Wireless Communication with LoRa for the IoT

THE UNIVERSITY OF WESTERN AUSTRALIA

SEEK WISDOM

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Guest Lecture

CITS5506 Internet of Things

Three Things

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

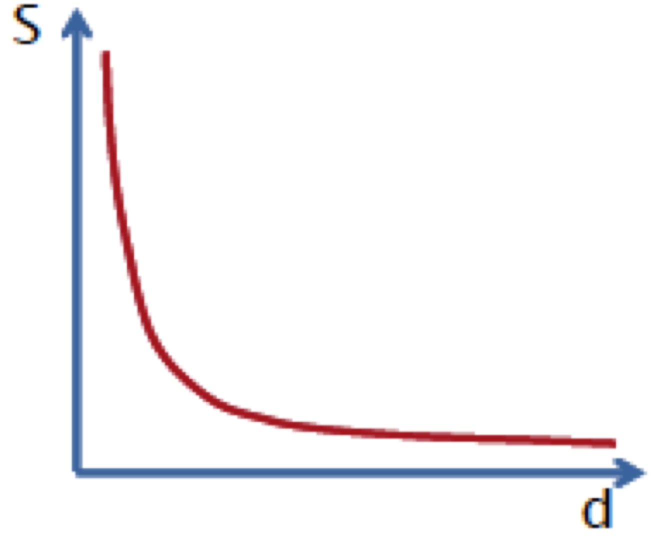
Wireless Communications

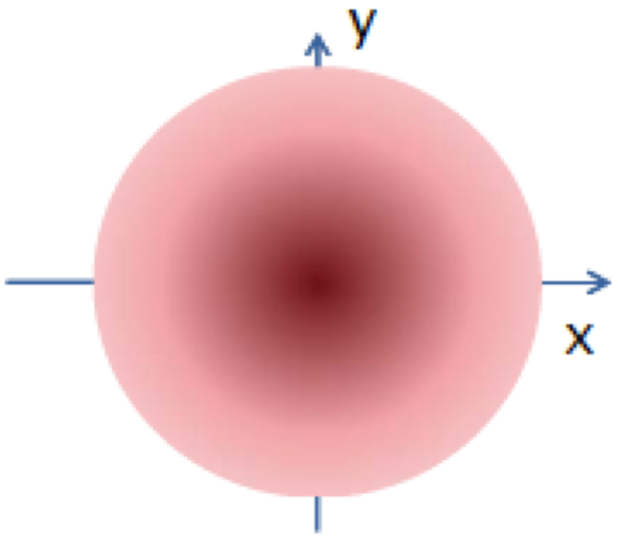
Wireless Networks

- 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

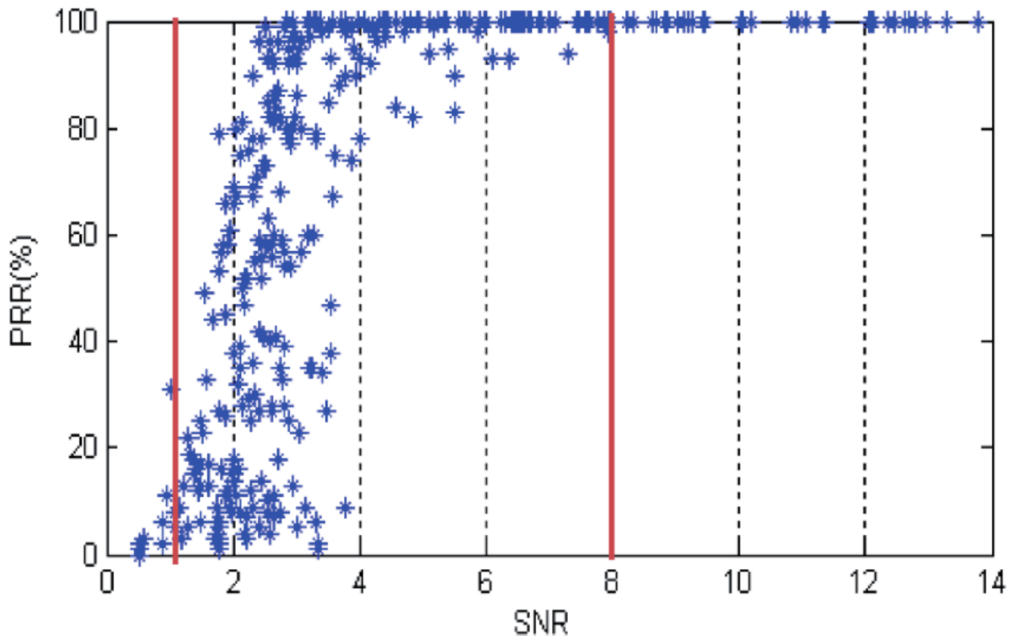
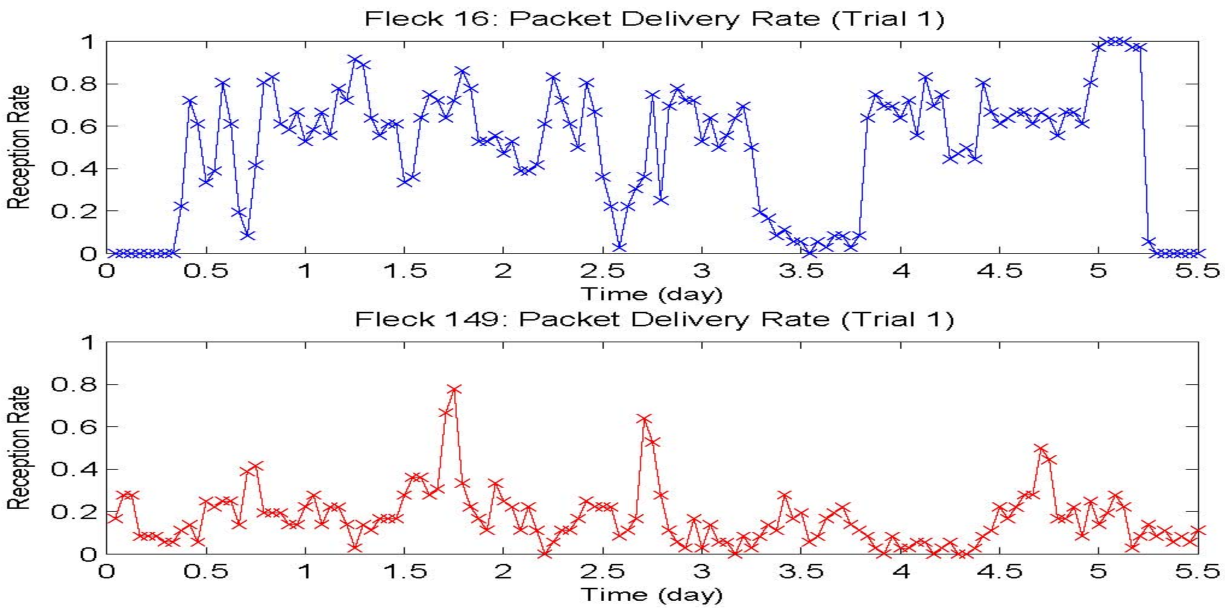


Fig. 6. The PRR/SNR curve. For *SNR* greater than 8 dBm, the *PRR* is equal to 100%, and for *SNR* less than 1 dBm, the *PRR* is less than 25%. In between, a small variation in the *SNR* can cause a big difference in the *PRR*; links are typically in the transitional region. Outdoor environment, using 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.

