Communication in Distributed Systems

4 WiLD - Physical Layer and Propagation

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Discussion of the Reading

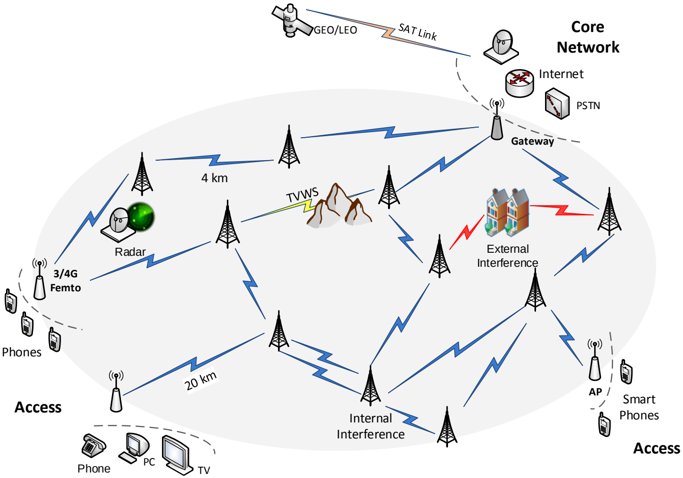
Alternative Networks: Toward Global Access to the Internet for All

Jose Saldana, Andrés Arcia-Moret, Arjuna Sathiaseelan, Bart Braem, Ermanno Pietrosemoli, Marco Zennaro, Javier Simó-Reigadas, Ioannis Komnios, and Carlos Rey-Moreno

Talking Points:

- What is the goal of this paper?
- What is an "Alternative Network" according to the authors?
- What is the "digital divide"?
- What is the difference between a primary and a secondary user for TV white spaces?
- What is the idea of a "shared infrastructure model"?

Overview for the next Lectures



- WiFi based Long Distance networks (WiLD)
- Long-Distance (Wi-Fi) Links
  - Radio Propagation
  - Hardware and MAC
  - Optimization

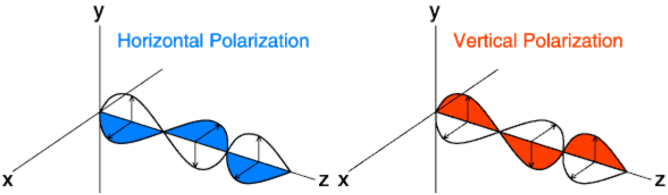
Propagation on p2p wireless links

Wireless Point To Point (P2P) communication.

Wireless communication

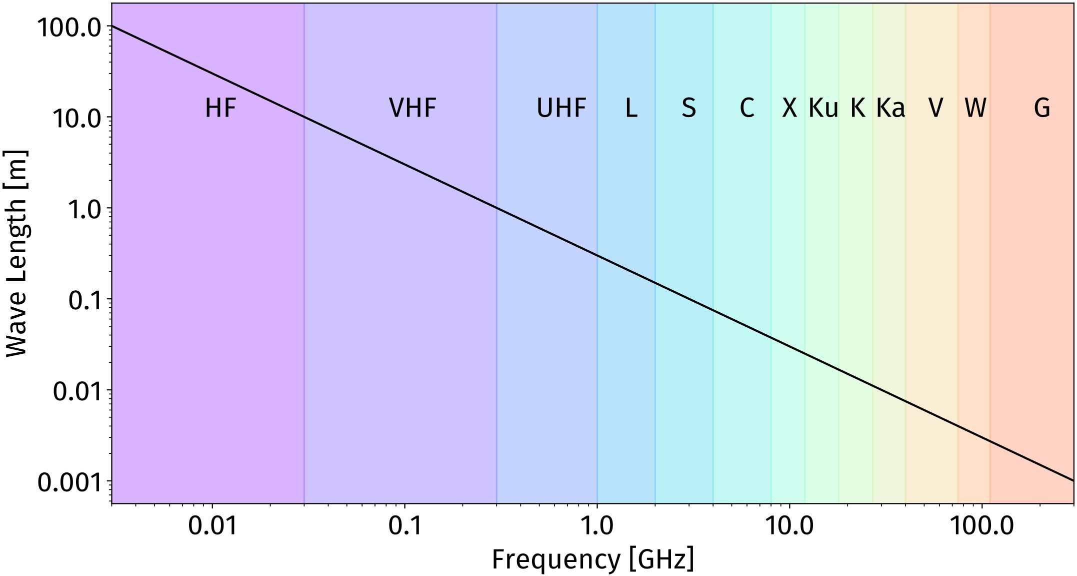
Wireless communication is the transfer of information between two or more points, that are **not** connected by an electrical conductor, using **modulated electromagnetic waves**.

