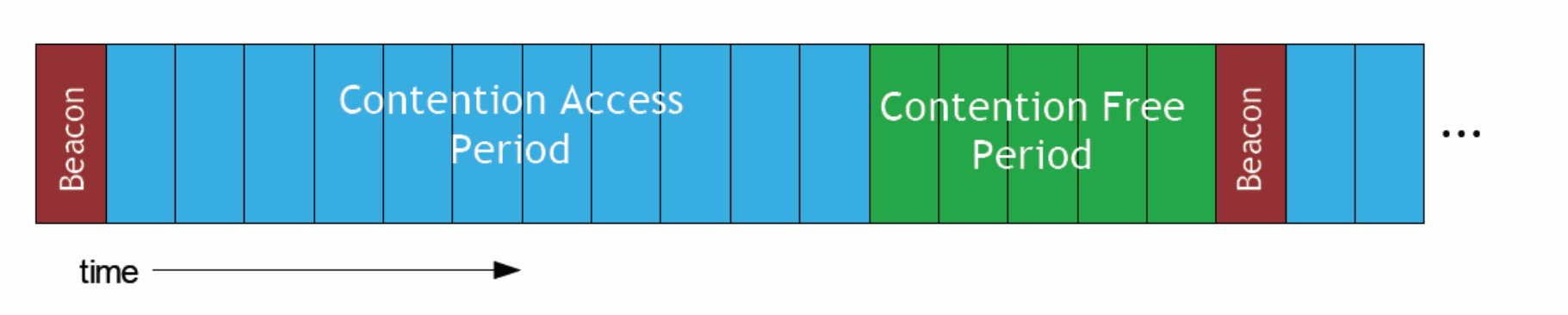
Every network has a unique *Personal Area Network Coordinator*

- Coordinator responsible for network management tasks, e.g., associating new nodes, transmitting beacons, etc.
- Star network: All nodes must talk to PAN (like 802.11)
- Peer-to-peer network: Individual nodes can talk to each other
  - *Only Full Function Devices can actually route messages*

IEEE 802.15.4 Superframe structure

- Superframe broken into 16 time slots between beacons
  - Beacons transmitted periodically by PAN coordinator
  - Used to synchronize nodes in a network to a common timebase
- Two types of time slots:
  - Contention Access Period: Nodes use CDMA/CA to transmit
  - Contention Free Period: Nodes are assigned guaranteed time slots, as in TDMA
  - Assignment of guaranteed slots performed by PAN Coordinator

IEEE 802.15.4 Superframe Structure



IEEE 802.15.4 Basic MAC Scheme

Beacon messages not subject to CSMA

- Used to coordinate network and are not expected to suffer collisions

CSMA/CA scheme very similar to 802.11

- Nodes listen before transmitting
- Random backoff between 0 – N time slots
- Double N each time a collision occurs

Transmitter can request ACK for each message

- Bit set in header to tell receiver an ACK is needed
- ACK will be transmitted shortly after reception (without CSMA)
- UnACK'd messages will be retransmitted up to some fixed number of times

