ETH zürich

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Extending Body Sensor Nodes' Lifetime Using a Wearable Wake-up Radio

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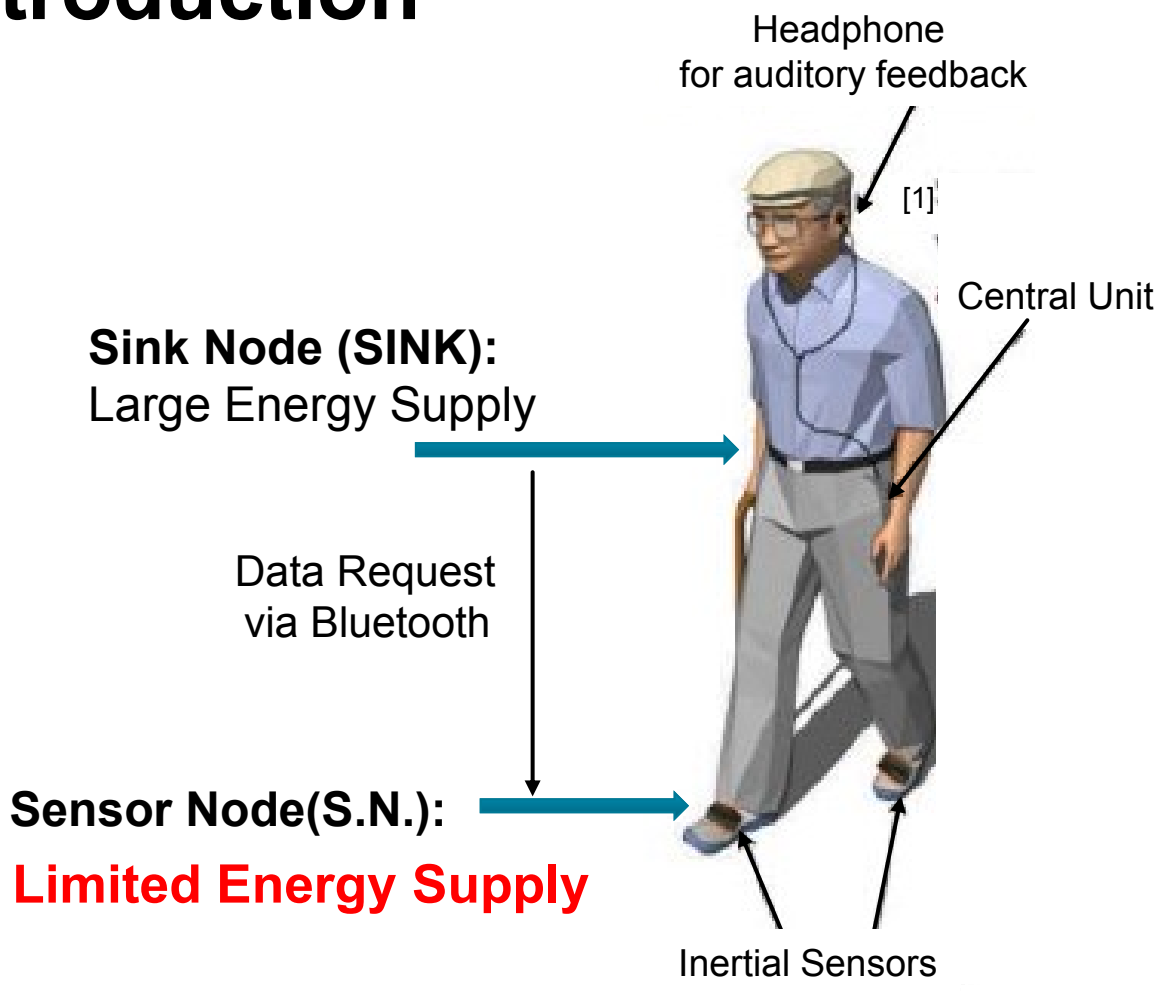
Introduction

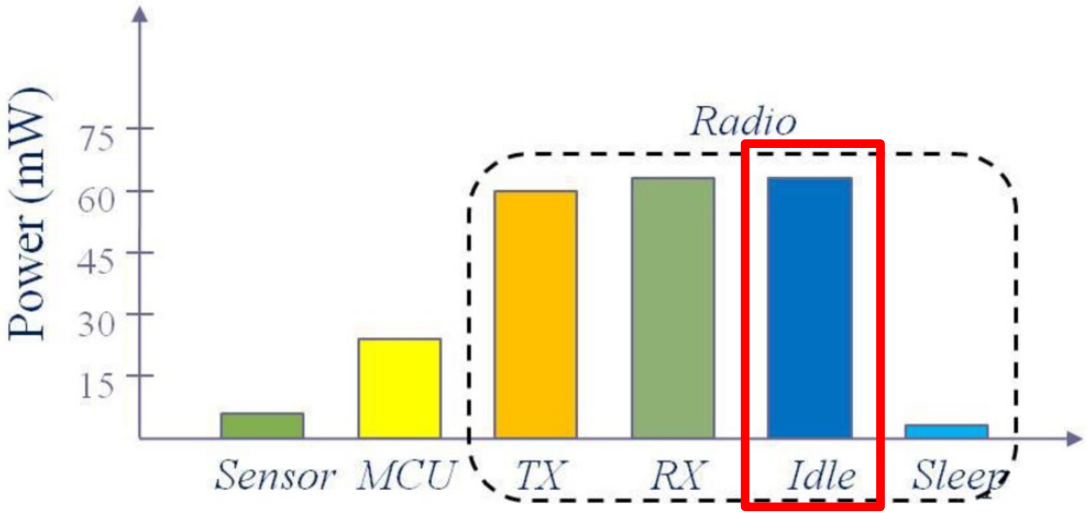


Gait Detection:

- Sink Node requests data from different sensor nodes at different times
  - Both sensor nodes need to be on
- Sink node processes data to detect gait disturbances

[1] Casamassima, F.; Ferrari, A.; Milosevic, B.; Ginis, P.; Farella, E.; Rocchi, L. ''A Wearable System for Gait Training in Subjects with Parkinson's Disease''. *Sensors* 2014, *14*, 6229-6246.

