Wireless Communication with LoRa for the IoT

THE UNIVERSITY OF WESTERN AUSTRALIA

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Guest Lecture

CITS5506 Internet of Things

Three Things

1. Wireless Communications
2. LoRa
3. Link Quality Experiments

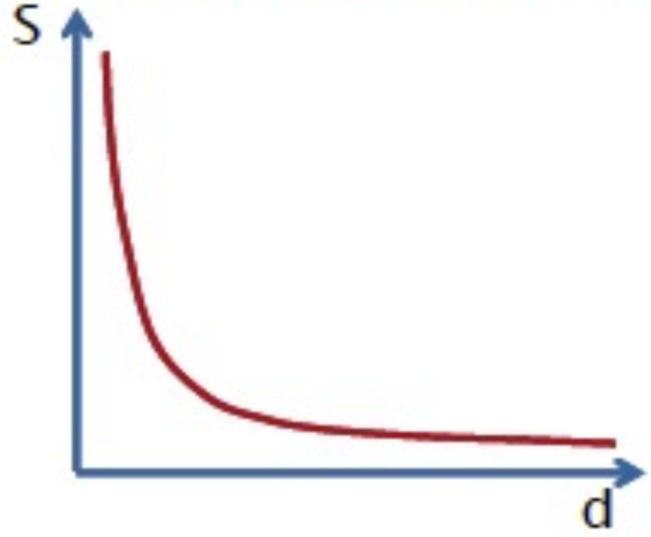
Wireless Communications

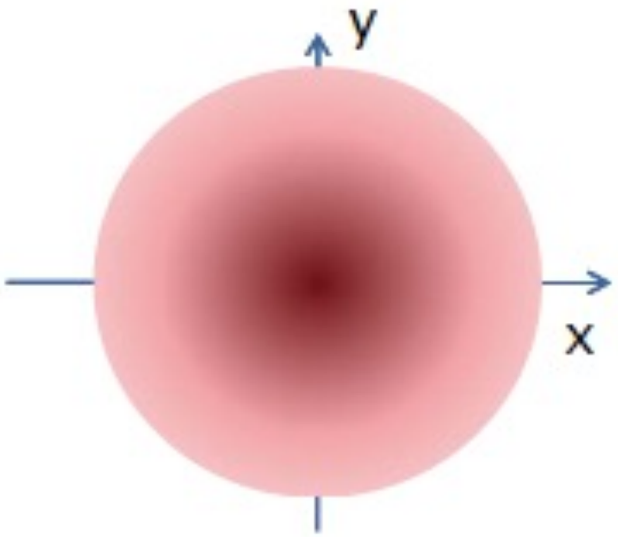
Wireless Networks

- No cables to connect the network
- Communication uses radio waves
- Many technologies from WiFi to bespoke radios and protocols

Signal propagation (in theory)