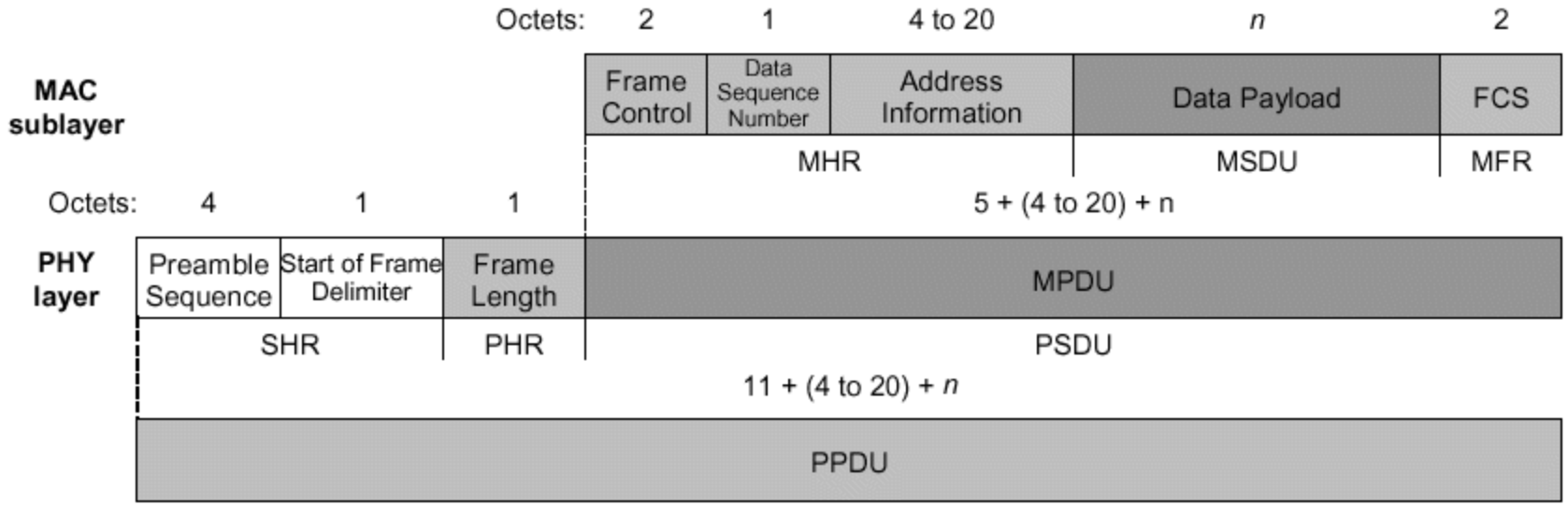
MAC Overview

- Employs 64-bit IEEE & 16-bit short addresses
  - Ultimate network size can reach 2^{64} nodes (more than we'll probably need…)
  - Using local addressing, simple networks of more than 65,000 (2^16) nodes can be configured, with reduced address overhead
- Three devices specified
  - Network Coordinator
  - Full Function Device (FFD)
  - Reduced Function Device (RFD)
- Simple frame structure

MAC Overview

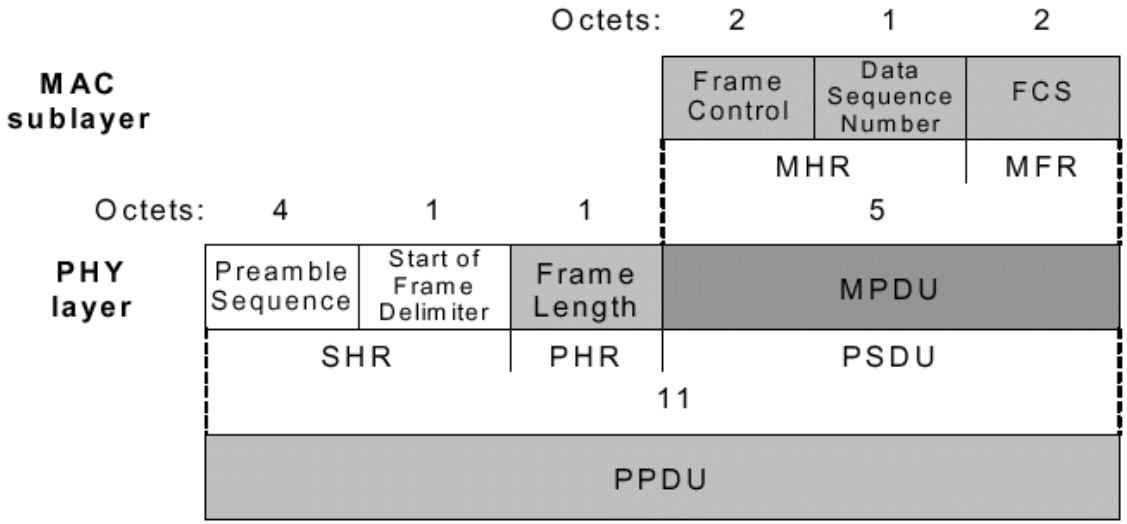
- Reliable delivery of data
- Association/disassociation
- AES-128 security
- CSMA-CA channel access
- Optional superframe structure with beacons
- Optional GTS mechanism