- Important effects:
  - Free-Space Path Loss (FSPL)
  - Reflection
  - Diffraction
  - Earth curvature
  - Weather conditions



- Vertical: Electric field is $\perp$ to earth's surface.
- Horizontal: Electric field is $\parallel$ to earth's surface.

Different Radio Bands (IEEE Std 521-2002)



Free Space Path Loss

Isotropic radiators/receivers: Theoretical baselines

$$S[\frac{W}{m^2}] = \frac{P_T}{4\pi d^2} \quad (1)$$

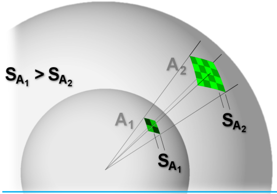
$$P_R = S * A_E = \frac{P_T}{4\pi d^2} * A_E \quad (2)$$

$$A_E = \frac{\lambda^2}{4\pi} \quad (3)$$

$$A_E = \frac{\lambda^2}{4\pi} * G \quad (4)$$

$$\frac{P_T}{P_R} = [\frac{4\pi d}{\lambda}]^2 = [\frac{4\pi df}{c}]^2 \quad (5)$$

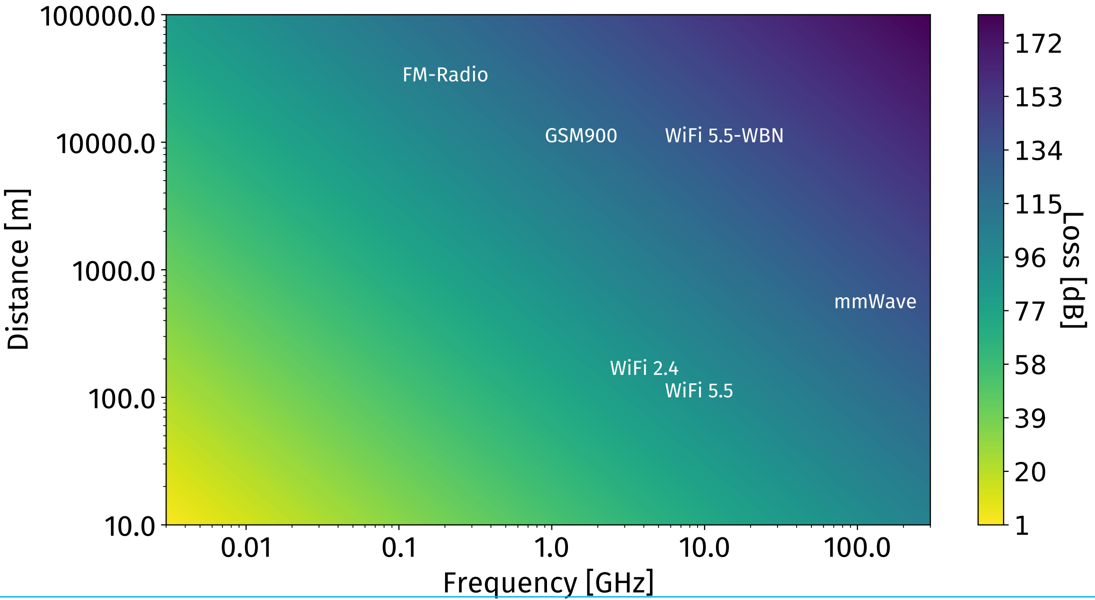
- Isotropic radiators spread the energy equally over a sphere surface (Power density S) (1)
- The received power depends on the effective area (A_E) of an antenna (2)
- For an isotropic antenna, the effective area is simple (3)
- The gain (G) of all other antennas is based on the isotropic antenna (4)
- Combining (2) and (3) leads to the Free-Space Path Loss (FSPL) eq. (5)