- Signal decreases with $1/d^2$





Signal Propagation in Practice

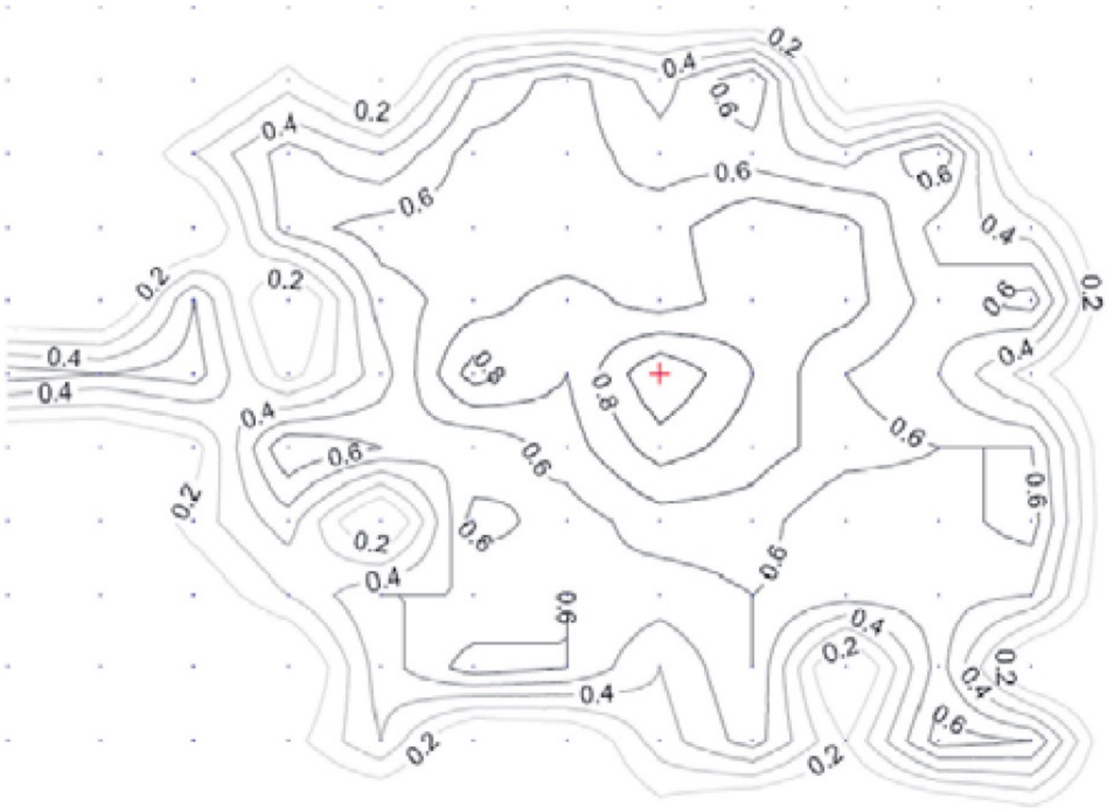


Fig. 4. Contour of PRR from a central node: anisotropy of link quality [Ganesan et al. 2002].

Radio Link Quality Estimation in Wireless Sensor Networks: A Survey, TOSN 8(4) 2012 DOI 10.1145/2240116.2240123

The Grey Zone

Packet reception has a **transitional (grey) zone** where packet reception is hard to predict

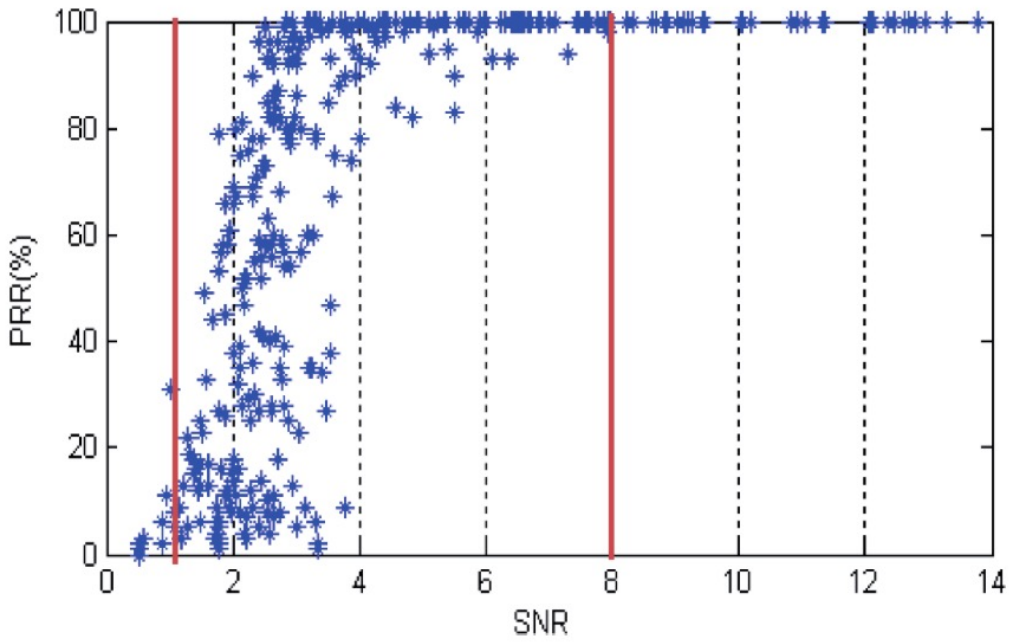
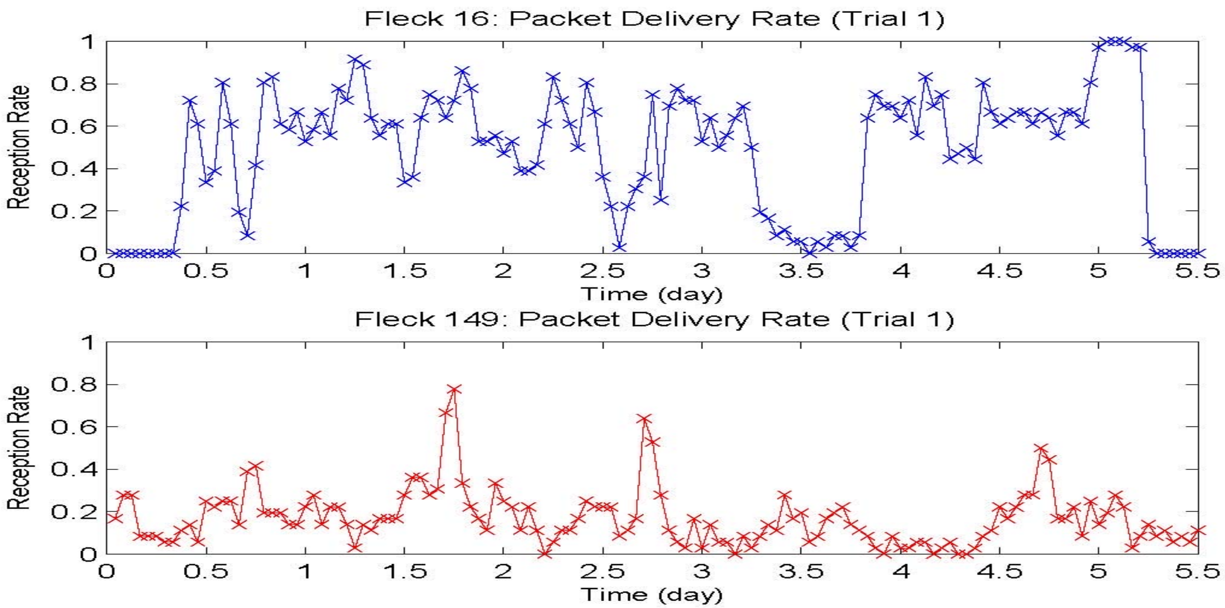