Power consumption of wearable nodes



[2]

Synchronization schemes:

- Synchronous (duty-cycling)
- Asynchronous

Wake-up radio shown to reduce idle power

Our Wake Up Radio (WUR):

- High sensitivity (up to -42dBm)
- Low power consumption (400 nW)
- fast reactivity (8us)
- Addressing capability

Wireless Sensor Network (WSN) → **Body Area Networks (BAN) ?**

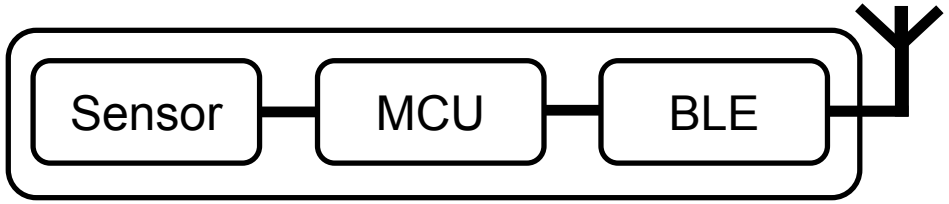
[2] Hyocheol Jeong, Jeonghyun Kim, and Younghwan Yoo 'Adaptive Broadcasting Method Using Neighbor Type Information in Wireless Sensor Networks''. *Sensors* 2011, *11*(6), 5952-5967

Contributions

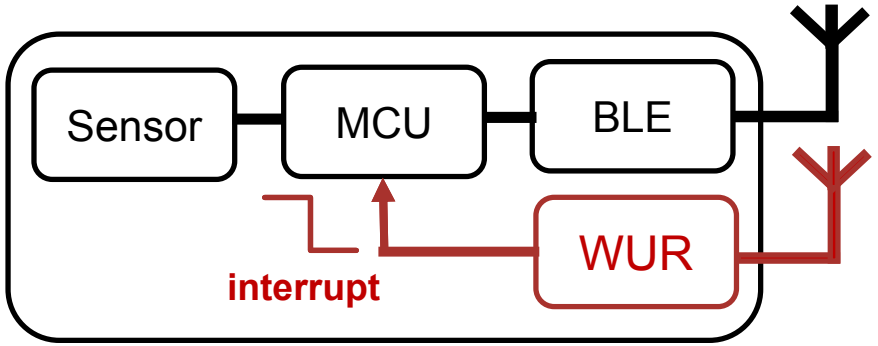
- Evaluation of WUR for BAN applications
- How much energy can be saved?
- Are there any performance trade-offs?
  - Range/sensitivity
  - Addressing or not addressing

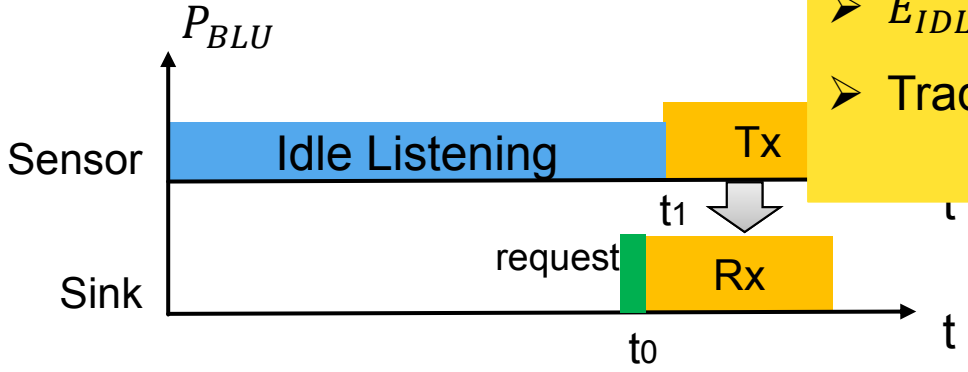
System Architecture

- Bluetooth(BLU):