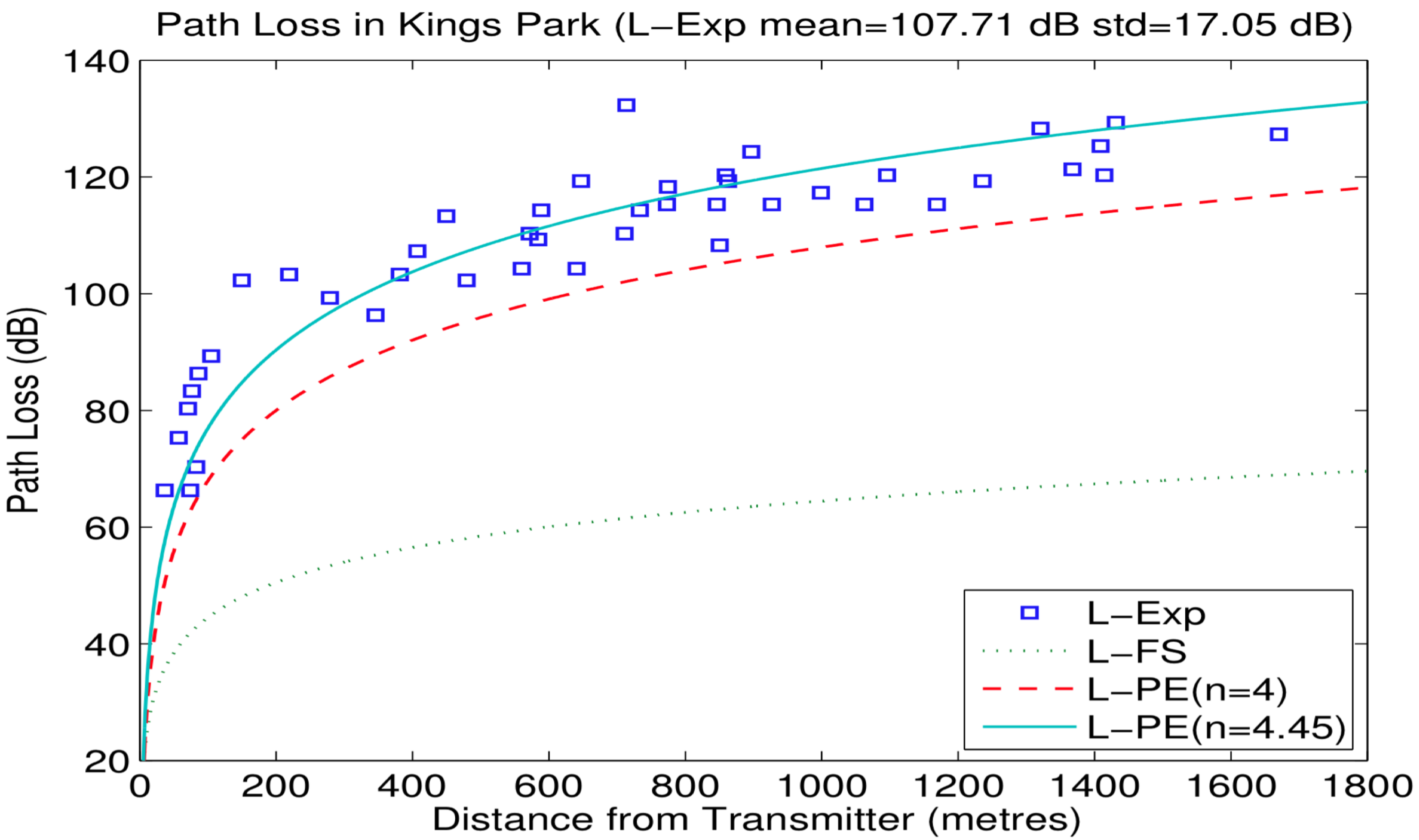
Plane Earth Path Loss Model

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

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)



