

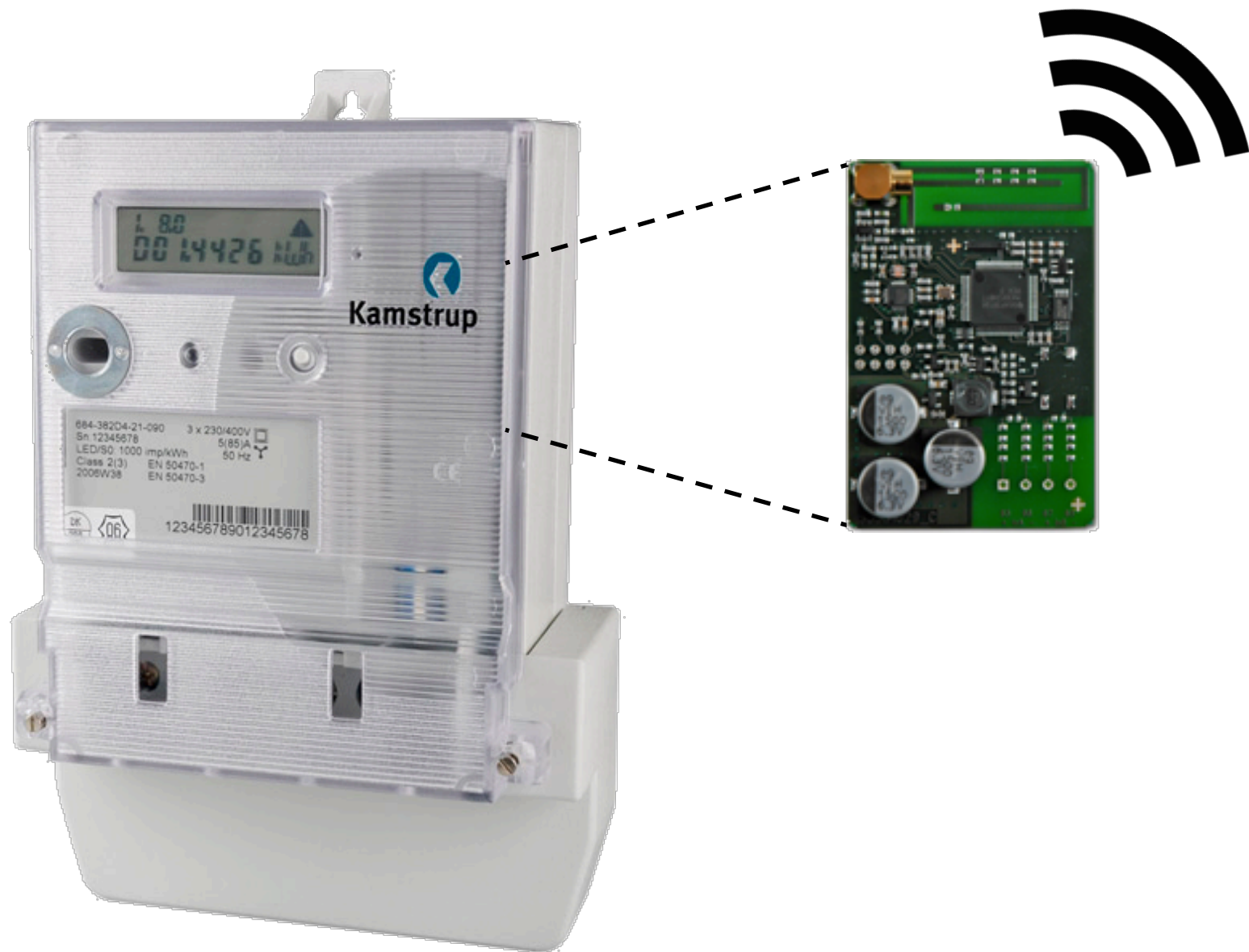


ICT Support for Adaptiveness and (Cyber)security in the Smart Grid

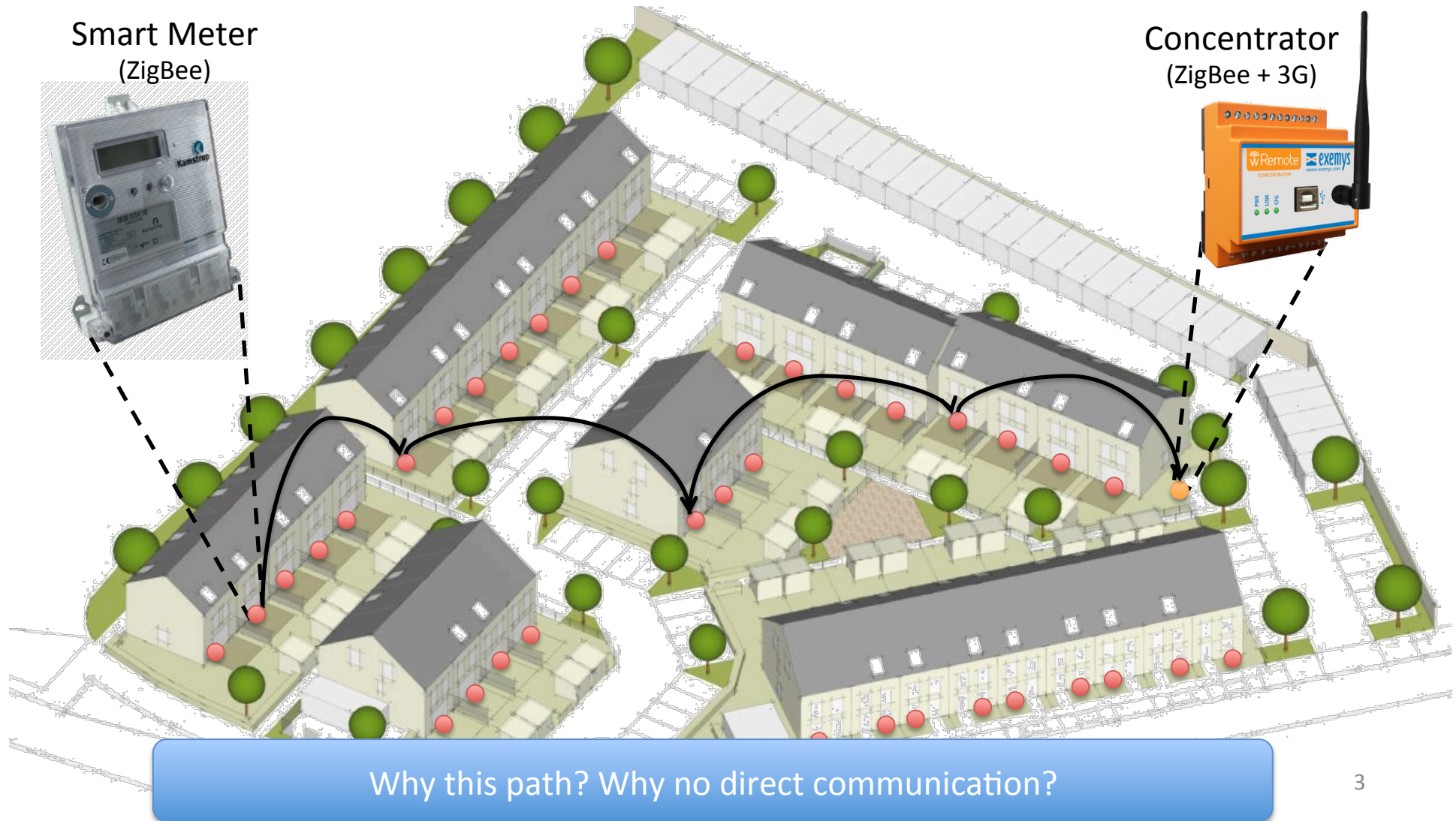
Low-Power Wireless Communication

Olaf Landsiedel

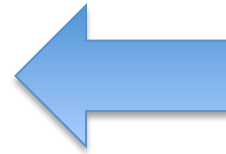
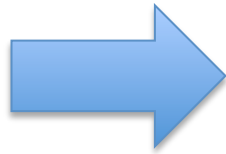
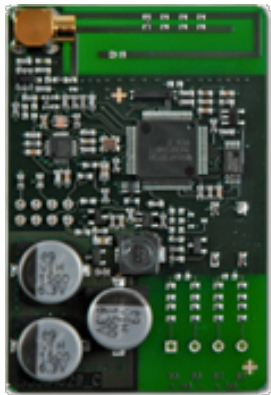
Devices



Routing



Lifetime



Goal for Today

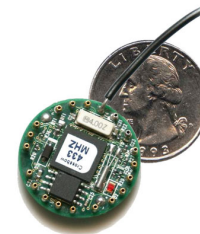
- Devices
 - Low-power wireless communication
 - Or a “wireless sensor node” in general
- Routing in low-power wireless networks
 - From source to sink
- Energy efficiency: often battery driven
 - Enable a life-time of years: allow devices to sleep