Fig. 6. The PRR/SNR curve. For *SNR* greater than 8 dBm, the *PRR* is equal to 100%, and for *SNR* less than 1 dBm, the *PRR* is less than 25%. In between, a small variation in the *SNR* can cause a big difference in the *PRR*; links are typically in the transitional region. Outdoor environment, using TelosB sensor motes and −25 dBm as output power (using the RadiaLE testbed [Baccour et al. 2011]).

Radio Link Quality Estimation in Wireless Sensor Networks: A Survey, TOSN 8(4) 2012

Time varying link quality

Jingbo Sun PhD 2009



- Wireless links are dynamic and lossy
  - Time
  - Space
- Energy is limited for communication

Communication Link Characteristics

1. Path Loss
2. Noise: probabilistic packet reception
3. Time varying link quality
4. Asymmetric links
5. Packet Collisions
6. Limited communication range (hidden terminal problem)

Link Budget

- A simple link budget equation:

Received Power (dBm) =

Transmit Power (dBm) + Gains (dB) − Losses (dB)

- Note that decibels are logarithmic measurements, so adding decibels is equivalent to multiplying the actual numeric ratios.

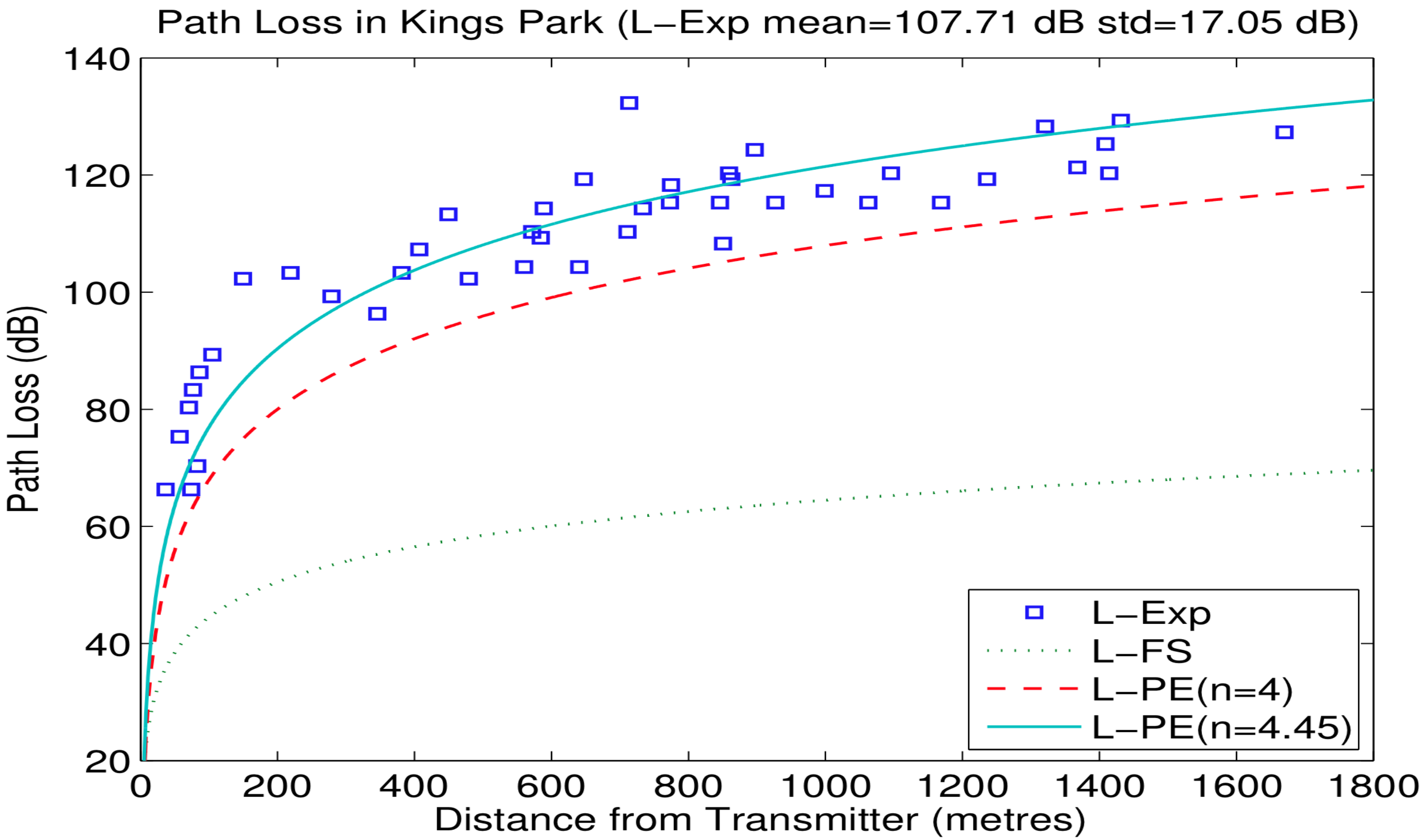
Plane Earth Path Loss Model

$$L_{PE}(dB) = 10n\log_{10}(d) - 20\log_{10}(h_T) - 20\log_{10}(h_R)$$

n = 4 standard, n>4 foliage or buildings
d = distance in meters
h = height of transmitter and receiver antennas

LPE is independent of frequency

Bushland LPE Model (n=4.45)



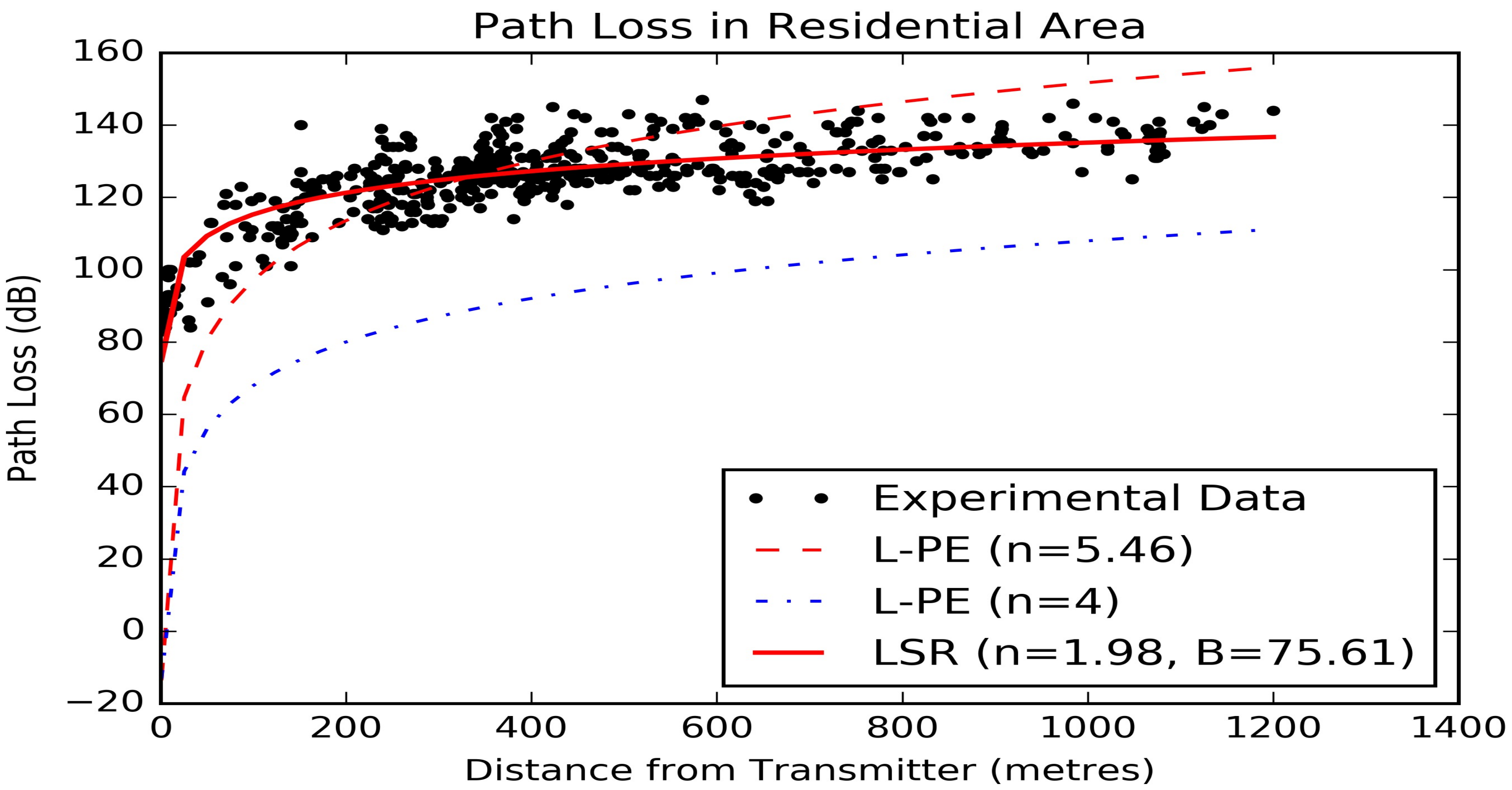
Long-range wireless sensor networks with transmit-only nodes and software-defined receivers
Wireless Communications and Mobile Computing 2013, 10.1002/wcm.1198

Log distance model

- Constants B and n and
  reference distance d0 = 1 meter

$$L_{log-distance}(dB) = B + 10n\ log_{10}(\frac{d}{d_0})$$

LoRa tx path loss observed



Link Quality Metrics (1) PRR

How good is my wireless channel?