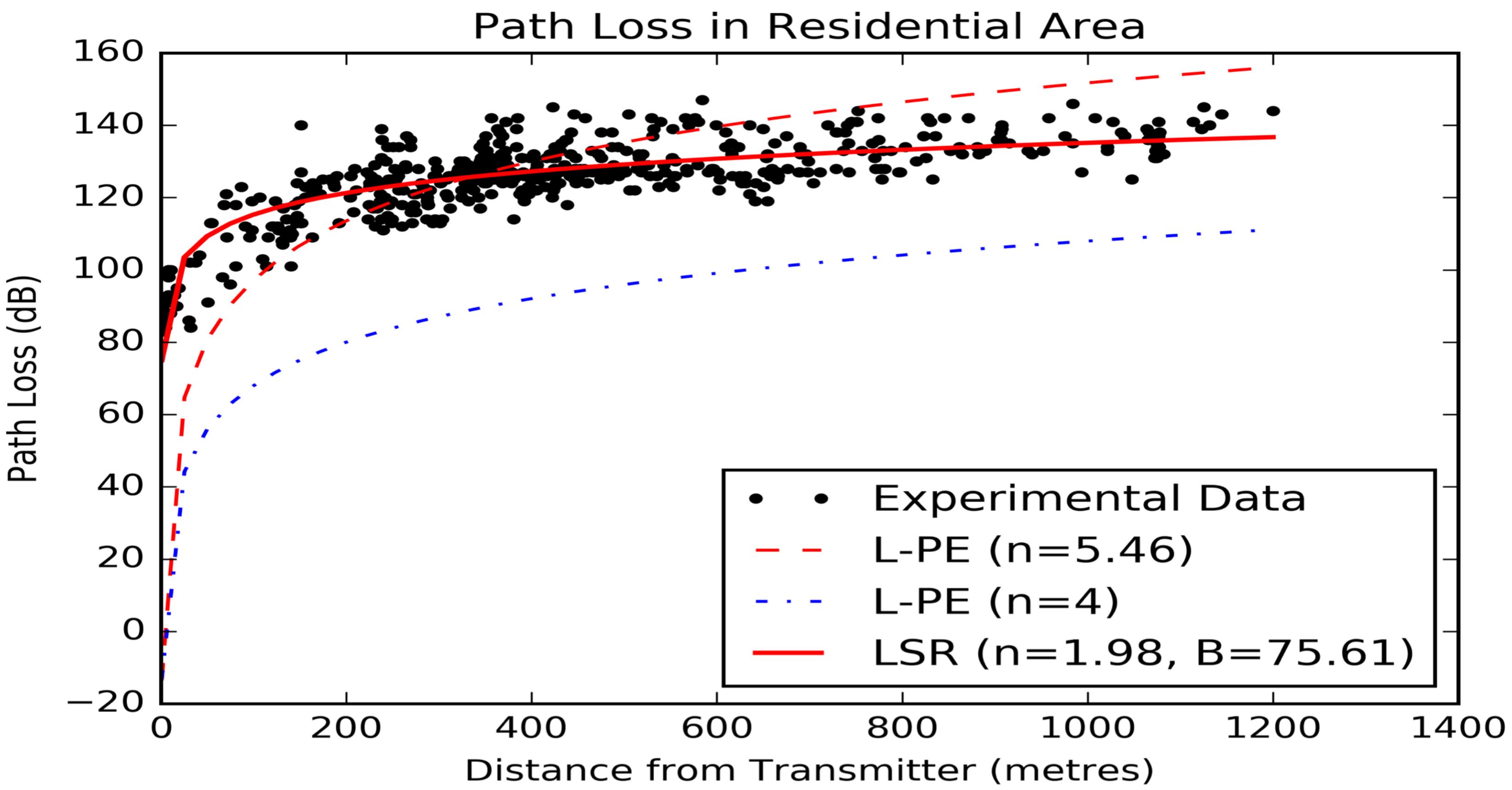
Long-range wireless sensor networks with transmit-only nodes and software-defined receivers
Wireless Communications and Mobile Computing 2013, 10.1002/wcm.1198