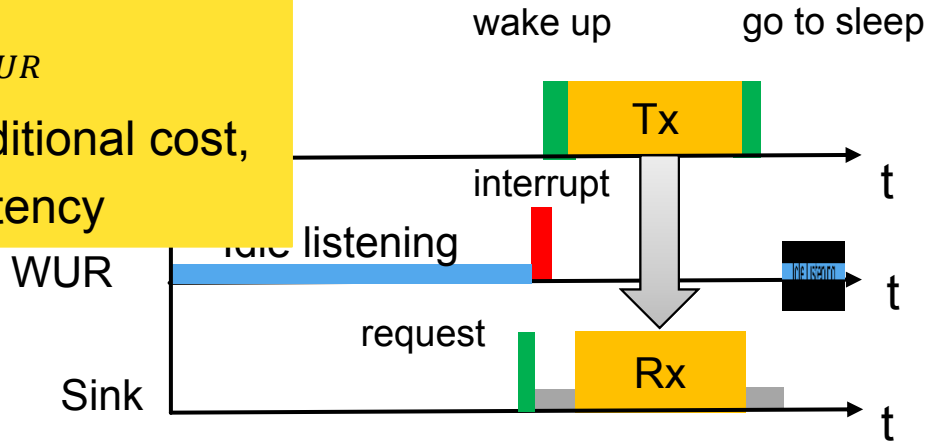


- BLU+Wake-up Radio

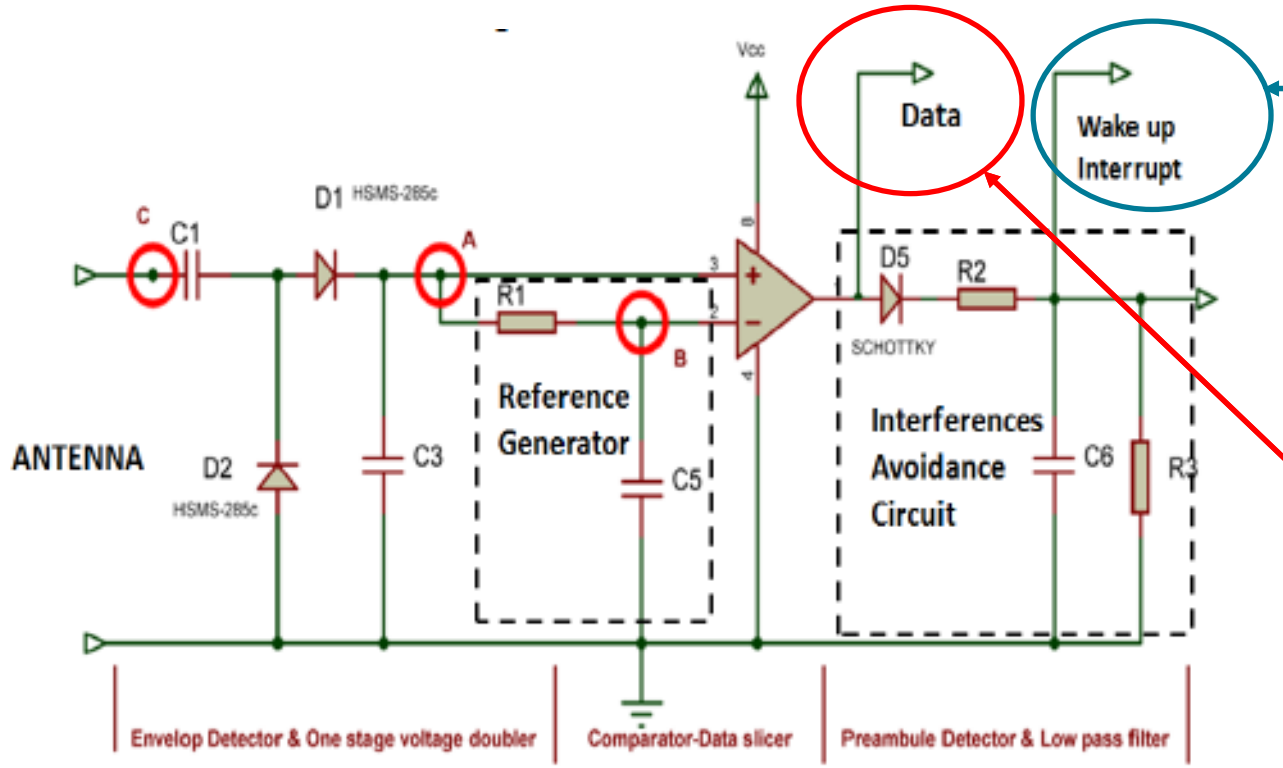




- $E_{IDLE,BLU} \gg E_{IDLE,WUR}$
- Trade-off: small additional cost, higher latency



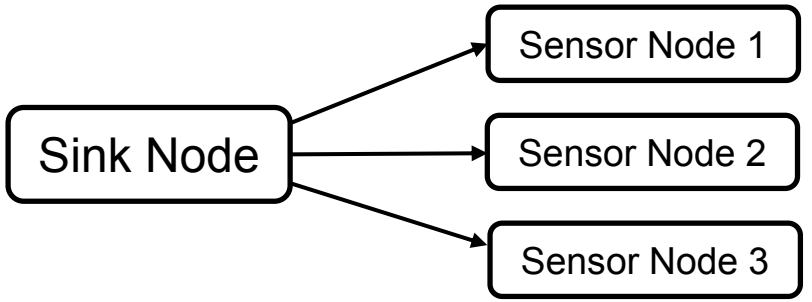
Wake-up Radio Architecture



WUR has two outputs:

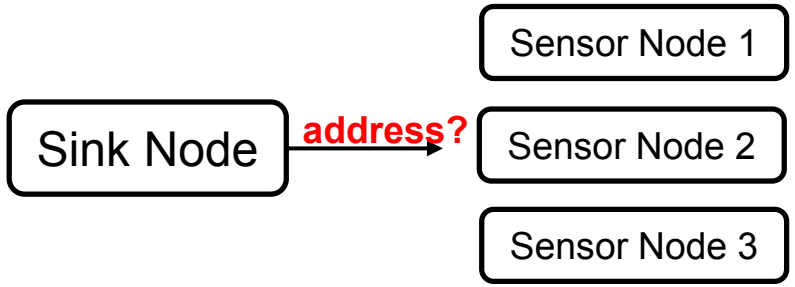
-TRIGGER:

Non-addressing mode:



-DATA:

Addressing mode:



Magno, M.; Benini, L., "An ultra low power high sensitivity wake-up radio receiver with addressing capability," *Proc. IEEE WiMob Conf.* 2014

What parameters are we interested in?

- Range/sensitivity
- Packet loss: number of lost packets during transmission

➢ **TRIGGER OUTPUT:**

- Success rate for trigger (SRT): $SRT = \frac{number\ of\ received\ triggers}{total\ \ number\ of\ packets} * 100\%$

➢ **DATA OUTPUT:**

- Success rate for data transmission (SR): $SR = \frac{number\ of\ correct\ packets}{total\ \ number\ of\ packets} * 100\%$
- Data error rate (DER): $DER = \frac{number\ of\ wrong\ bits}{total\ number\ of\ bits} * 100\%$

What parameters are we interested in?

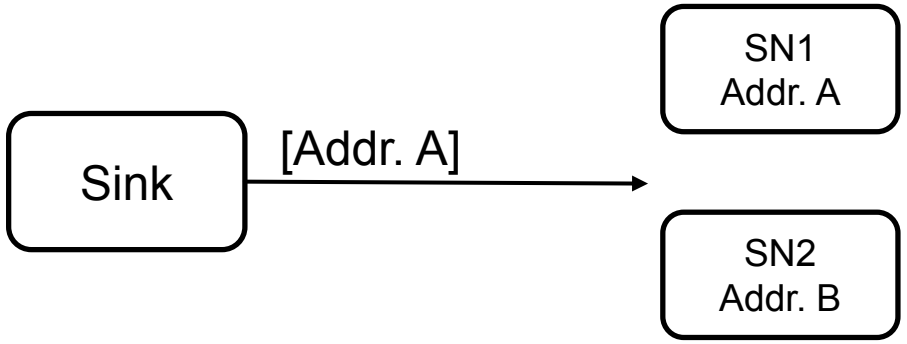
- False positives (FP):
  - Waking up when you don't need to

Energy LOSS!