IEEE 802.15.4 Data Frame format



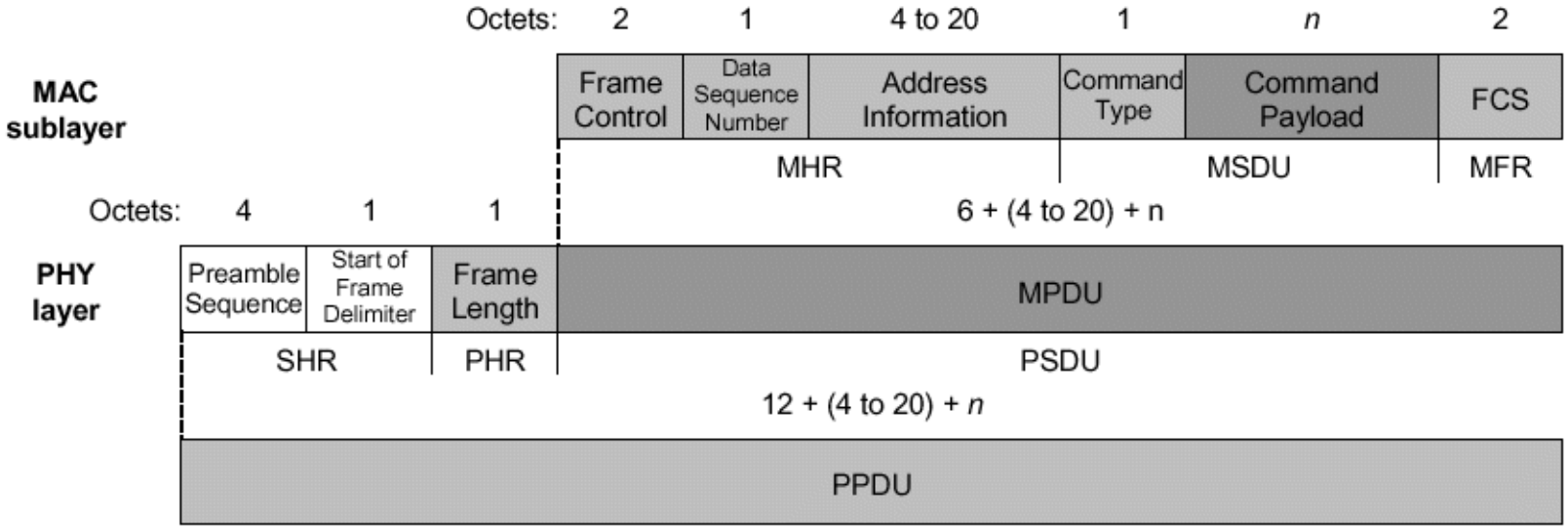
- One of two most basic and important structures in 15.4
- Provides up to 104 byte data payload capacity
- Data sequence numbering to ensure that packets are tracked
- Robust structure improves reception in difficult conditions
- Frame Check Sequence (FCS) validates error-free data