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)

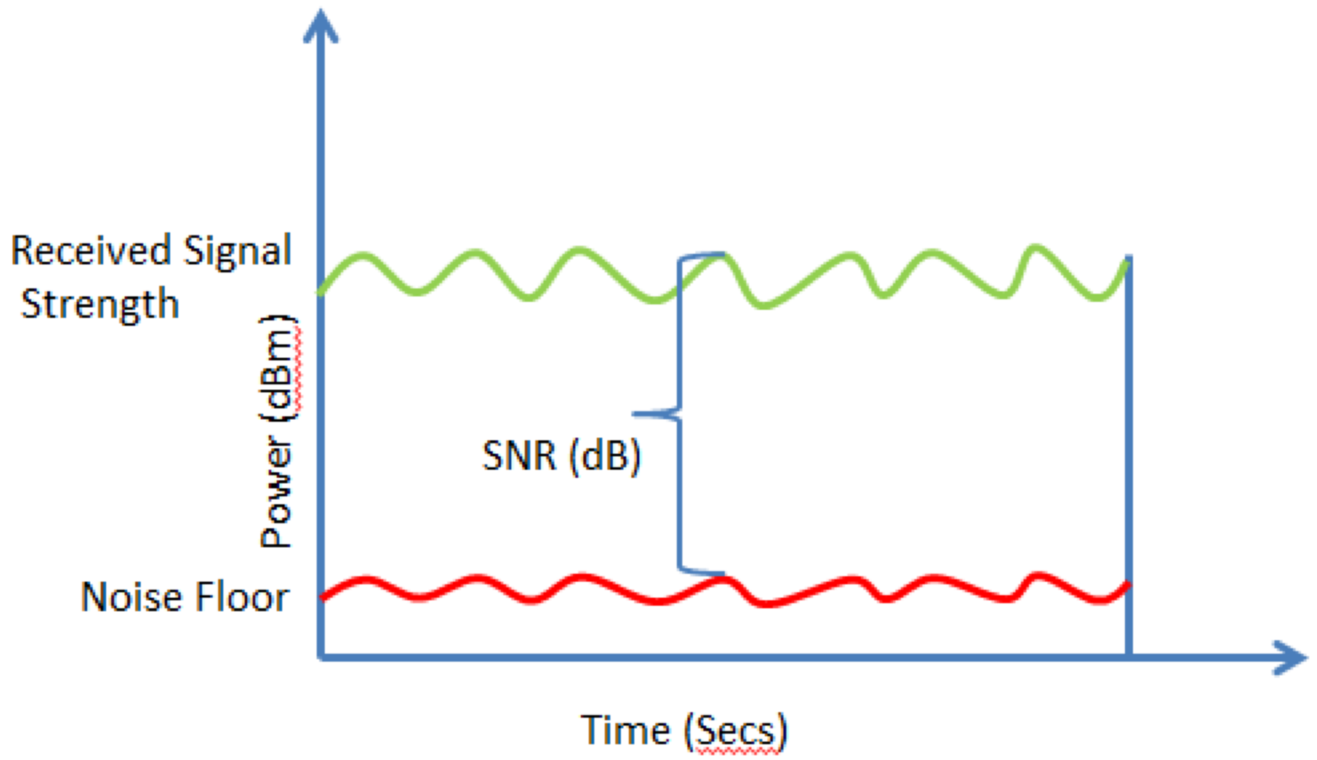
Defn Difference in decibels between the received signal and background noise (noise floor)