Packet Reception Rate = Rx/Tx

PRR Proportion of transmitted packets that are correctly received
Bit Error Rate (BER) Proportion of transmitted bits that are corrupted

++ Application-relevant result
-- Does not explain **why** the channel is good or not
++ Low BER can be addressed with error correcting codes

Link Quality Metrics (2) RSSI

Received Signal Strength Indicator

Defn Physical layer measurement of the signal quality at the receiver

++ Direct measure of channel quality

-- Can be hardware and vendor specific

-- Weakly correlated with PPR, so usually used with other metrics

Link Quality Metrics (3) SNR

Signal to Noise Ratio (not actually a ratio)

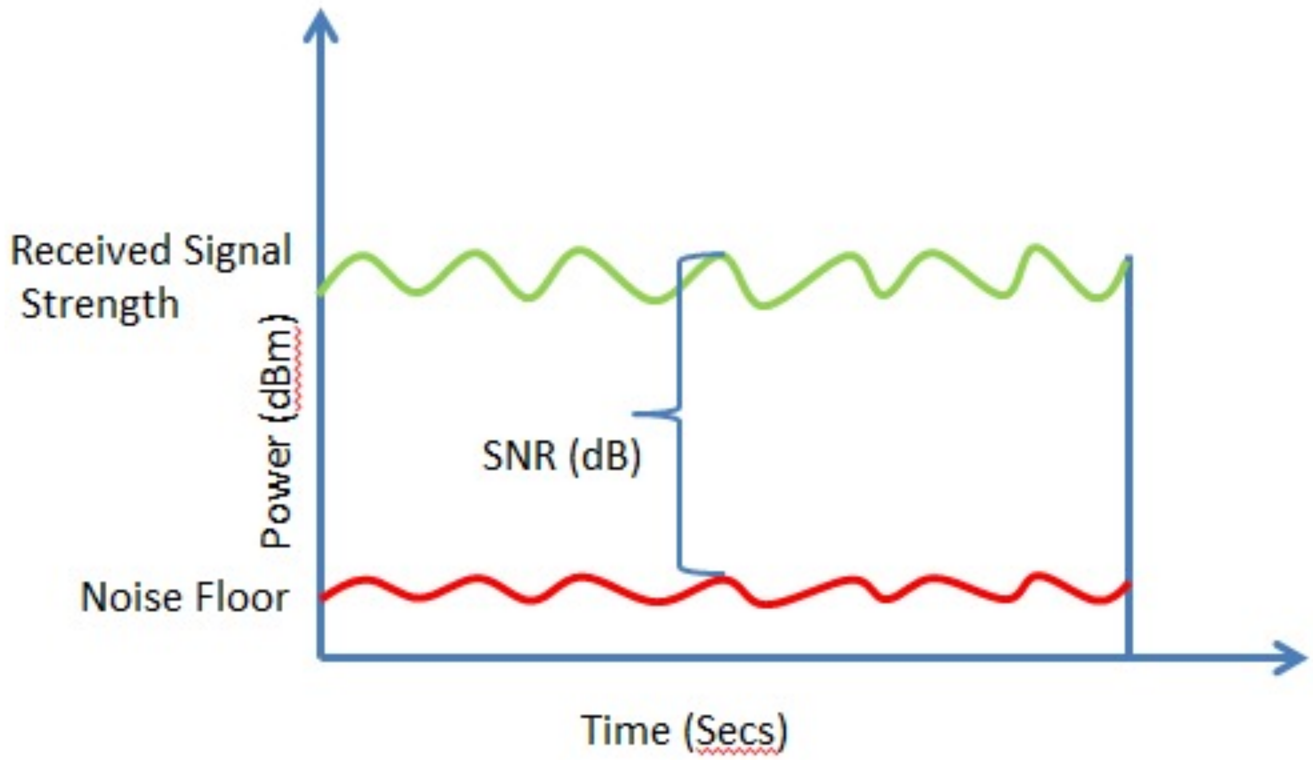
Defn Difference in decibels between the
received signal and
background noise (noise floor)