IEEE 802.15.4 Ack Frame Format



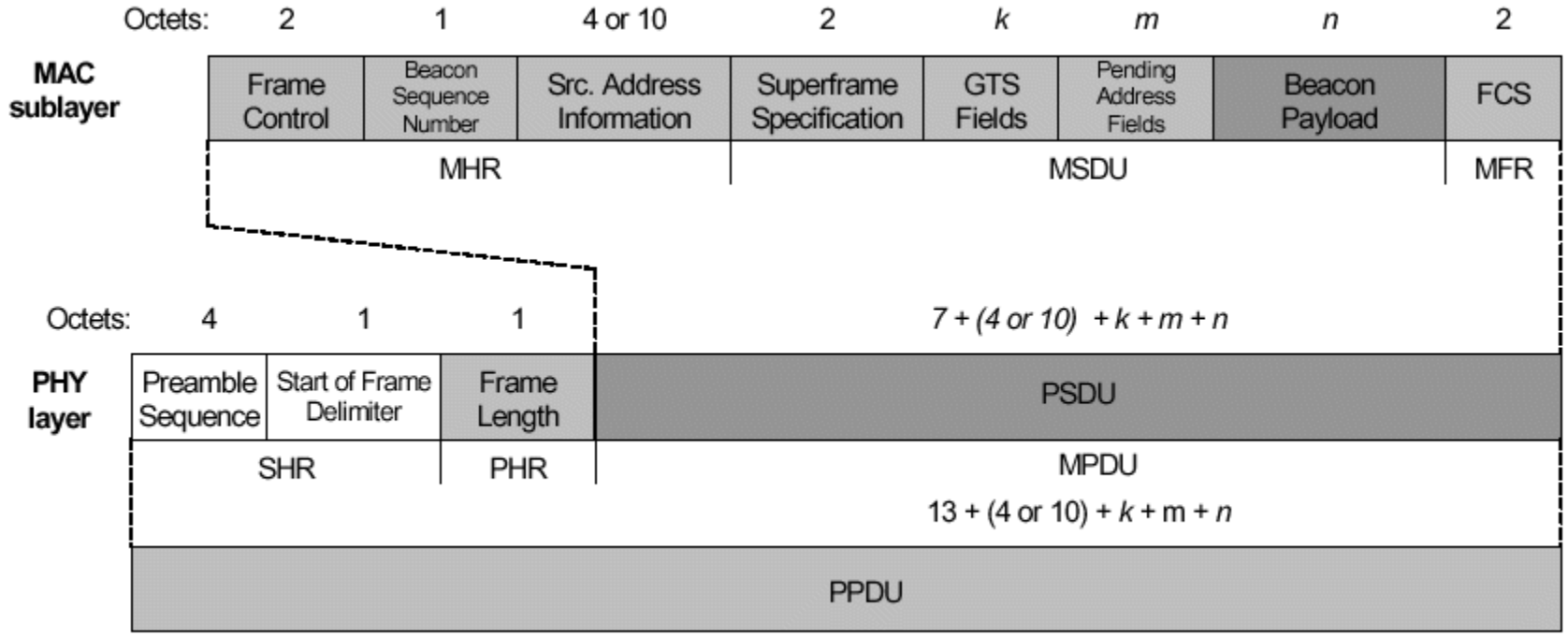
- The other most important structure for 15.4
- Provides active feedback from receiver to sender that packet was received without error
- Short packet that takes advantage of standards-specified "quiet time" immediately after data packet transmission

IEEE 802.15.4 MAC Command Frame



- Mechanism for remote control/configuration of client nodes
- Allows a centralized network manager to configure individual clients no matter how large the network

IEEE 802.15.4 Beacon Frame Format



- Beacons add a new level of functionality to a network
- Client devices can wake up only when a beacon is to be broadcast, listen for their address, and if not heard, return to sleep
- Beacons are important for mesh and cluster tree networks to keep all of the nodes synchronized without requiring nodes to consume precious battery energy listening for long periods of time

IEEE 802.15.4 Power Saving Features

To save power, it's a good idea to power down a node's radio

- Means that node cannot transmit or receive

Coordinator can define *idle period* within the superframe

- Means that all nodes can sleep during that time (even the coordinator!!)

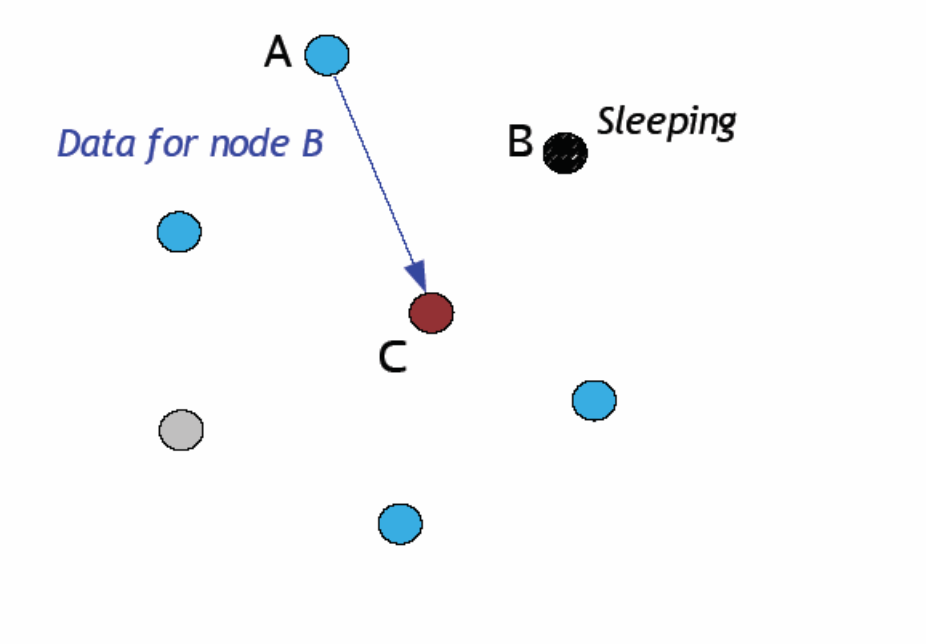
However, individual nodes can enter a low-power state any time.