Common to express the eq. in decibel [7]:

$$L_f[dB] = 20 * log_{10}(f_{MHz}) + 20 * log_{10}(d_{km}) + 32.4dB$$

Comparison of FSPL for different frequencies

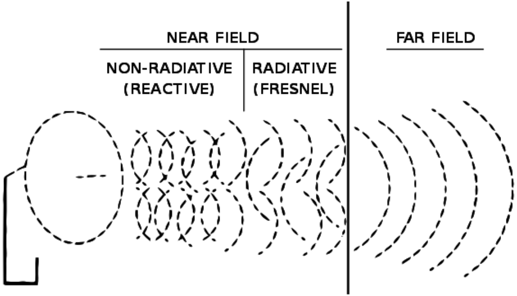


Fields after an antenna

Limit: Fraunhofer distance [6].

$$d_f = \frac{2D^2}{\lambda}$$

D: largest physical linear dimension of the antenna Exp.: $d_f = 1.5\ m$ for D=0.2 m at 5.5 GHz



? Near field/non-radiative field
- Electric and magnetic waves can exists independently
- One field dominates the other

! Far field or Fraunhofer field
- Electronic and magnetic waves in phase
- Fixed ratio between amplitudes

FSPL is only applicable in the far field of an antenna!

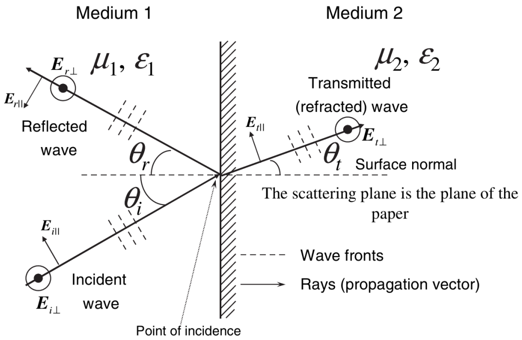
Reflection

Reflection

Reflection

Reflection occurs when propagating electromagnet waves impinges upon an object which has very large dimensions when compared to the wavelength of the propagation wave [2].

- **Depending on the reflection coefficient**:
  - A certain amount of power is reflected. The phase (sometimes) changes.
  - A certain amount of power is refracted into the medium.



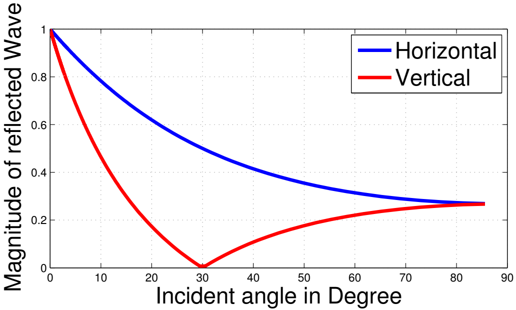
$$\theta_i = \theta_r$$

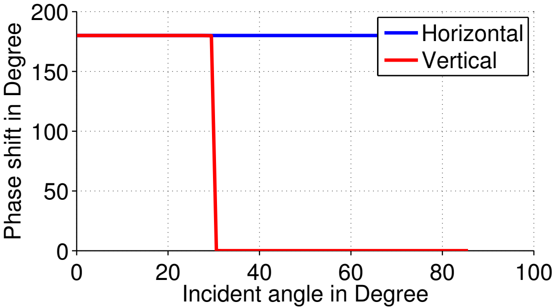
Snell's law of refraction (n = refractive index):

$$\frac{sin(\theta_i)}{sin(\theta_t)} = \frac{n_2}{n_1}$$

Reflection coefficient

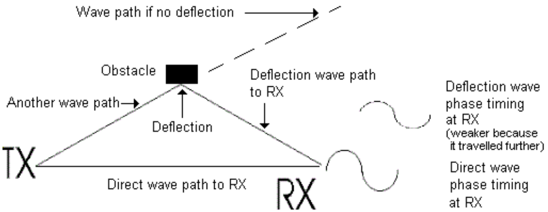
- The reflection coefficient is a complex number depended on [4]:
  - The polarization
  - The angle of incidents
  - Some medium characteristics (conductivity, ...)
  - The frequency
- The ITU-R provides medium factors for different types of ground