Low-Power Wireless

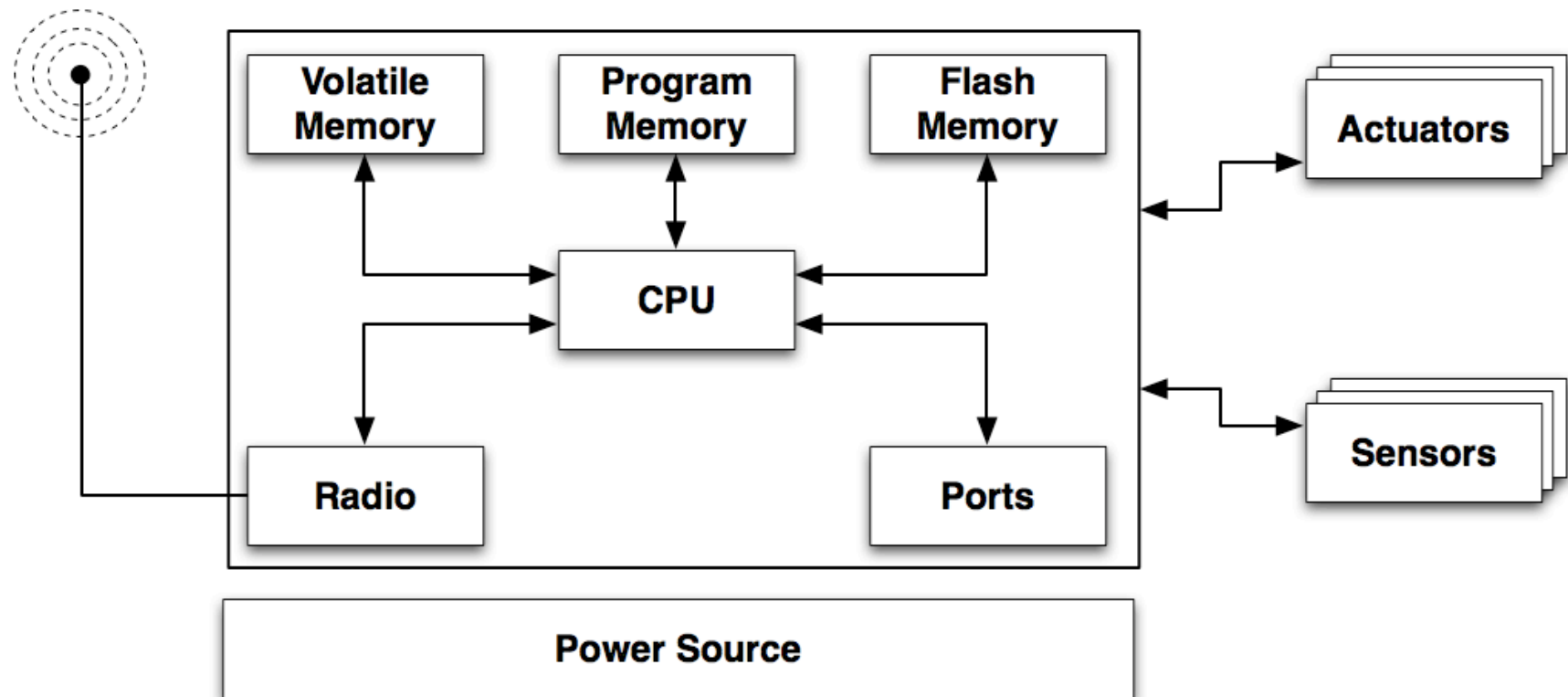
Devices

Requirements for such a Device

- Low cost
- High energy efficiency
- Small size

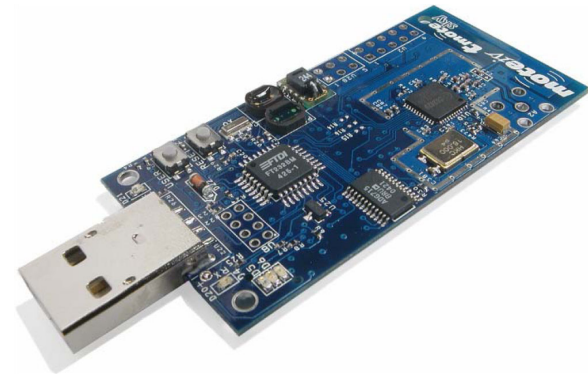


A Sensor Node (or low-power wireless device)



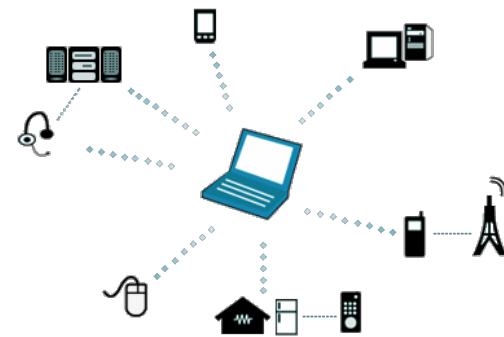
A Sensor Node (or low-power wireless device)

- TI MSP 430 (16 bit RISC)
 - 8 MHz
 - 10 KB RAM
 - 48 KB code, 1MB flash
- Chipcon CC2420 radio
 - IEEE 802.15.4 compliant
 - 50 m. range indoor,
250 m. range outdoor
 - bandwidth 250 kbits/s
- On-board antenna



Why not use WiFi or Bluetooth?