++ Direct measure of channel quality

-- Weakly correlated with PPR, so usually used with other metrics

-- Quantifies how good/bad the channel is

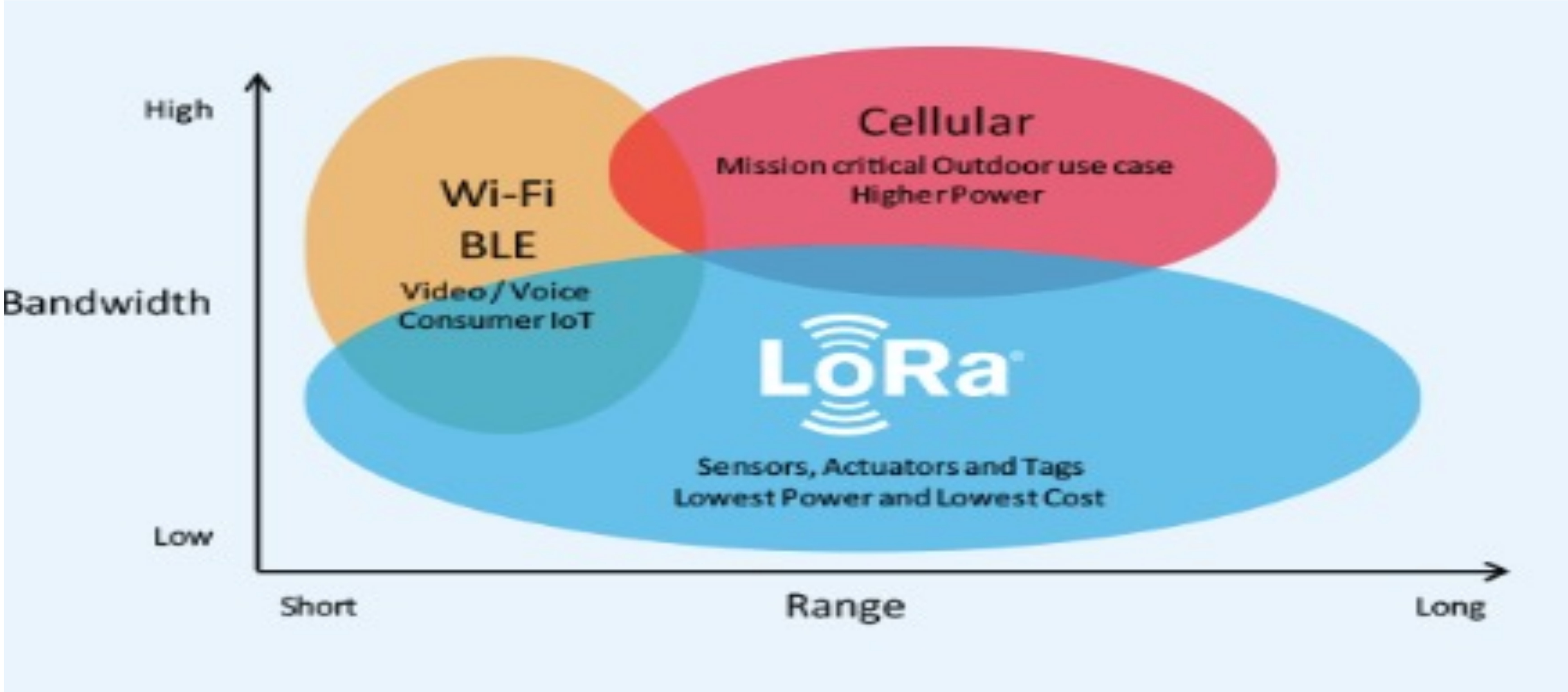
Signal to Noise Ratio



Source: https://documentation.meraki.com/MR/WiFi_Basics_and_Best_Practices

LoRa

www.semtech.com/lora/why-lora



LoRa

- Spreads the signal over a wider frequency band – so resilient to jamming and interference
- LoRa proprietory PHY layer from Semtech
- You can fine tune performance by selecting from over 6000 parameter settings

Which LoRa

- LoRa Physical Layer
  - Patented Technology by Semtech (2012)
  - Settable parameters to trade throughput with range
- LoRa MAC Layer = LoRaWAN
  - LoRa Alliance lora-alliance.org
  - 500 companies, Standardisation of LoraWAN
  - Open source
  - Eg. The Things Network: globally distributed, crowd sourced network

LoRa Parameters [source: Cattani et al]

Setting	Values	Effects
Bandwidth	$125 \ldots 500$ kHz	Higher bandwidths allow for transmitting packets at higher data rates (1 kHz = 1 kcps), but reduce receiver sensitivity and communication range.
Spreading Factor	$2^6 \ldots 2^{12} \frac{\text{chips}}{\text{symbol}}$	Bigger spreading factors increase the signal-to-noise ratio and hence radio sensitivity, augmenting the communication range at the cost of longer packets and hence a higher energy expenditure.
Coding Rate	$4/5 \ldots 4/8$	Larger coding rates increase the resilience to interference bursts and decoding errors at the cost of longer packets and a higher energy expenditure.
Transmission Power	$-4 \ldots 20$ dBm	Higher transmission powers reduce the signal-to-noise ratio at the cost of an increase in the energy consumption of the transmitter.