- False negatives (FN):
  - Not waking up when you need to
  - No energy loss, SINK sends new request

Greater Latency

Ex:



Sensor Node 1 (Addr. A):

- if [DataReceived]==[Addr A]:

True Positive

- Else

< False Negative>

Sensor Node 2 (Addr. B):

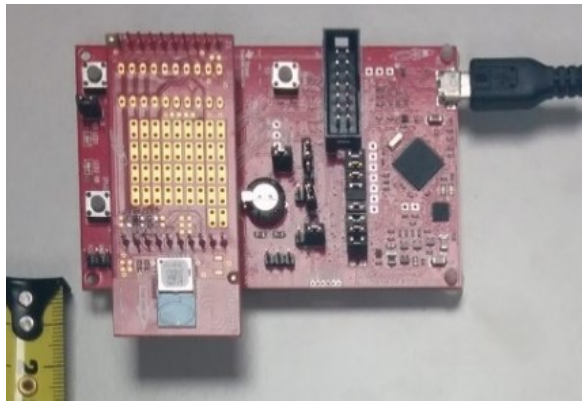
- if [DataReceived]==[Addr A]:

True Negative

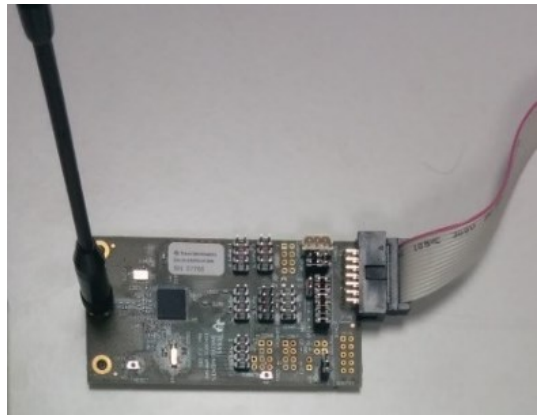
- if [DataReceived]==[Addr B]:

< False Positive>

Experimental Set-Up: Sink Nodes



- Sink Node with low gain antenna (MSP430FR5969+CC110L)
  - 868 MHz
  - 1.2 Kbits/s
  - +10 dBm
  - OOK modulation
  - On chip antenna (0dBi)

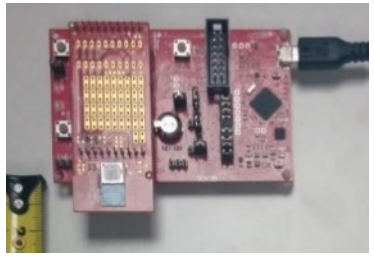


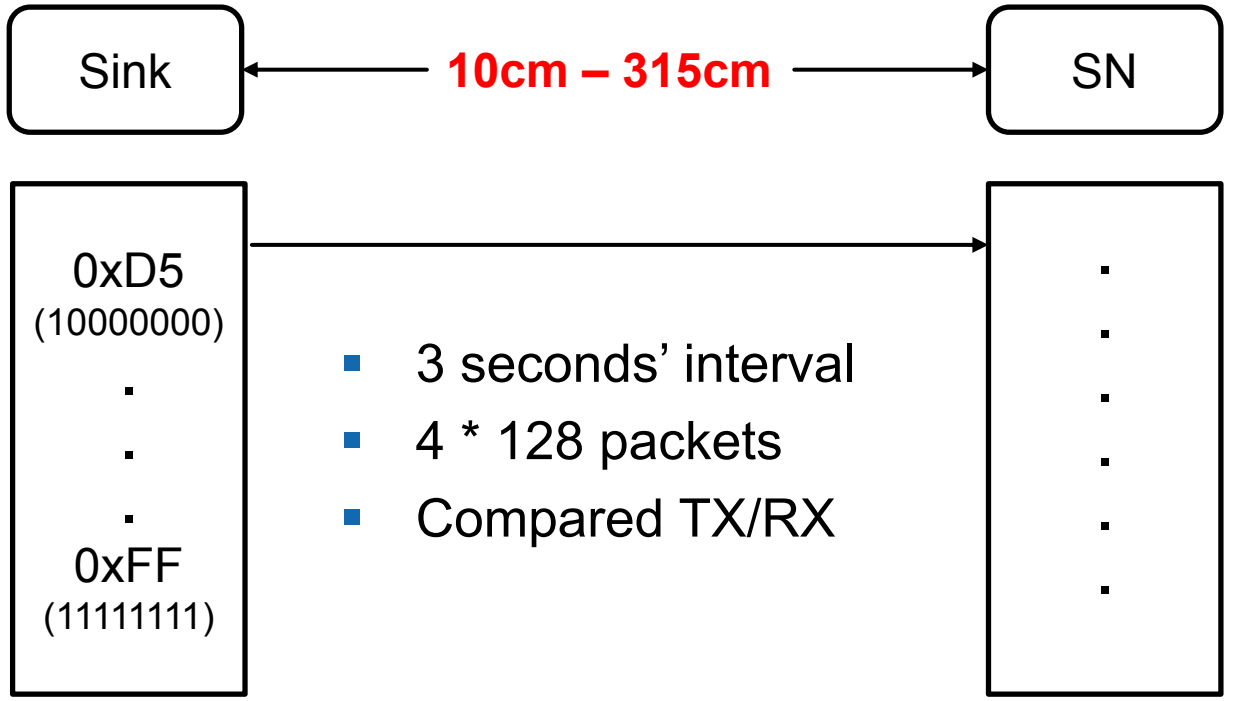
- Sink Node with low gain antenna (EM430F6137RF900)
  - 868 MHz
  - 1.2 Kbits/s
  - +10 dBm
  - OOK modulation
  - Off chip antenna (2dBi)

Experimental set-up: Wearable Antennas (Sensor Node)

	Fxp280	Fxp14	Molex
Frequency (MHz)	863 to 870	850	824 to 896
Return Loss (dB)	-20	-7	-7.7
Efficiency (%)	40	52	67
Gain (dBi)	1.5	2	2.2