Reflection with different incident angles at 5.5 GHz, dry ground

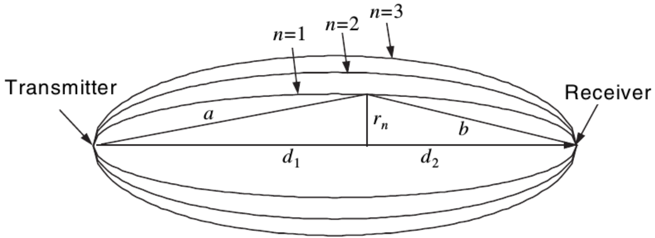
Fresnel-Zones: A simplification for reflection.



Secondary waves reflect on obstacles. Fresnel-Zones make it easy to calculate if they are in phase or out of phase at the receiver.

Fresnel-Zones

Fresnel-Zones are described as successive regions where secondary waves have a path length from the transmitter to receiver which are $n\lambda/2$ greater than the total path length of a LOS path [6].



$$r_n = \sqrt{\frac{n \cdot \lambda \cdot d_1 \cdot d_2}{d_1 + d_2}}$$

! **Negative correlation** for frequency and diameter

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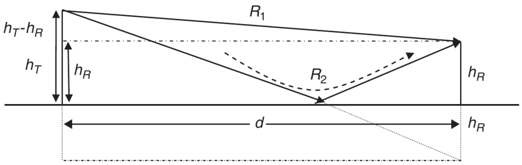
Two-Ray-Model: Assuming significant ground reflections



Ancient greek guy

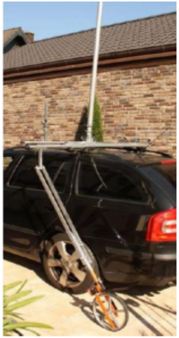
$$(R_2 - R_1) = \sqrt{(h_T + h_R)^2 + d^2} - \sqrt{(h_T - h_R)^2 + d^2} \approx \frac{2h_T h_R}{d}$$

$$A_{total} = A_{direct} + A_{reflected}$$

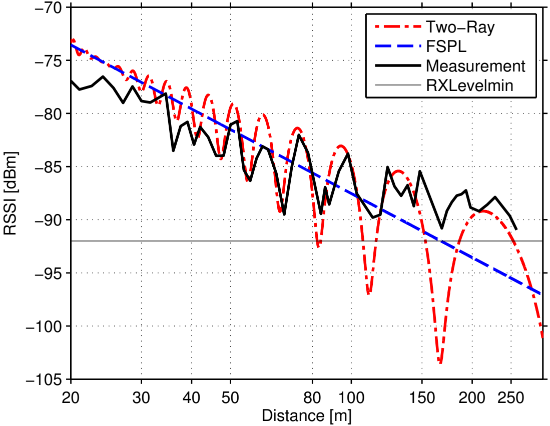
- Under the assumption of small angles $r \approx -1$ (proof in the appendix)

$$\frac{P_R}{P_T} = 2 * (\frac{\lambda}{4\pi d})^2[1 - cos(\frac{2\pi f}{c}\frac{2h_T h_R}{d})]$$

Our Research: Verification of the Two-Ray-Model [5]

Omni-directional antennas mounted on the bottom of the outdoor-enclosures



Results; Frequency: 5180. Polarization: Horizontal. Conductivity (δ): 0.125 S/m. Relative permittivity (ϵ_r): 5