What does this mean for sending data to this node?

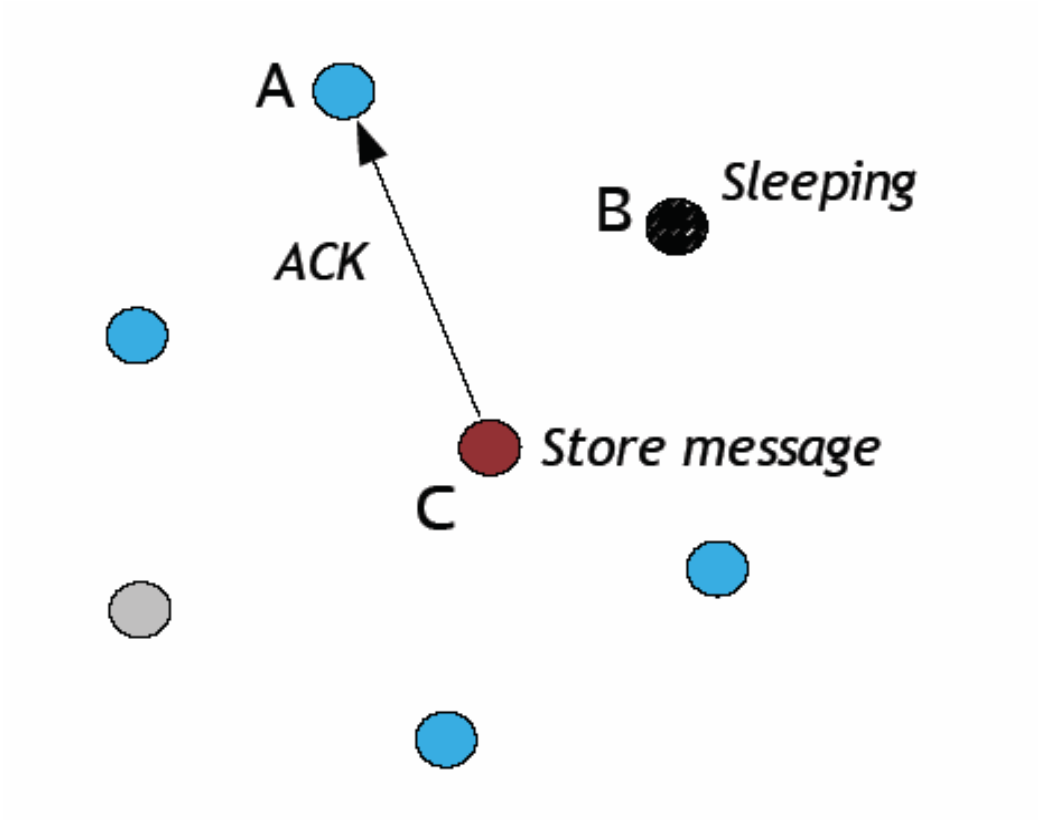
- The receiver won't hear any incoming transmissions ....
- Should the transmitter just keep trying to send the same message?
- Is this really a “transmission failure” (e.g., caused by collisions)?