- WiFi/WLAN (IEEE 802.11)
 - Topology: mesh + single hop
 - Throughput: >100 Mbps
 - Power Consumption: ~300mW
- Bluetooth
 - Topology: Single-hop network
 - Master <-> Slave
 - Not good for multi-hop networking
 - Throughput: up to 24 Mbit/s
 - Power Consumption: up to 30mW



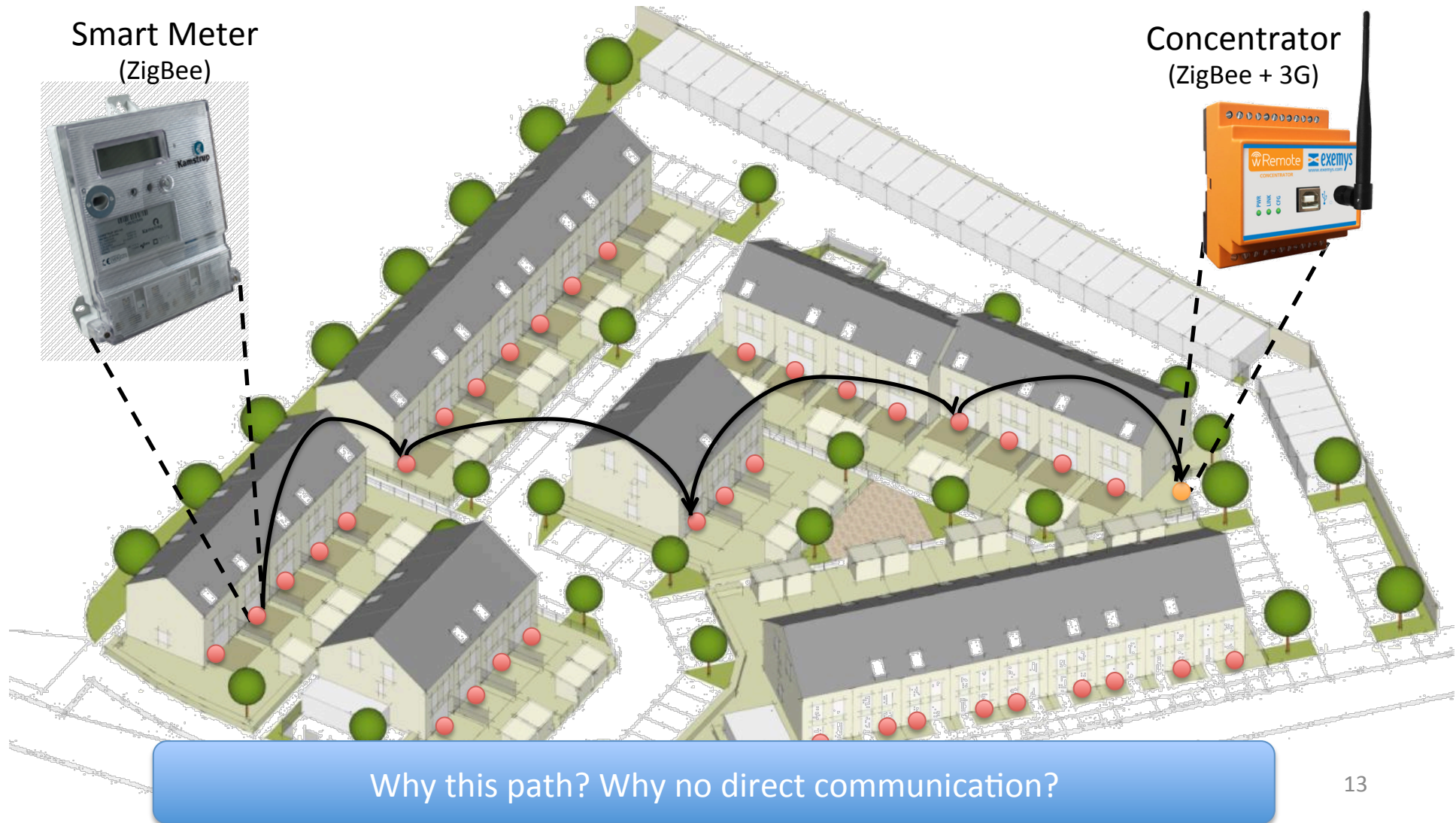
Summary: Device

- Low-Power Hardware
 - Simple Processor
 - Simple, energy-efficient radio
- Low cost, low energy consumption