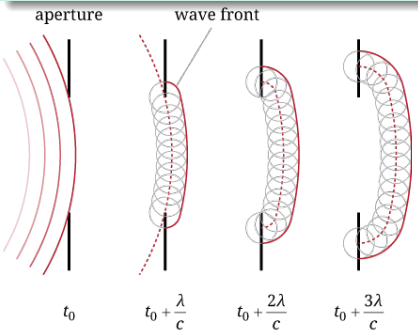
- Omni: The Two-Ray-Model fits better than FSPL
- Directional: More complex due to antenna diagram

Diffraction

The Huygens - Fresnel-Principle

Huygens - Fresnel-Principle

Each element of a wavefront at a point in time may be regarded as the center of a secondary disturbance, which gives rise to spherical wavelets. The position of the wavefront at ANY later time is the envelope of all such wavelets [8].



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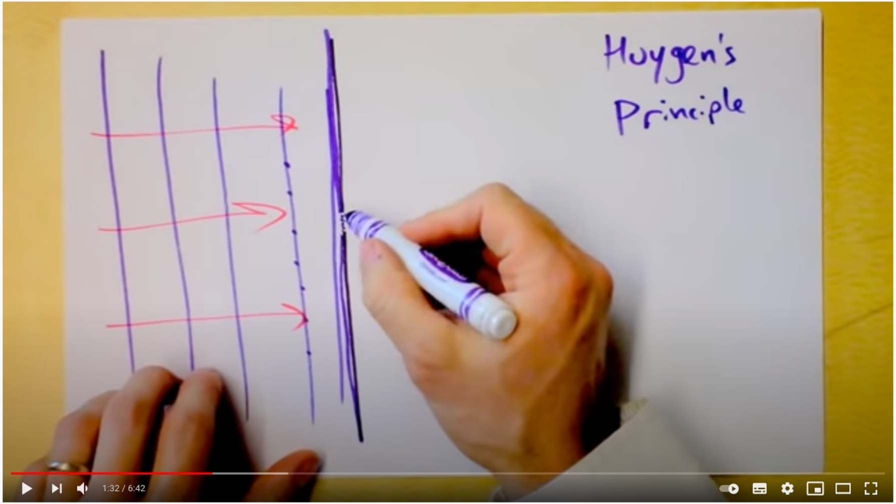
The Huygens - Fresnel-Principle - Video-Explanation

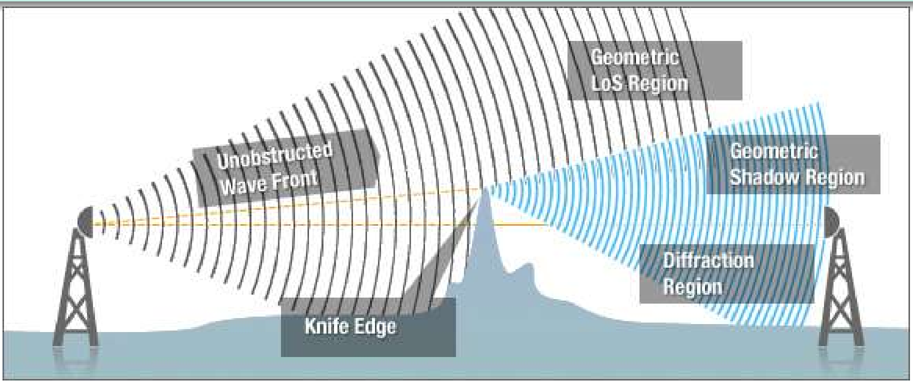


Doc Schuster: "Huygens Principle | He's Dutch! | Doc Physics"
https://youtu.be/_03sfhb7Mvg

Diffraction: Shadowing by an object

Diffraction

A radio wave that meets an obstacle has a natural tendency to bend around the obstacle. The bending, called diffraction, results in a change of direction of part of the wave energy from the normal line-of-sight path.