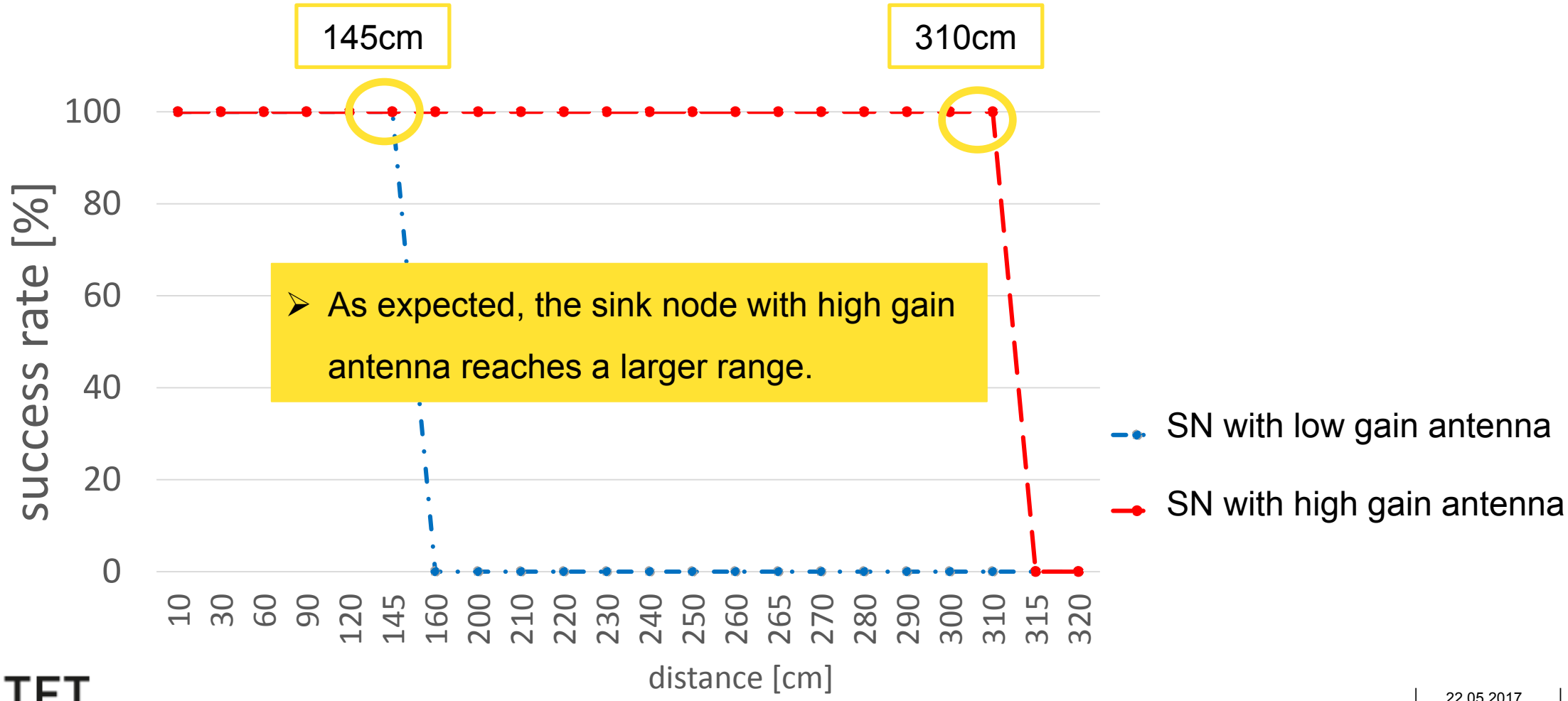
Initial Characterization





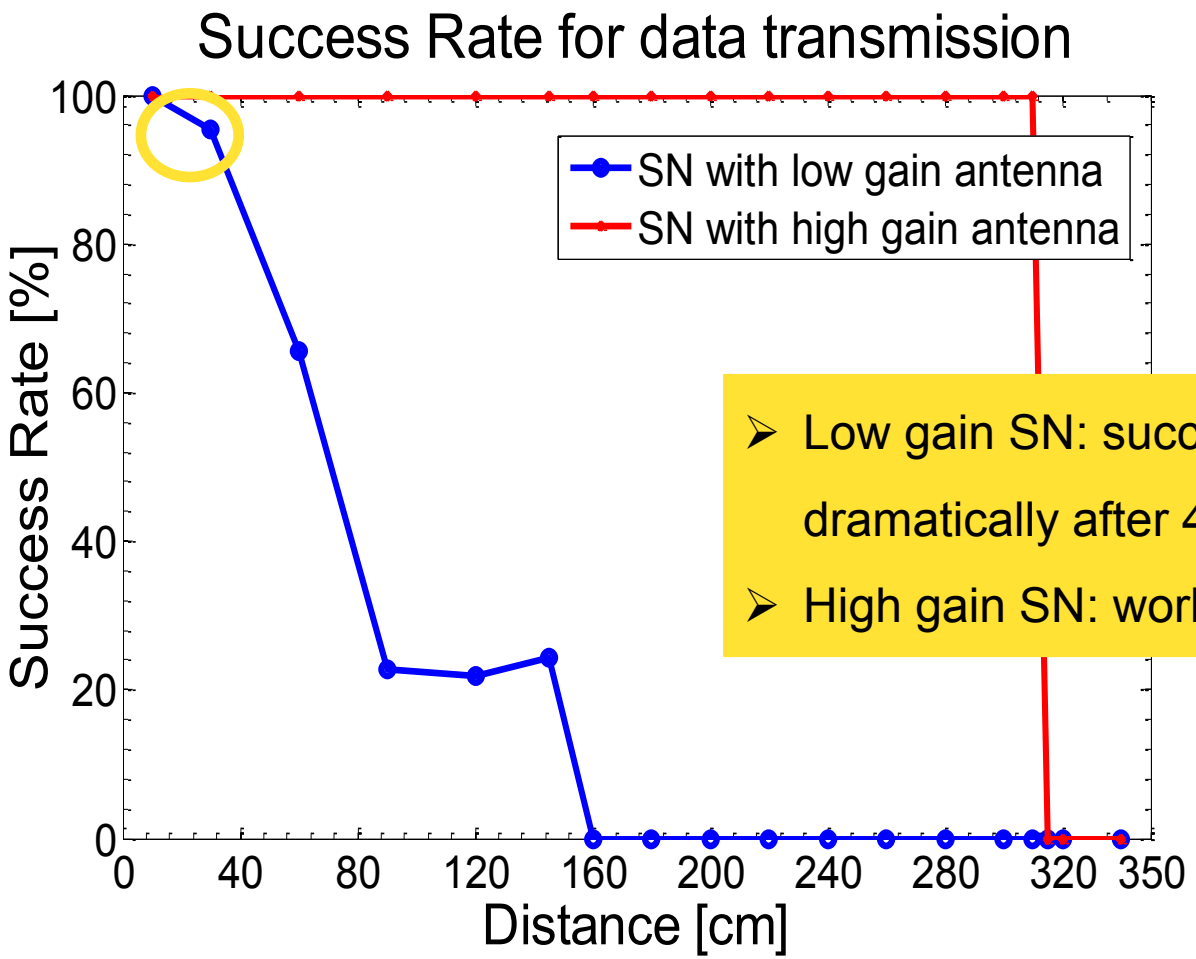
[Sink Node] Vs [Sensor Node]