IEEE 802.15.4 Poll-based Transfer

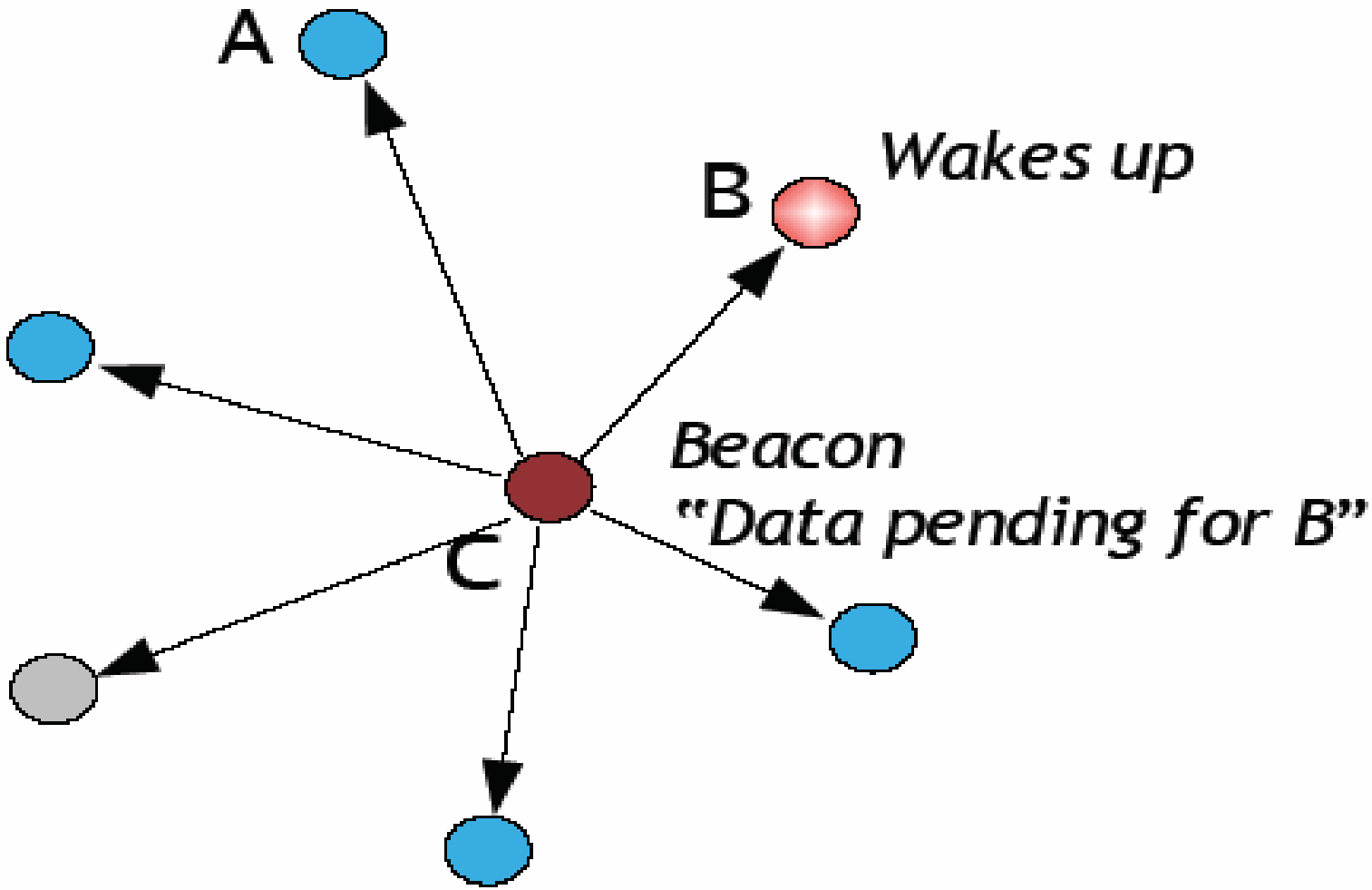
- **Solution:** Poll-based transfer



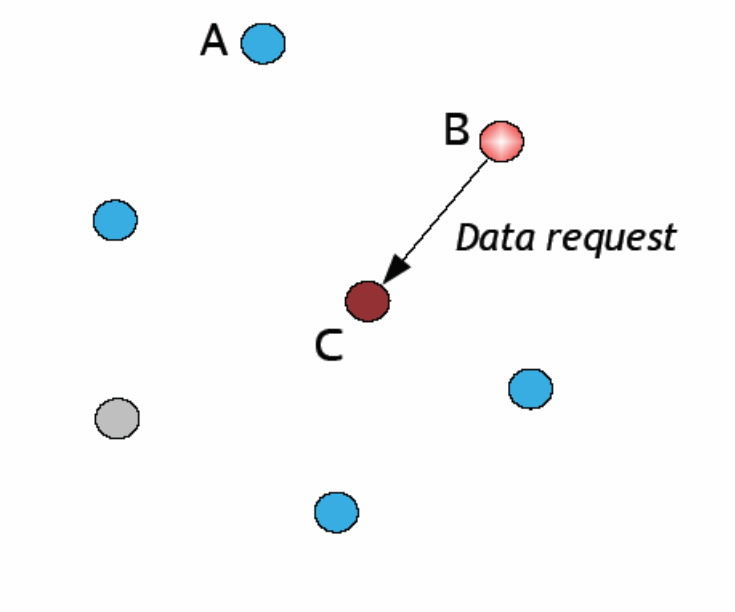
IEEE 802.15.4 Poll-based Transfer



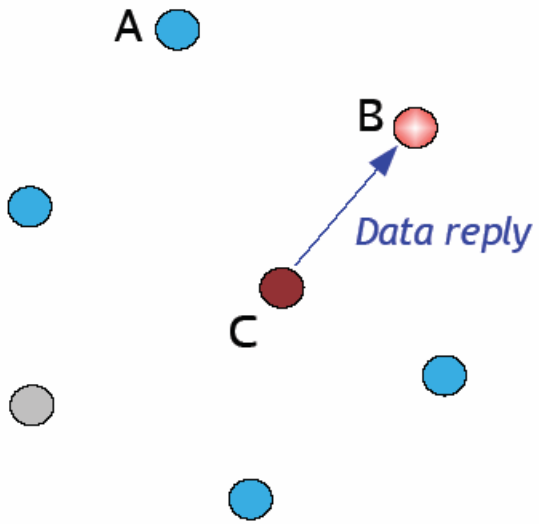
Poll-based Transfer



IEEE 802.15.4 Poll-based Transfer



IEEE 802.15.4 Poll-based Transfer



- Allows nodes to sleep when not requiring use of the radio
- Increases latency for communications
- Requires coordinator to buffer messages for individual nodes.

IEEE 802.15.4 15.4/ZigBee vs Bluetooth

- Instantaneous Power Consumption
  - 15.4 Transceivers are "similar" to Bluetooth Transceivers
    - 802.15.4
      - O-QPSK with shaping
      - Max data rate 250kbps over the air
      - 2Mchips/s over the air Direct Sequence Spread Spectrum (62.5ksps*32 spread)
      - -92 dBm sensitivity nominal
      - 40ppm xtal
    - Bluetooth
      - FSK
      - Max data rate 720kbps over the air
      - 1Msps over the air Frequency Hop Spread Spectrum (79 channels @ 1600 hps)
      - -83 to -84 dBm sensitivity nominal
      - 20ppm xtal
- Instantaneous power consumption will be similar for the raw transceivers without protocol
- Bluetooth's FHSS makes it impractical to create extended networks without large synchronization cost