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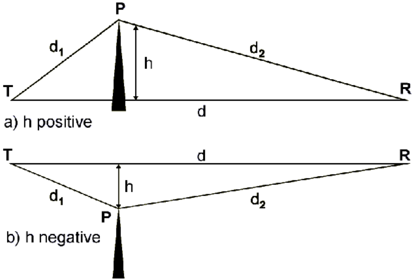
Diffraction: Calculations are complicated

- Common Assumption: Single-knife-edge diffraction
- A link is free of diffraction if 55% of the first Fresnel-Zone are free of obstacles

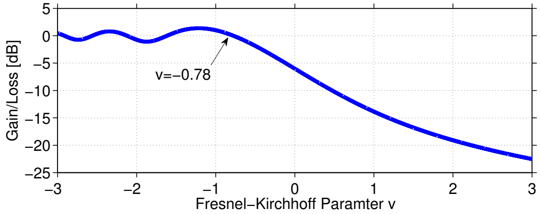


Fresnel-Kirchoff Parameter,

$$v = h\sqrt{\frac{2*(d_1+d_2)}{\lambda*d_1*d_2}}$$

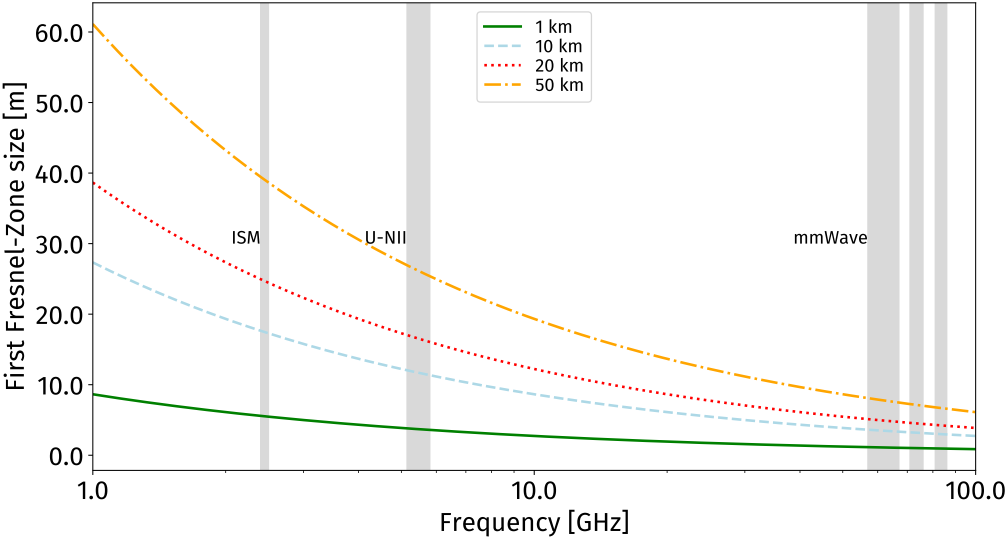
with h = 55% of first Fresnel-Zone:

$$v = -0.55*\sqrt{\frac{1*\lambda*d_1*d_2}{d_1+d_2}}\sqrt{\frac{2*(d_1+d_2)}{\lambda*d_1*d_2}} = -0.78$$



1. Calculate Fresnel-Kirchhoff Parameter
2. Use the diagram or a table to get the gain/loss in dB

Fresnel-Zone size



Additional influences

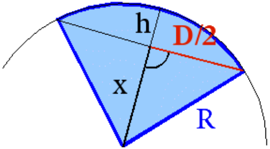
Additional influences: Earth Curvature

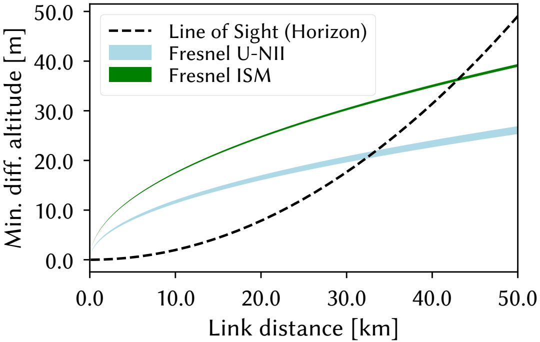
- The earth is not a flat surface but rather a sphere (surprise)
- The horizon influences the minimum antenna altitude

Netflix - Behind the curve.