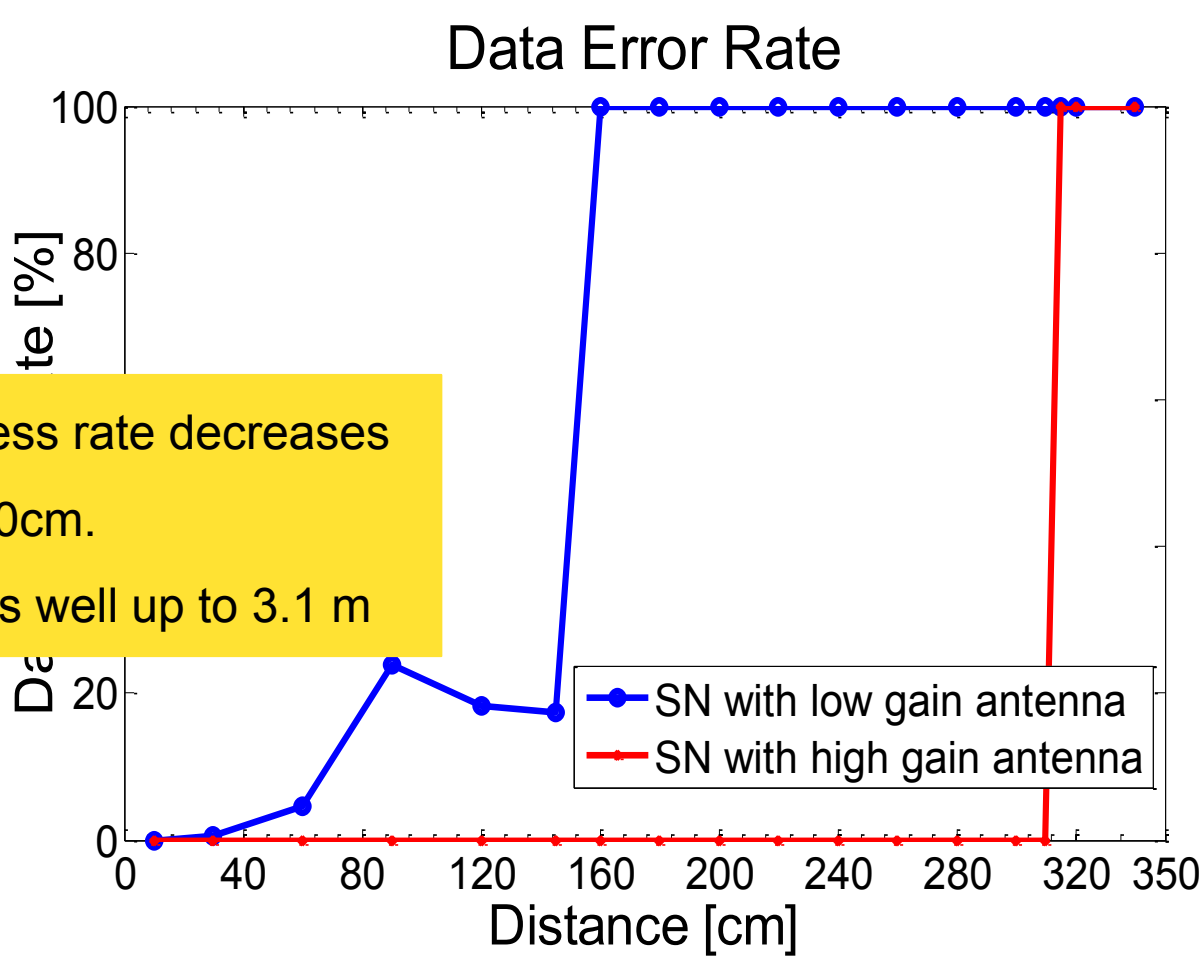
Experimental Result for Trigger Output



- As expected, the sink node with high gain antenna reaches a larger range.

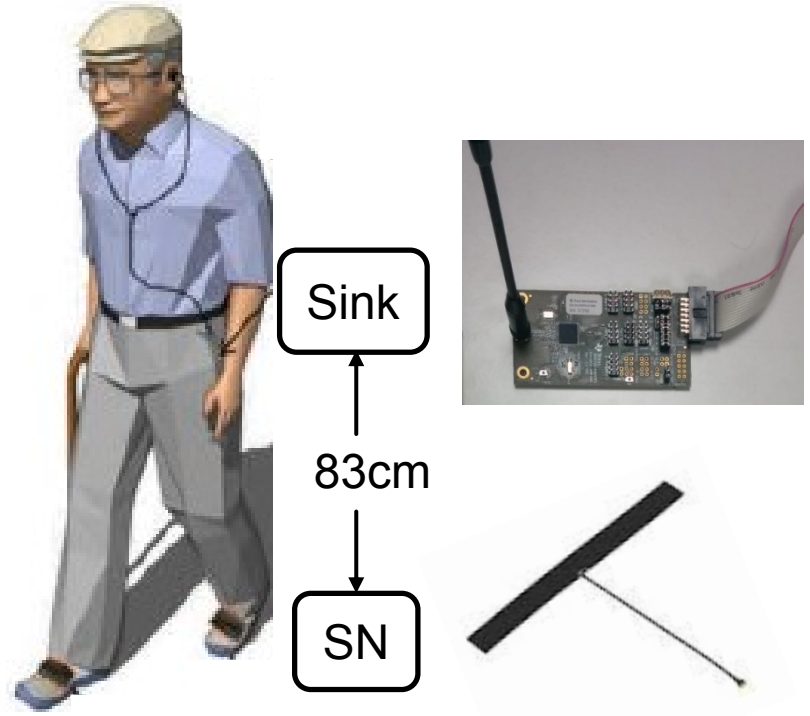
Experimental Result for Data Output





- Low gain SN: success rate decreases dramatically after 40cm.
- High gain SN: works well up to 3.1 m