++ Direct measure of channel quality

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

-- Quantifies how good/bad the channel is

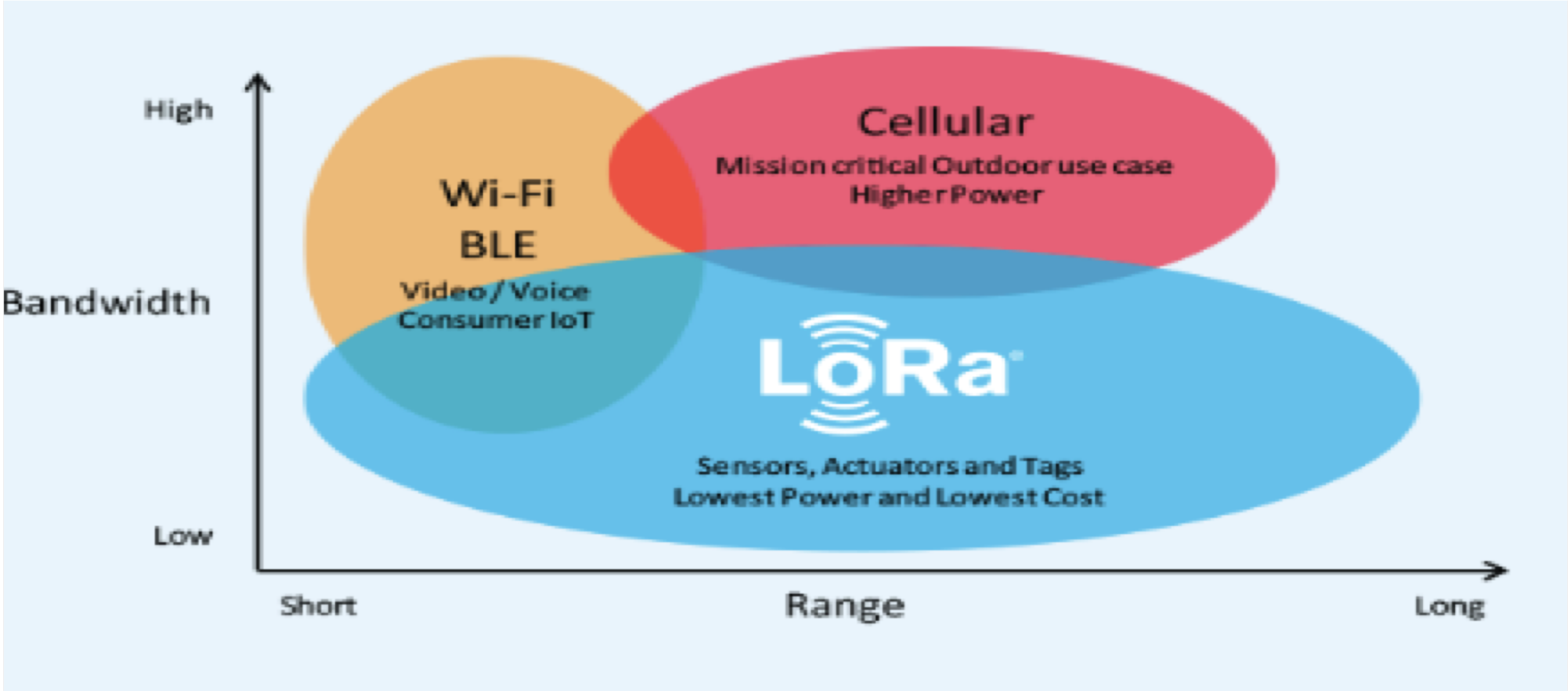
Signal to Noise Ratio



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}
```

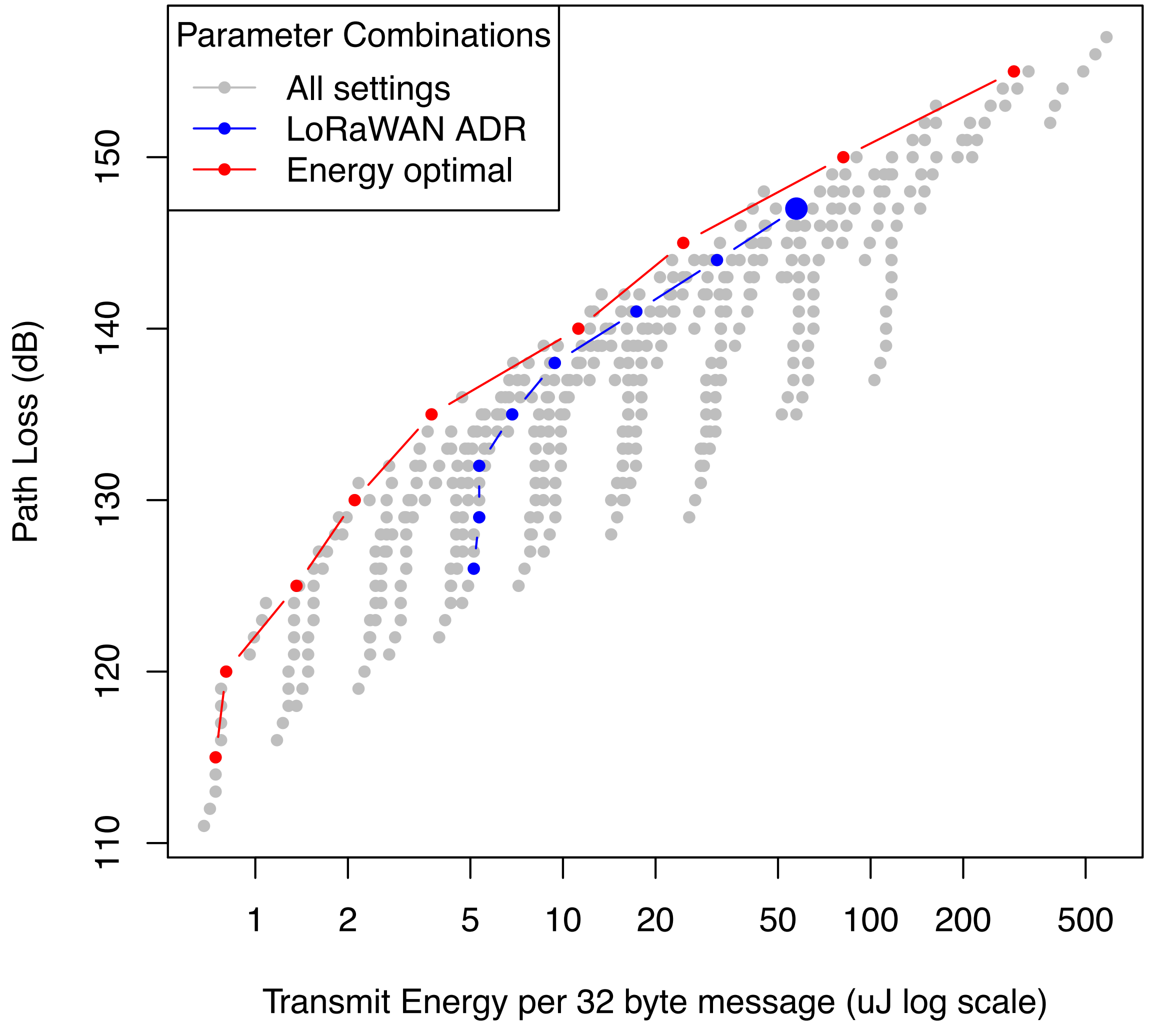
Coding Rate

- 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

Ben Dix-Matthews, Rachel Cardell-Oliver
Christof Huebner

University of Western Australia
University of Applied Sciences Mannheim

RealWSN, Shenzhen, China
November 2018

Link Quality Experiments

Link Quality Experiments