$$x = \sqrt{R_{Earth}^2 - \left(\frac{d}{2}\right)^2}$$

$$h = R_{earth} - x$$

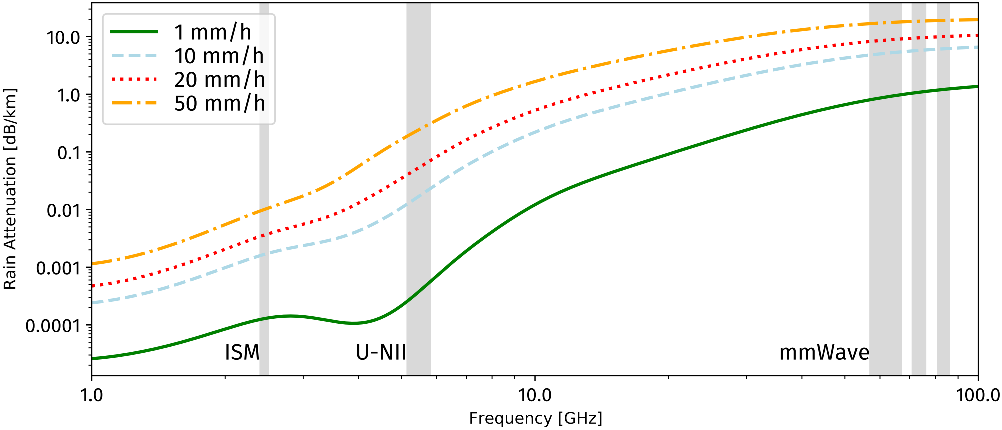




Additional influences: Weather conditions

Weather conditions (rain, fog, snow) can lead to additional attenuation and transmission errors (BER $\uparrow$).

But Rain $>= 25$ mm/h leads to a weather warning in Germany but only to 0.05 dB per km additional attenuation at 5.5 GHz.



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Computer-aided propagation planning

Computer-aided propagation planning

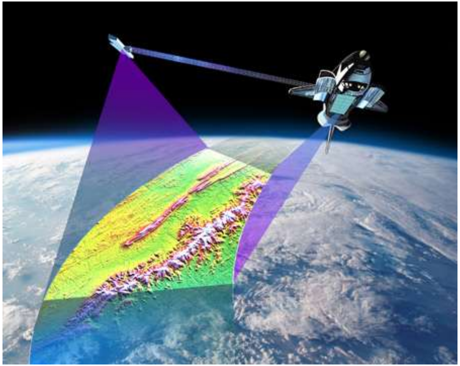
There are numerous Software projects to conduct a detailed radio planing. Most of them are closed source and very expensive. A few good Open-Source alternatives exists:

- **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
  - Analysis and visualization of large areas.
- Radio Mobile

Computer-aided propagation planning

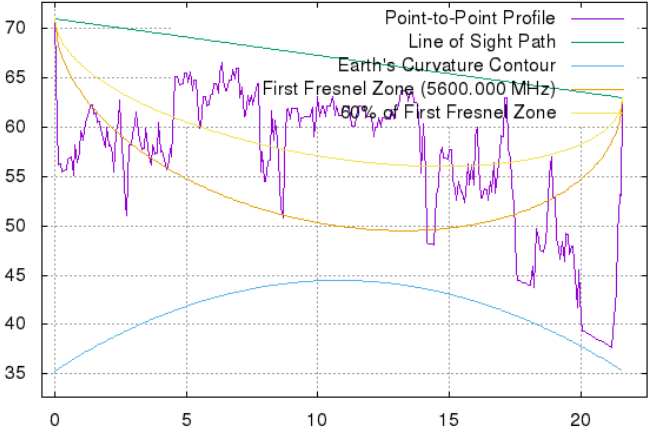
Terrain based models need topography data:

- Shuttle Radar Topography Mission (SRTM) data [1]
  - resolution: 1-arc-second ($\approx 30\ m$)
- Light Detection and Ranging (LiDAR)[2]
  - resolution: $\approx 0.25\ m$