Application scenario with CC430F6137



- Payload A: 10101010 ---address 1
- Payload B: 11010101 ---address 2

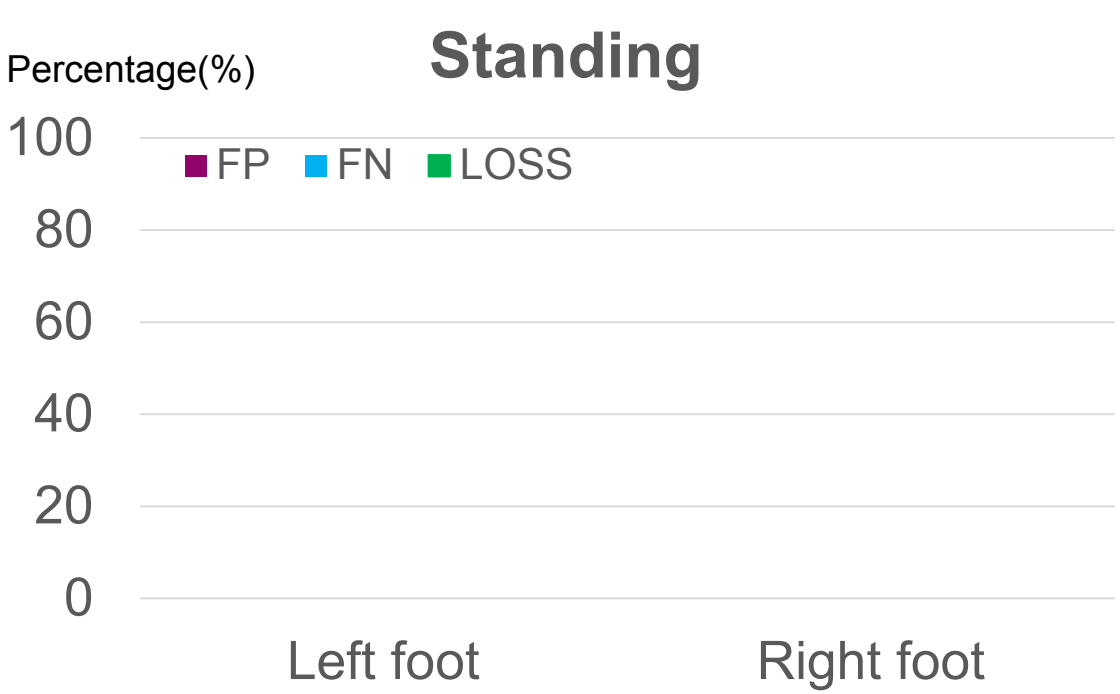
Distinguish between two feet

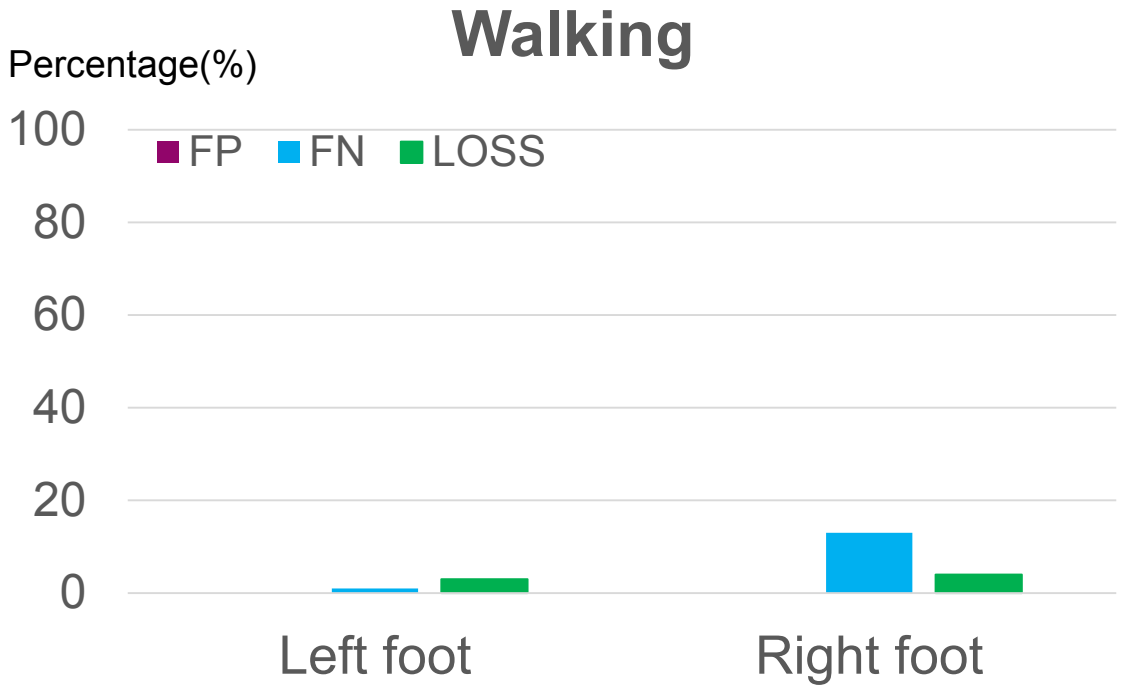
- 100 packets, Molex, +10dBm, 868MHz, 1.2Kbits/s, OOK
- ***Two scenario: standing, walking***

Without addressing

	FP	FN
Left foot	50%	~0%
Right foot	50%	~0%

Experimental Result in addressing mode





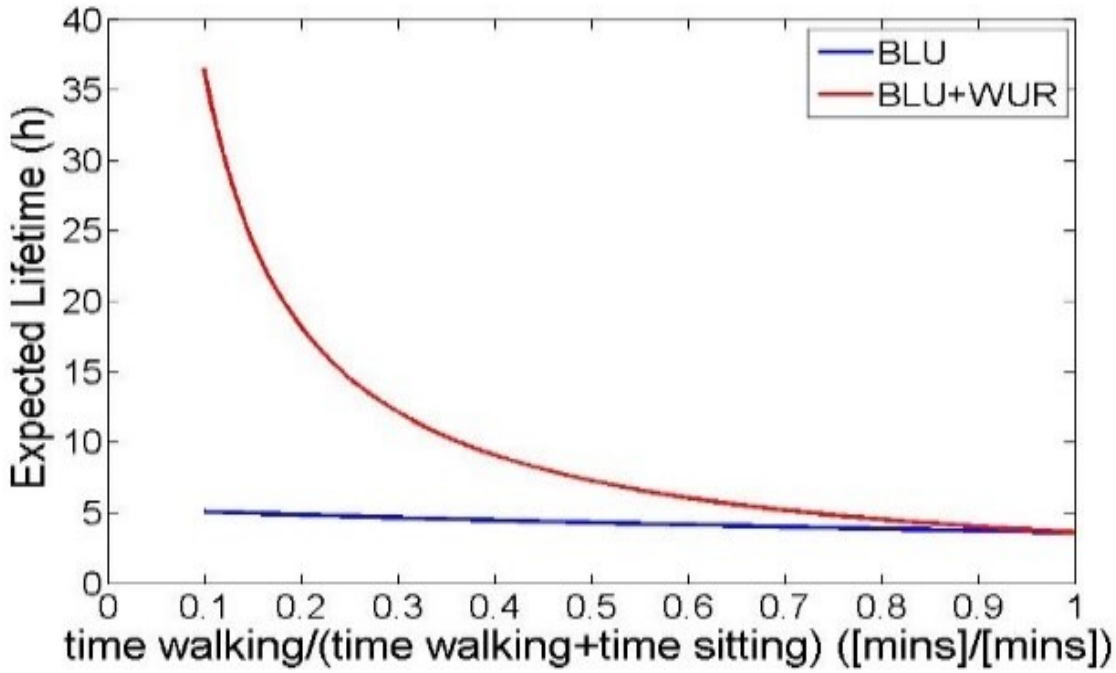
PERFECT ☺

Lifetime Extension

	Bluetooth	Bluetooth +WUR
Idle power	92.4mW	400nW
Tx Power	135.3mW	135.3mW

Wake-up Time	3 seconds
Walking Period	30 minutes
Sitting Period	0-30 minutes
Battery	150 mAh