LoRa Carrier Frequencies

- 137 MHz, 433, 868 and 915 MHz (depends on country)
- Country regulations define useable channels
- For Australia: 433 and 915

Transmission Power

- HW dependent, but typically -2 to 20 dBm
- Increasing Tx power increases energy use
- Increasing Tx power also increases range
- For Tx power > 17 dBM, hardware limitations and legal regulations limit duty cycle (<1%)

Bandwidth

- LoRa bandwidth can be set to 125 kHz, 250 kHz or 500 kHz
- Also allowed 62.5 and others
- Higher bandwidth gives lower receiver sensitivity (so weaker pkt signal can be received)
- Higher bandwidth increases the data rate
- So increasing bandwidth reduces time on air and energy use

```
# Receiver sensitivity floor depends on bandwidth
 if(BWidth==125):
   RSF={6:-121,7:-124,8:-127,9:-130,10:-133,11:-135,12:-137}
 elif(BWidth==250):
   RSF={6:-118,7:-122,8:-125,9:-128,10:-130,11:-132,12:-135}
 else: #500
   RSF={6:-111,7:-116,8:-119,9:-122,10:-125,11:-128,12:-129}
```

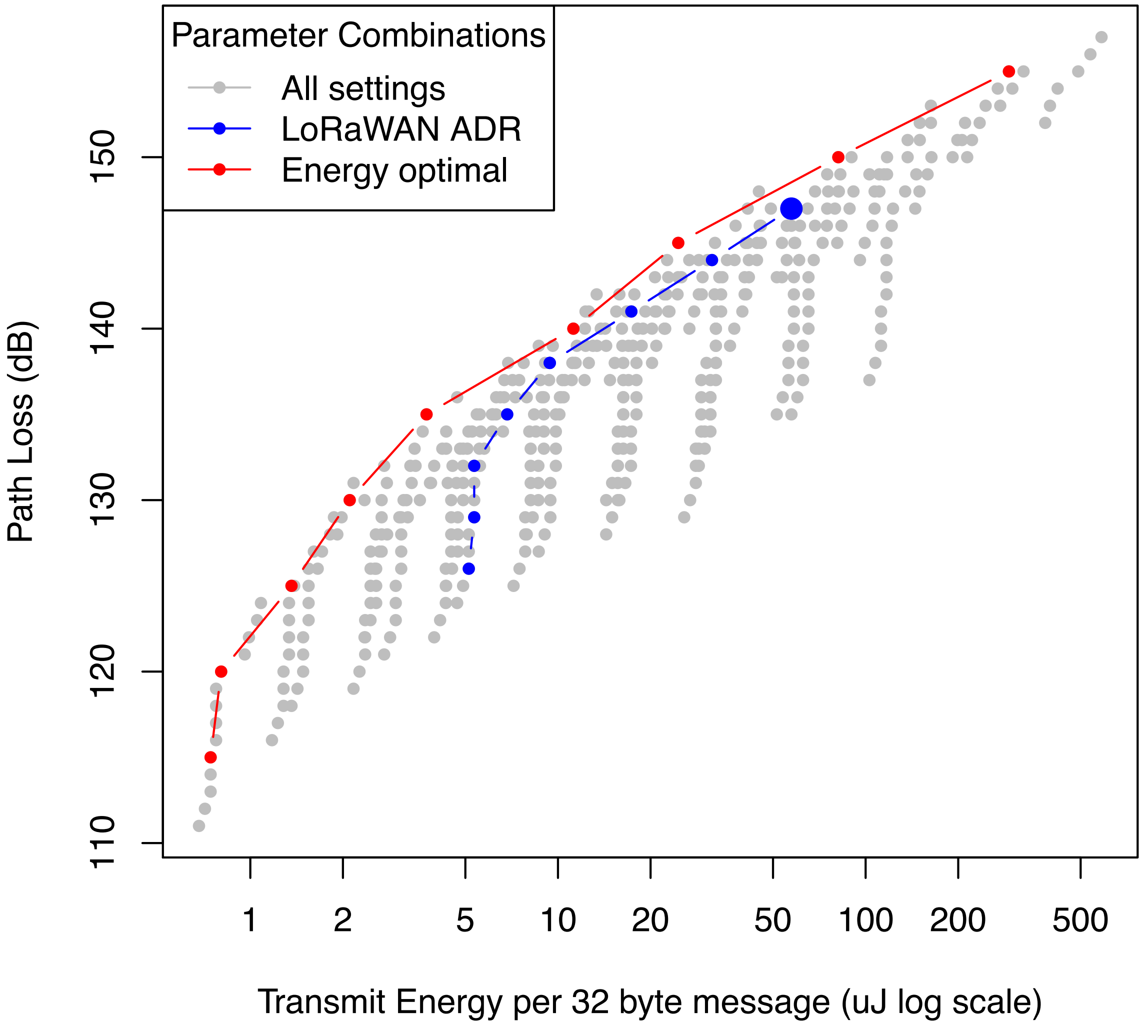
Coding Rate

- Inbuilt Forward Error Correction
- For protection from bursts of interference
- Adds from 1..4 redundant bits
- Called SF 4/5, 4/6, 4/7 and 4/8
- Increasing CR provides protection against burst interference
- Increased CR increases the message length, so time on air and so energy use