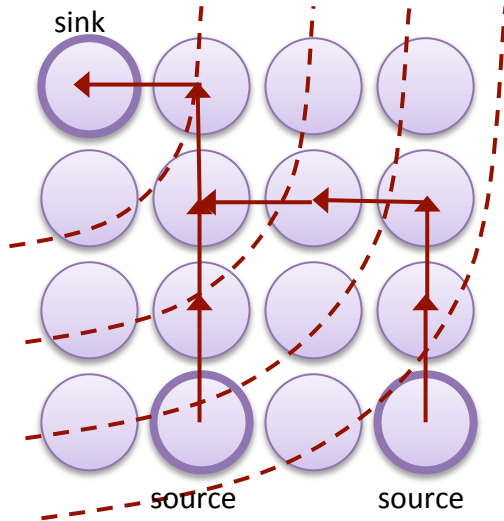
Low-Power Wireless

Routing

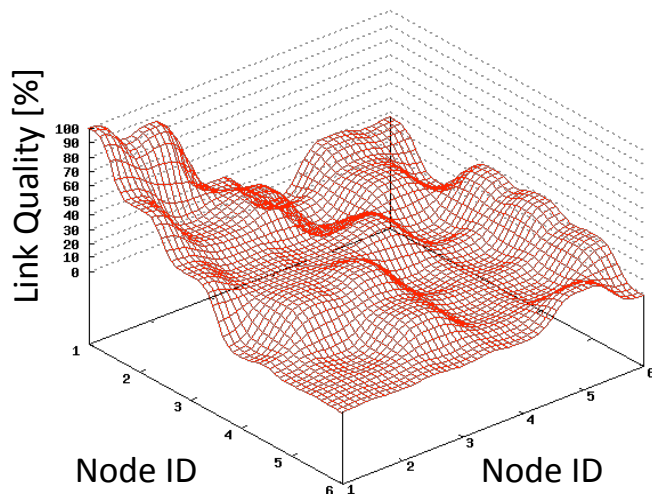
Routing



Routing Metrics



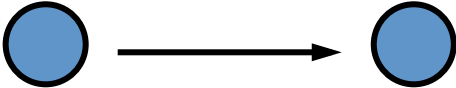
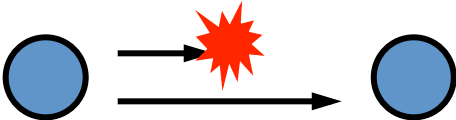
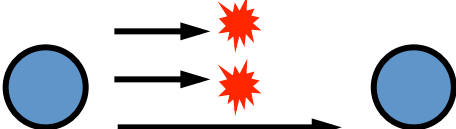
- Path Selection
 - Which path to select?
 - Routing Metric?
 - Minimize Hops?
 - Reliability?



- Wireless Links
 - Highly dynamic

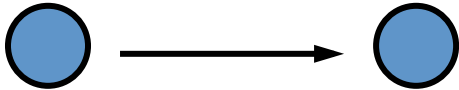
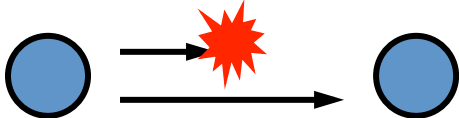

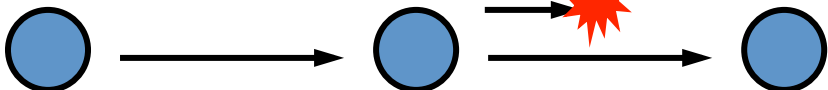
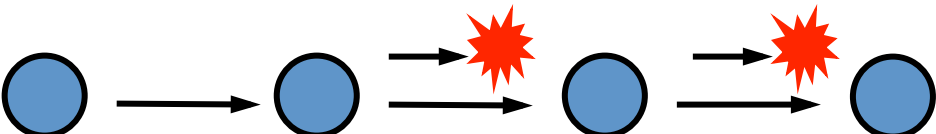
Routing Metric: ETX

- Goal: Minimize total transmissions per packet
 - Use Metric: Expected Transmission Count (ETX)
 - Measure link over a time to determine ETX
 - Link throughput $\approx 1 / \text{Link ETX}$