$$E_{cycle} = P_{idle} * t_{idle} + P_{active} * t_{active}$$



$$Lifetime = \frac{C_{batt} * V_{cc}}{E_{\text{cycle}}} * (t_{idle} + t_{active})$$

Summary

- The WUR is suitable for BAN

- It decreases the total energy consumption, therefore extend the lifetime of BAN

- But it has some trade-offs with performance/cost :
  - Sink node's antenna / transmit power
  - Reduced range, FNs, packet loss

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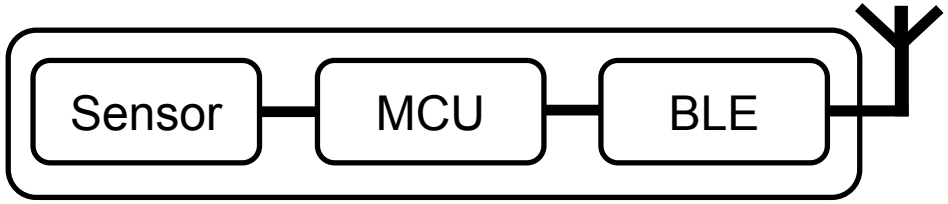
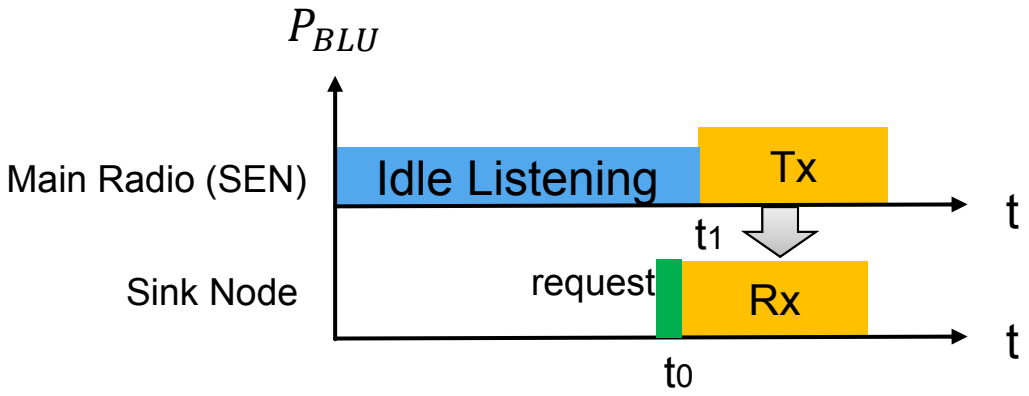
Thank you for your attention!

System Architecture

- Bluetooth(BLU):





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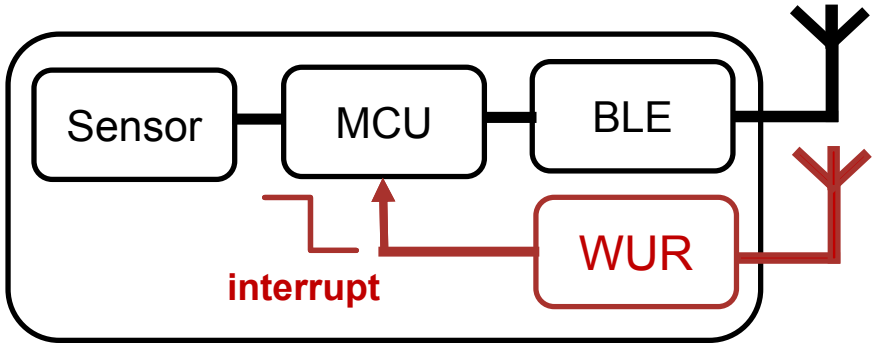

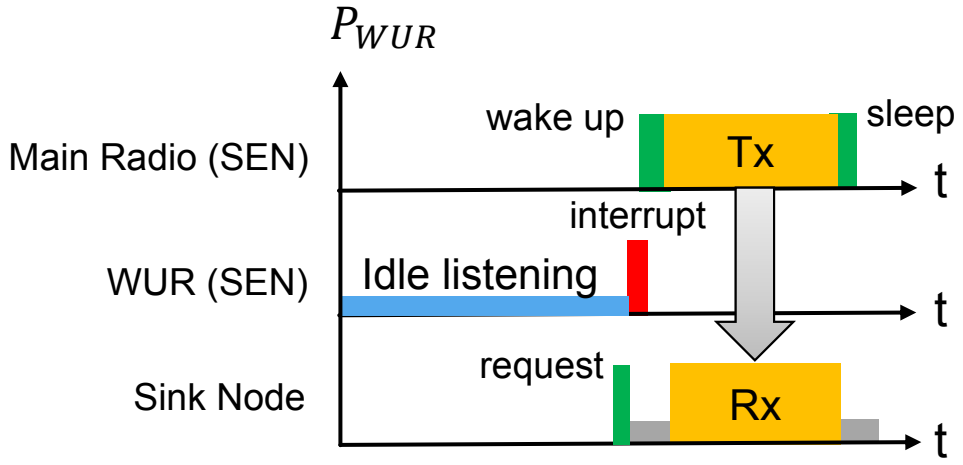

Wake-up Radio Architecture

Radio Frequency Wake-up radio
- Fully passive circuits
  - ✓ 0 power consumption
  - x limited range/sensitivity: -25 dBm
- Semi-active circuits
- Fully active circuits
  - ✓ High sensitivity: -90dBm
  - x Non-negligible power consumption: > 10's μW

Trade-off between power consumption and sensitivity

Our WURx High sensitivity (up to -42dBm), low power consumption (400 nW), fast reactivity (8us) , with addressing capability.☺