Spreading Factor

- Spreading factor values from 6 to 12
- Each symbol has 2^{SF} chirps
- Bit rate depends on SF, BW and Coding rate
- Increase SF halves the tx rate, so increases (doubles) tx time and so energy use
- Channels with different SF are orthogonal, so can tx at the same time

LoRa Parameter Choices



LoRa Parameter Choice for Minimal Energy Usage, Real WSN 2018 DOI 10.1145/3277883.3277888

LoRa Parameter Choice for Minimal Energy Usage

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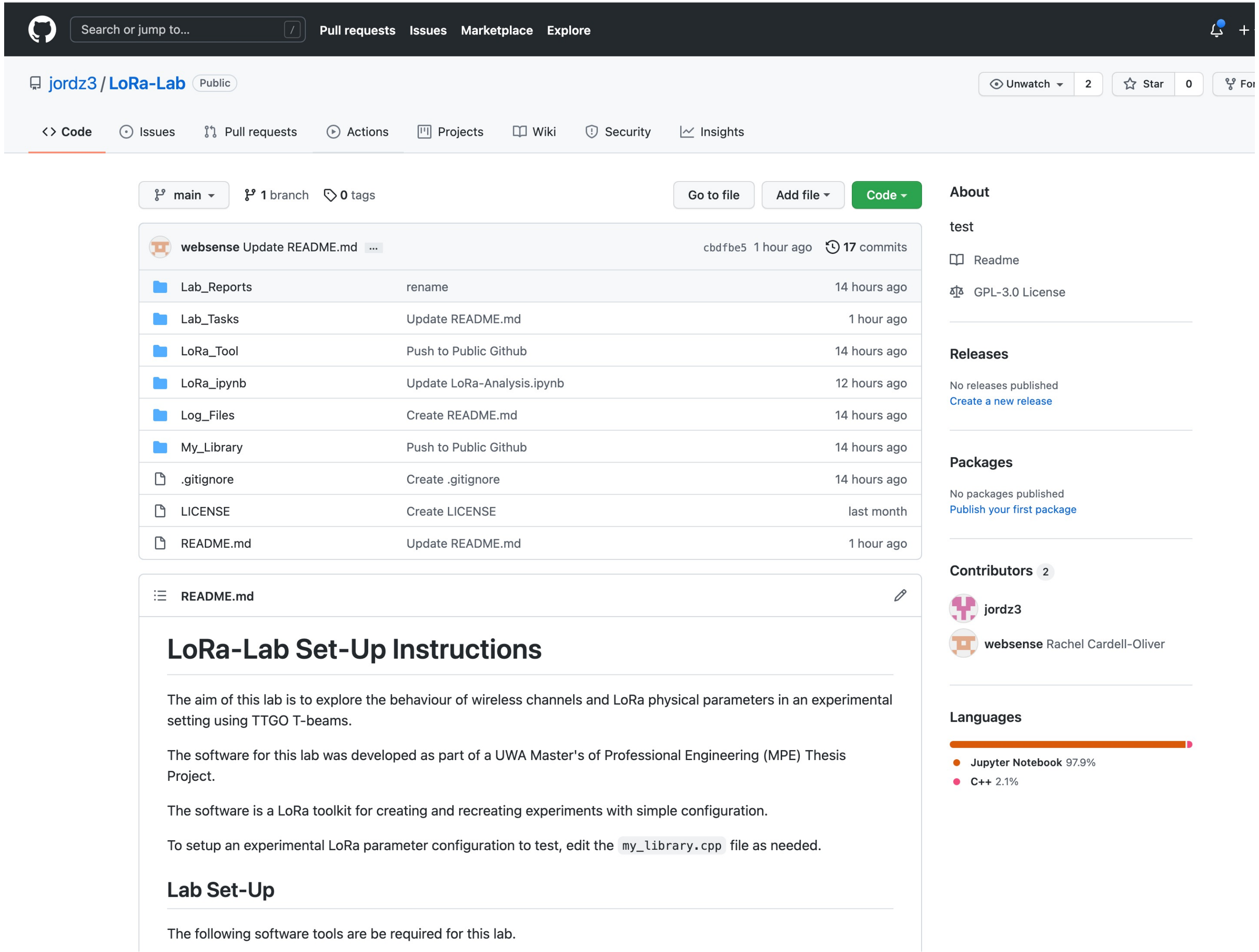
RealWSN, Shenzhen, China
November 2018

LoRa Parameter Choice for Minimal Energy Usage, Real WSN 2018 DOI 10.1145/3277883.3277888

Link Quality Experiments

Today’s Lab https://github.com/jordz3/LoRa-Lab

TODO slides from Jordan here



Summary

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