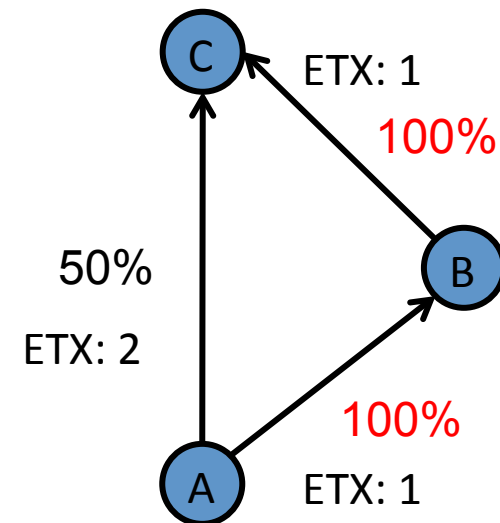
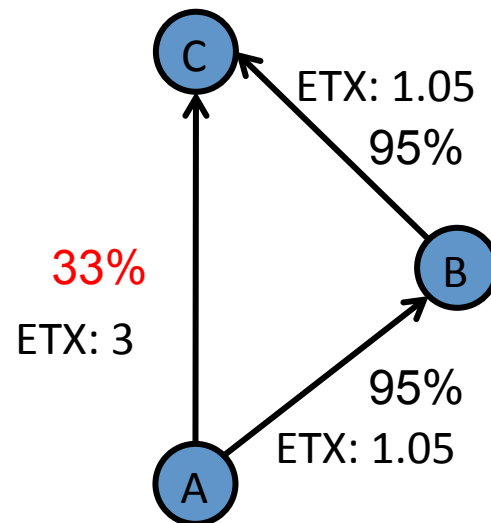
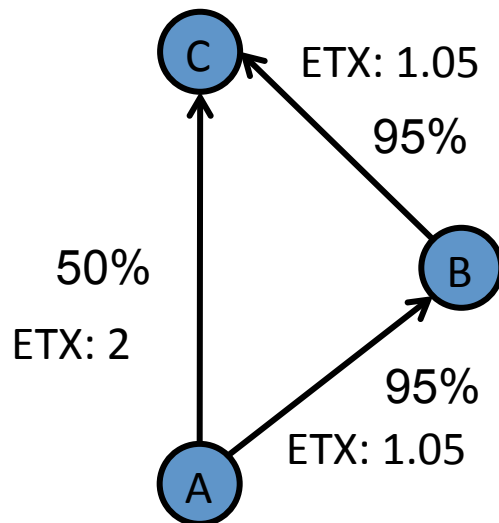
<u>Delivery Ratio</u>		<u>Link ETX</u>	<u>Throughput</u>
100%		1	100%
50%		2	50%
33%		3	33%

Route ETX

- Route ETX = Sum of link ETXs
 - Communication is expensive
 - ETX predicts the tx count of a packet -> Reflects energy
 - Route selection:
 - Choose route with lowest route ETX

	<u>Route ETX</u>	<u>Throughput</u>
	1	100%
	2	50%
	2	50%
	3	33%
	5	20%

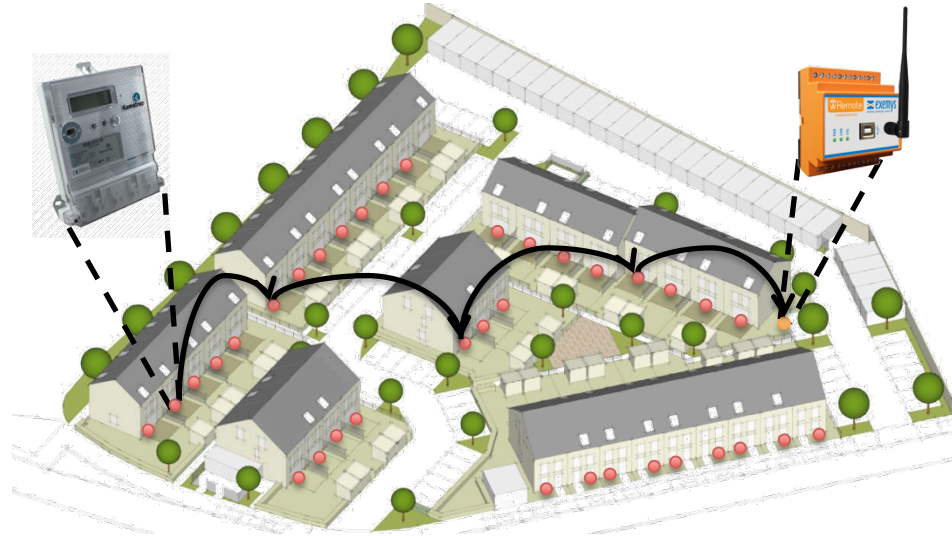
Question: Which Route is better?



- Which route to take
 - A -> B -> C or A -> B?
 - Example 1
 - A -> B -> C: 2.1 TX
 - A -> B: 2 TX
 - Take A->B

- Example 2
 - A -> B -> C: 2.1 TX
 - A -> B: 3 TX
 - Take A -> B -> C
- Example 3
 - A -> B -> C: 2 TX
 - A -> B: 2 TX
 - Take any

Summary: Routing Metric



- Expected Transmission Count (ETX)
 - Minimize total number of transmission
 - Good for energy: More transmissions -> more energy
 - Combines hops and reliability into single metric