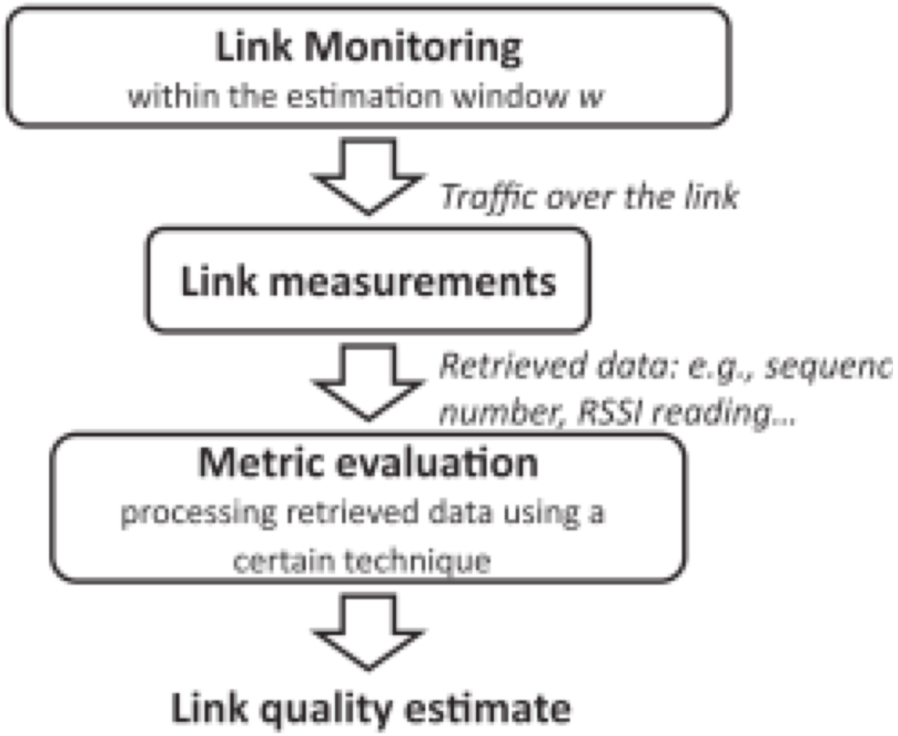
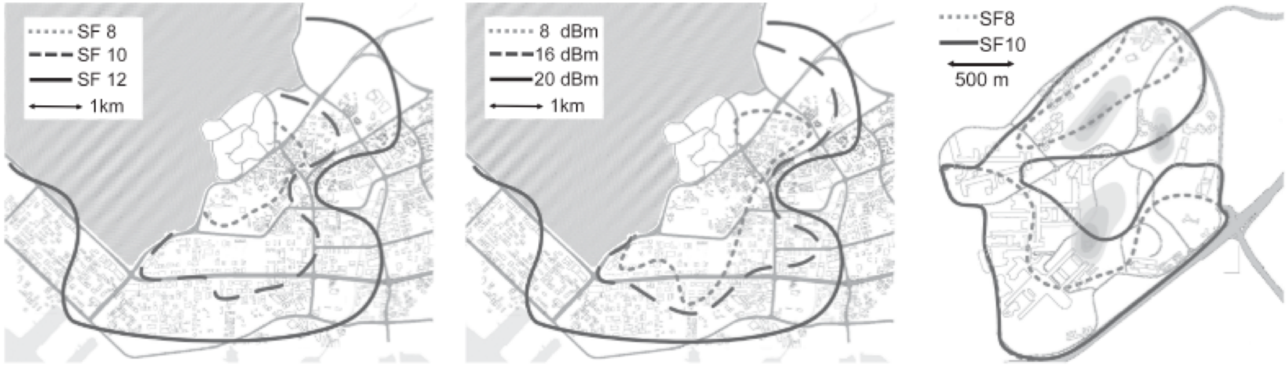


Fig. 8. Steps for link quality estimation.



(a) Outdoor coverage with TX Pow 20dBm and varying SF.

(b) Outdoor coverage with SF12 and varying TX Pow.

(c) Indoor coverage with TX Pow 20dBm and varying SF.

Fig. 6. LoRa coverage for different environments with PRR >70% and CR4/8. LoRa coverages are severely impacted on the east side of the map due to high density of buildings obstructing LoS.

Radio link quality estimation in wireless sensor networks, Baccour et al, ToSN 8(4) 2012, doi: 10.1145/2240116.2240123
