Experimental Results for the Propagation of Outdoor IEEE802.11 Links

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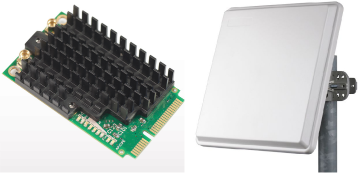
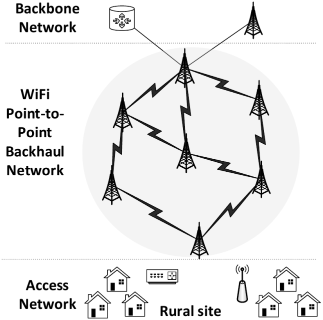
Motivation

Providing a different Broadband Access Solution for rural areas



Commercial Off-The-Shelf (COTS) WiFi transmitters and (directional) antennas

- Low CAPEX
  - Inexpensive hardware
- Low OPEX
  - Use of license-free frequencies
  - Low energy consumption
- High data throughput
- Well developed and documented



used in a controlled Multi-Radio Multi-Channel Wireless Mesh Network (WMN)

Object of Investigation

Radio propagation models essential for network planning and design process

- Calculation of indoor coverage of a WiFi infrastructure
- Forecast of possible size of an outdoor network cell

Do propagation models exist supporting the network planning process for (long distance) outdoor WiFi links?

- Most models are not suitable for WiFi-based Long Distance (WiLD) links [1]
  - Okamura [2] and Hata [3] models used for large urban-macro cells and are only specified between 150 and 1500 MHz
  - COST231-Hata Model is only specified up to 2 GHz
  - Those models are based on antenna heights above 30 m

Radio Propagation Models for Outdoor WiFi Links

- **Free Space Path Loss (FSPL)**
  - Simplified propagation description, no obstacles = no reflection, no diffraction
  - Loss due to decreasing power density with the square of the separation

2002 Calculation of path loss for Line-of-Sight (LoS) WiFi links [1]

2007 FPSL sufficient for WiLD propagation attenuation, but in some cases statistical models better [4]

2008 Link distance increased up to 7 km by two car-mounted antennas on a flat desert surface with no interference by other transmitters [5]

- **Fresnel Zones and diffraction**
  - Regions with path length greater than $n\lambda/2$ as LoS
  - Additional attenuation through obstructions, negligible if > 55 % is free (first zone)
  - Calculation is a complex mathematical problem (shape, size and material of obstacles)

2011 Path loss calculation based on deterministic modeling techniques and generated terrain profiles, which provide information about obstructions in the first Fresnel Zone, approximated as knife edges [6]

Radio Propagation Models for Outdoor WiFi Links

- **Two-Ray Path Loss Model**
  - Additional attenuation through Multi-Path propagation, even if LoS and Fresnel Zone clear
  - considers properties of LoS wave, reflected wave and ground parameters

2007 No Inter-Symbol Interference (ISI) caused by Multi-Path interference on WiLD links [7]

2007-2011 Propagation prediction using simple Two-Ray Path Loss Model for WiLD links validated by various experiments at land and sea with more accurate results than FSPL prediction [7] [8] [9]

- **Longley-Rice Model**
  - Irregular Terrain Model (ITM) uses electromagnetic theory, terrain condition statistics and radio measurements
  - considers also ground reflection and diffraction

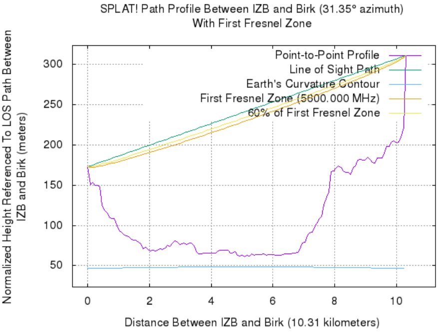
2007 Longley-Rice as promising candidate for propagation prediction [4]

- Detailed terrain profiles for all links needed [10]
- Only for link distances > 1 km [1]

Methodology: SPLAT!

SPLAT! = Signal Propagation, Loss And Terrain

- Linux-based open-source tool for RF analysis above 20 MHz
- Analysis and visualization of P2P-link properties between antenna sites
  - Digital elevation topography models captured by satellites
  - Location files with longitude, latitude and additional antenna height above ground level
  - delivers Fresnel Zone condition, attenuation and received signal strength
  - recommends antenna height in case of obstructions in LoS path



Methodology: Measurements

Signal Flow measurement with WiFi cards

- Validation of propagation models through RSS measurements with COTS hardware
- Accuracy of RSS values reported from the radio-tap header with specific models of WiFi cards sufficient for validation [11]

Link Budget estimations [4]

$$P_{RX} = P_{TX} - L_{C_{TX}} + G_{TX} - L_P + G_{RX} - L_{C_{RX}}$$

- P_{RX} and P_{TX} = received and transmitted power
- $L_{C_{RX}}$ and $L_{C_{TX}}$ = loss due to cables and connectors
- G_{RX} and G_{TX} = antenna gain of the receiver and transmitter
- L_P **= loss due to the signal propagation**

Experiment 1: Ground reflection with omni-directional antennas

Is ground reflection a measurable phenomenon for IEEE 802.11 outdoor links?