Low-Power Wireless

Sleeping Devices

Energy-Efficient MAC

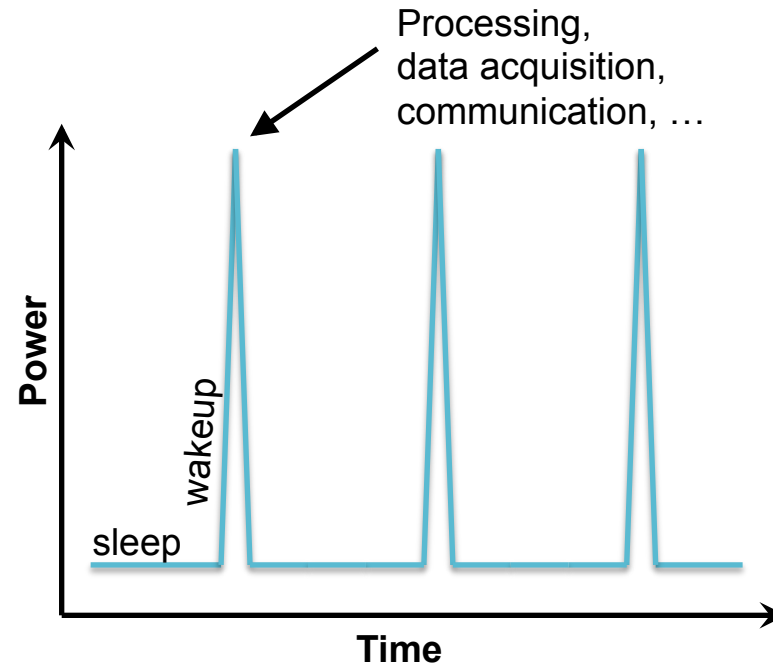
- Targeted life time of WSN
 - Months or years
- Simple back of the envelope calculation:
 - AA battery: About 2000 mAh
 - CC2420 radio:
19.7mA in RX mode
(listening to channel)
 - $2000\text{mAh} / 19.7\text{mA}$
= 101.5 hours
= 6 days

Operation	Telos
Minimum Voltage	1.8V
Mote Standby (RTC on)	5.1 μA
MCU Idle (DCO on)	54.5 μA
MCU Active	1.8 mA
MCU + Radio RX	21.8 mA
MCU + Radio TX (0dBm)	19.5 mA
MCU + Flash Read	4.1 mA
MCU + Flash Write	15.1 mA
MCU Wakeup	6 μs
Radio Wakeup	580 μs

- We want month or years: How?
 - Keep radio off most of the time

Solution: Duty Cycling

- Duty cycle
 - Wakeup, work, **sleep long**
 - Both: CPU and radio
 - Periodic
 - Data collection
 - Network maintenance
 - *Majority of operation*
 - Triggered events
 - Detection / notification
 - *Occurs infrequently*
 - *But... must be reported quickly and reliably*
 - Sleep:
 - CPU in deep sleep (timers only)
 - Radio off
- Result: Long lifetime
 - Months to years without changing batteries
 - Duty cycle from 0.1% to 1%

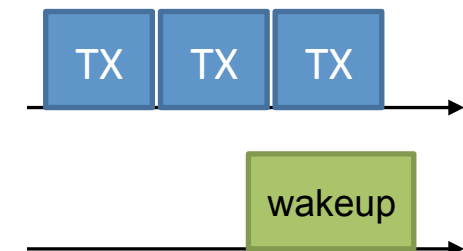
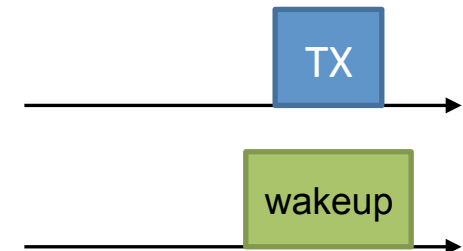


How to communicate with a node sleeping 99% of the time?

Synchronous vs. asynchronous wakeups

Duty Cycling

- Synchronous duty cycling
 - Knowing the wakeup time of destination
 - Transmit accordingly
 - Advantage: very energy efficient
 - Disadvantage: requires synchronization
- Asynchronous duty cycling
 - Not knowing the wakeup time
 - Example: Repeat transmission until destination wakes up and acknowledges
 - Advantage: simple, no time synchronization
 - Disadvantage: not as energy efficient