Known and Unknown Facts of LoRa, Liando et al, ToSN 15(2) 2019 doi: 10.1145/3293534

https://github.com/jordz3/LoRa-Lab

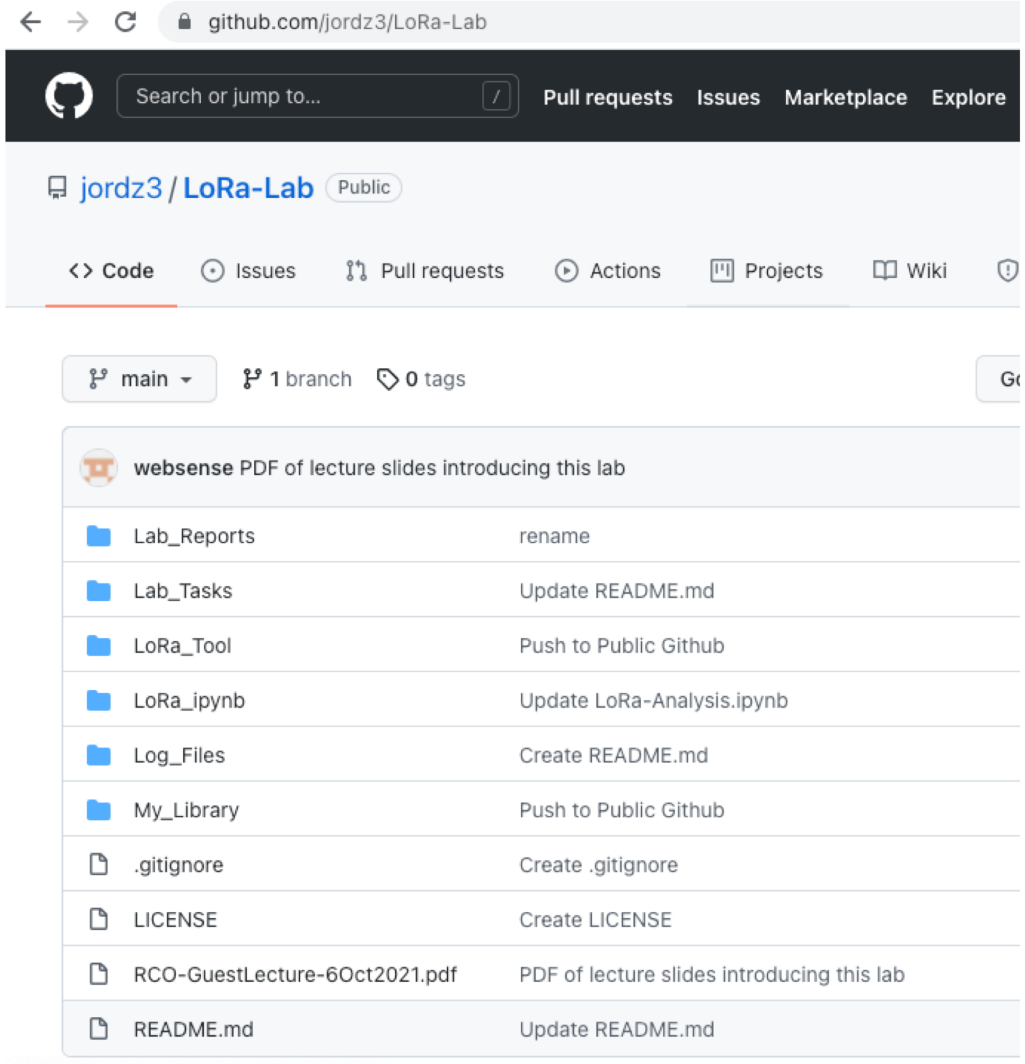
LoRa-Lab Set-Up Instructions

The aim of this lab is to explore the behaviour of wireless channels and LoRa physical parameters in an experimental setting using TTGO T-beams.

The software for this lab was developed as part of a UWA Master's of Professional Engineering (MPE) Thesis Project.

The software is a LoRa toolkit for creating and recreating experiments with simple configuration.

To setup an experimental LoRa parameter configuration to test, edit the `my_library.cpp` file as needed.



Summary

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Further Reading

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- Known and Unknown Facts of LoRa, Liando et al, ToSN 15(2) 2019 doi: 10.1145/3293534
- An Experimental Evaluation of the Reliability of LoRa Long-Range Low-Power Wireless Communication, Cattani et al, J Sensor and Actuator Networks 6(2) 2017, doi: 10.3390/jsan6020007
- LoRa from the City to the Mountains: Exploration of Hardware and Environmental Factors, Iova et al, Int. Conf. on Embedded Wireless Systems and Networks (EWSN), 2017. doi: 10.5555/3108009.3108091