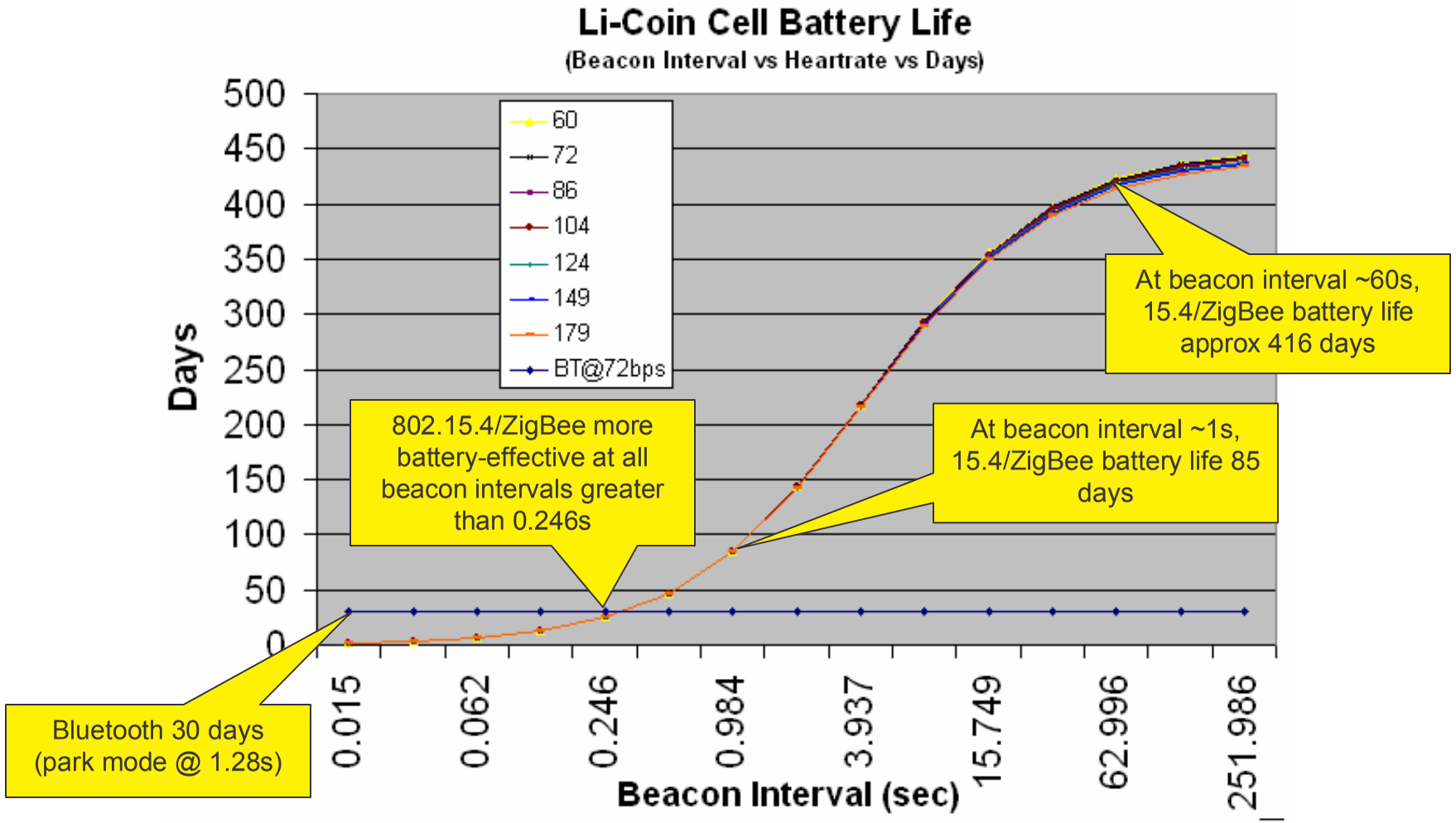
802.15.4 Design

- 15.4 Protocol was developed for very different reasons than Bluetooth
  - 802.15.4
    - Very low duty cycle, very long *primary* battery life applications as well as mains-powered
    - Static and dynamic mesh, cluster tree and star network structures with potentially a very large number (>>65534) of client units, low latency available as required
    - Ability to remain quiescent for long periods of time without communicating to the network

802.15.4 Design

- Bluetooth
  - Moderate duty cycle, secondary battery operation where battery lasts about the same as master unit
  - Wire replacement for consumer devices that need moderate data rates with very high QoS and very low, guaranteed latency
  - Quasi-static star network structure with up to 7 clients (and ability to participate in more than one network simultaneously)
  - Generally used in applications where either power is cycled (headsets, cellphones) or mains-powered (printers, car kits)
- Protocol differences can lead to tremendous optimizations in power consumption

802.15.4 vs Bluetooth



Summary

- IEEE 802.15.4 and ZigBee
  - Designer concentrates on end application
    - Silicon vendors and ZigBee Alliance take care of transceiver, RF channel and protocol
  - Reliable and robust communications
  - Flexible network architectures
  - Very long primary battery life (months to years to decades)
  - Very inexpensive Bill Of Materials
  - Low system complexity for the OEM
- More Information
  - Motorola: www.motorola.com/zigbee
  - ZigBee: www.zigbee.org