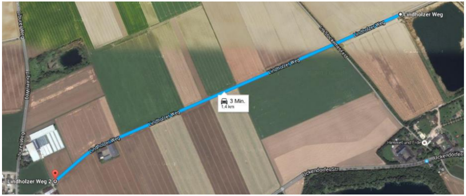
- Car-mounted antenna and fixed antenna in rural area without interference in 5 GHz band
- Fixed antenna generates traffic and car antenna measures signal strength at certain increasing distances
- Implementation of Two-Ray Model [2] in Matlab, estimating values for experiment

Received power follows estimated maximum and minimum of the Two-Ray Model

- Ground reflection is a measurable phenomenon

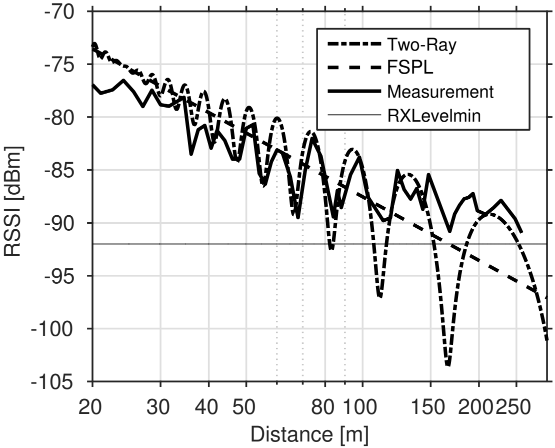
Experiment 1: Setup

Experiment 1: Measurement setup for Two-Ray Path Loss verification. Omni-directional antennas mounted on the bottom of the outdoor enclosures.



Experiment 1: Measurement route for Two-Ray Path Loss verification

Experiment 1: Results



Experiment 1: Two-Ray Path Loss Model with omni-directional antennas. Parameter of Two-Ray Model: Frequency: 5180. Polarization: Horizontal. Ground conductivity (δ): 0.125 S/m. Ground relative permittivity (ϵ_r): 5

Experiment 2: Testbed with directional antennas

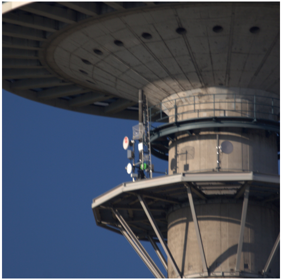
Is it possible to predict the path loss on a real-world WiLD network with well-known propagation models?

- Validating predictions by SPLAT! with several propagation models by comparing them with actual measurements from the Rhein-Sieg testbed

Experiment 2: Rhein-Sieg testbed visualization generated with Google Earth

Basically possible, but highly dependable on the link distances and the properties of the antenna sites

Experiment 2: Setup

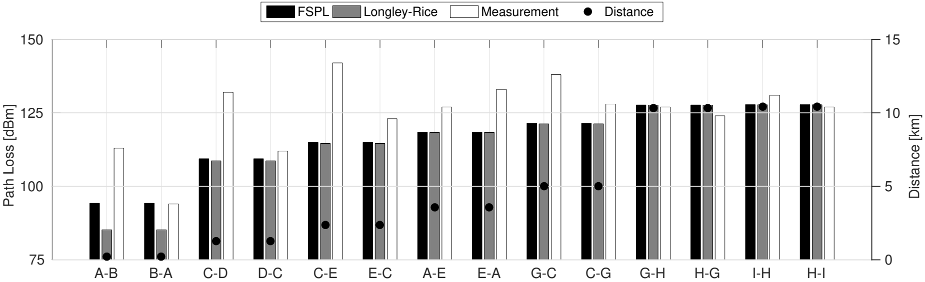


Build up at location H

Build up at location A

Build up at location C

Experiment 2: Results



Experiment 2: Path loss for 7 different links in our long distance testbed

Experiment 3: Influence of environmental factors

Is there a measurable influence of environmental factors to the propagation attenuation on long distance links?

- RSSI values in correlation to temperature, humidity and atmospheric pressure
- Measured on 5 km and 10 km link on 275 days
- RSSI every minute and environmental factors every 15 minutes

No statistically significant influence of the environmental factors

- Confirms results of [12]
- Stands in contrast to [13]

Conclusion and Future Work

Conclusion

- Two-Ray Path Loss Model superior for short distance links with measurable ground reflection
- Longley-Rice and FSPL Model for long distance links estimating similar results
- Site surveys are essential
- No influence by environmental factors on WiLD links

Future Work

- Investigation of additional path loss in our testbed
- Further analysis on environmental factors

Thank you very much!

Are there any questions?

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