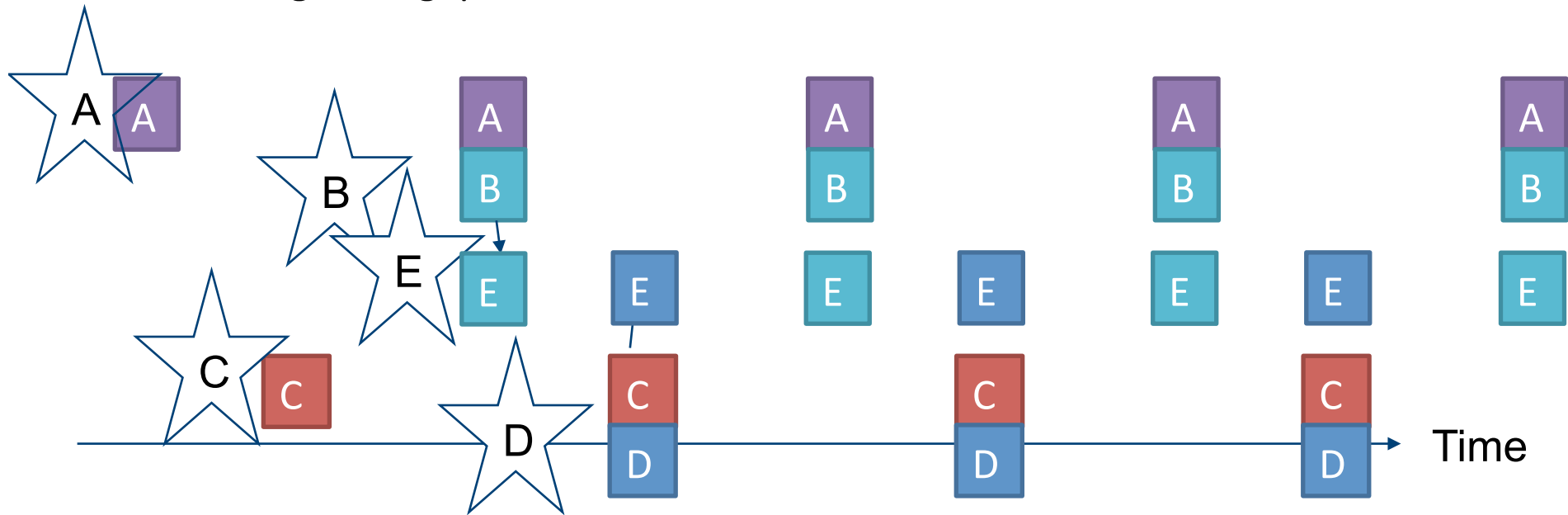


Synchronous Duty Cycling

- Idea:
 - Switch nodes, radios off
 - Ensure that neighboring nodes turn on simultaneously
 - To allow packet exchange (rendezvous)
 - Requires Time Synchronization
 - Called “Synchronous duty cycling”
- In wakeup phase
 - Only in these ***active periods***, packet exchanges happen
 - Need to also exchange wakeup schedule between neighbors

Synchronous Duty Cycling

- 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

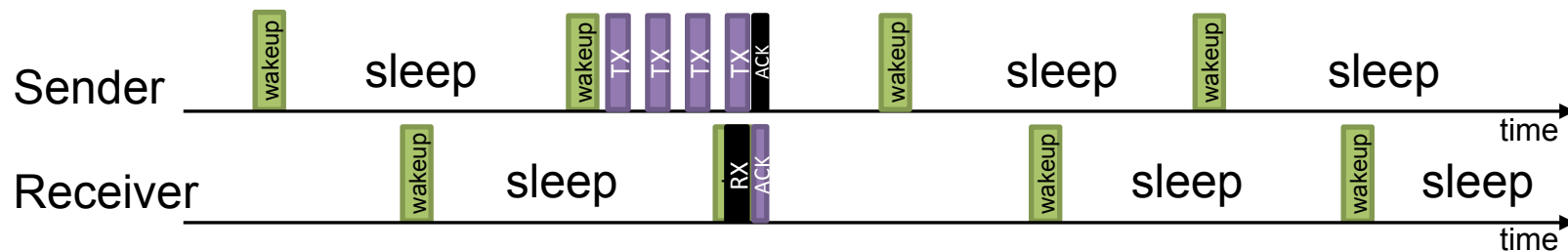


Synchronous Duty Cycling: Discussion

- Pro: Energy-Efficient
 - A node sleeps most of the time
 - Periodically wake up for short intervals to see if any node is transmitting a packet
- Cons
 - Time sync overhead
 - Account for clock drifts etc.
 - Add guard spaces
 - Some nodes are in multiple “clusters”
 - More wakeups
 - Have higher energy consumption

Asynchronous Duty Cycling

- So far: Periodic sleeping
 - Need some means to synchronize wake up of nodes
 - Ensure rendezvous between sender and receiver
- Alternative option: Don't try to explicitly synchronize nodes
 - Have receiver sleep and only periodically sample the channel
- Repeat packet until receivers wakes up
 - And acknowledges
 - No Synchronization required! Asynchronous duty cycle



Asynchronous Duty Cycling: Discussion

- Pro: Energy-Efficient
 - A node sleeps most of the time
 - No need for time sync
 - Periodically wake up for short intervals to see if any node is transmitting a packet
- Cons
 - Transmission are costly
 - Especially when nodes wakeup rarely
 - A single transmissions is repeated many times
 - High channel utilization in this time

Summary

- Devices: cheap, low-power
 - Low-power wireless
- Routing: Expected Transmission Count (ETX)
 - Account for link dynamics
- Synchronous and asynchronous duty cycling
 - Sleeping devices

Questions?

In part, inspired from / based on slides and figures from Jochen Schiller, Holger Karl, Klaus Wehrle, Kyoung-Don Kang, Leonardo Leiria Fernandes, Joe Polastre, Chenyang Lu, Leo Selavo, Luca Mottola, Adam Dunkels, and many others