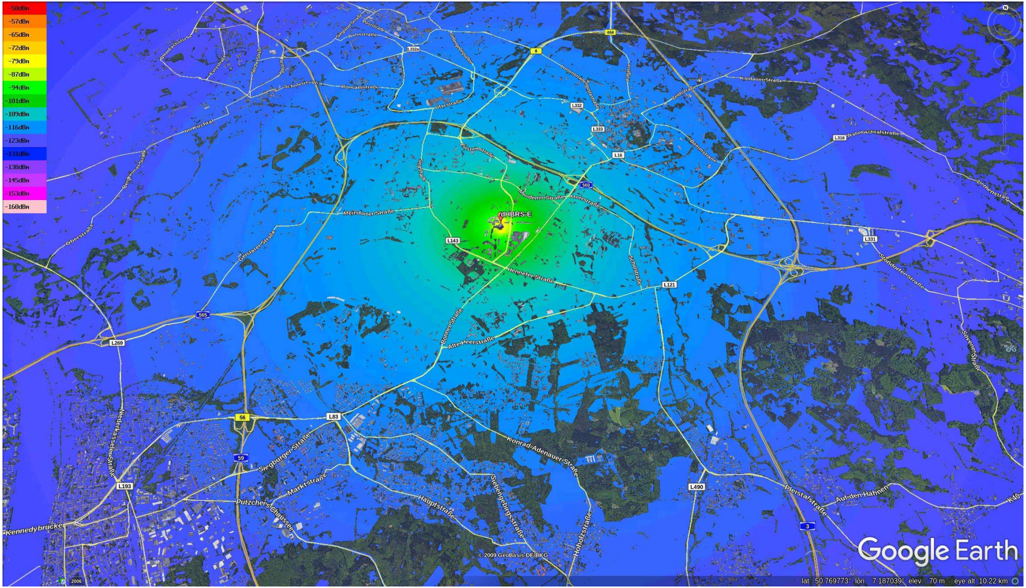


[1] https://dds.cr.usgs.gov/srtm/version1/Eurasia/
[2] https://www.opengeodata.nrw.de/produkte/geobasis/dgm/dgm1l/index.html

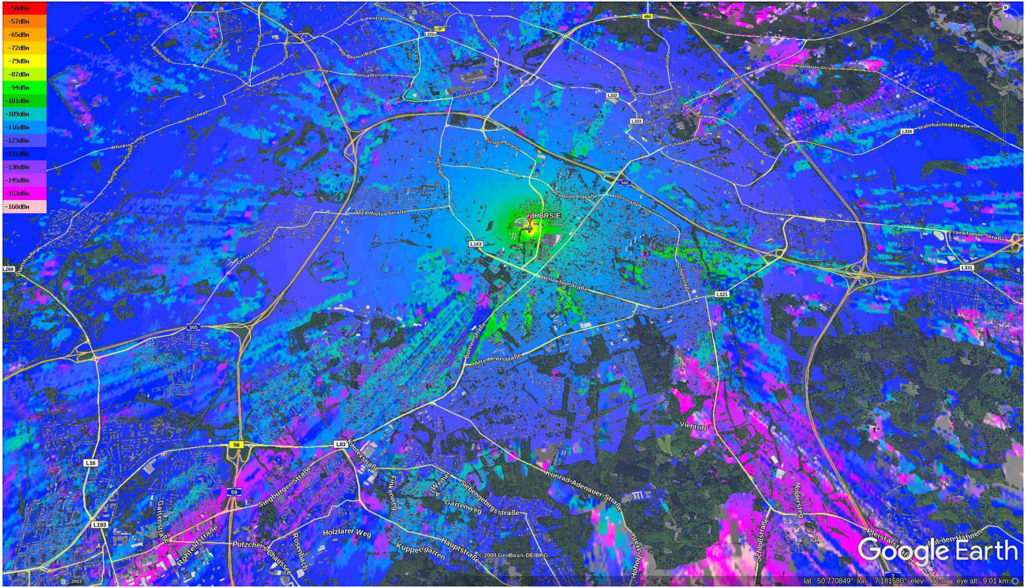
H-BRS to TH Cologne p2p



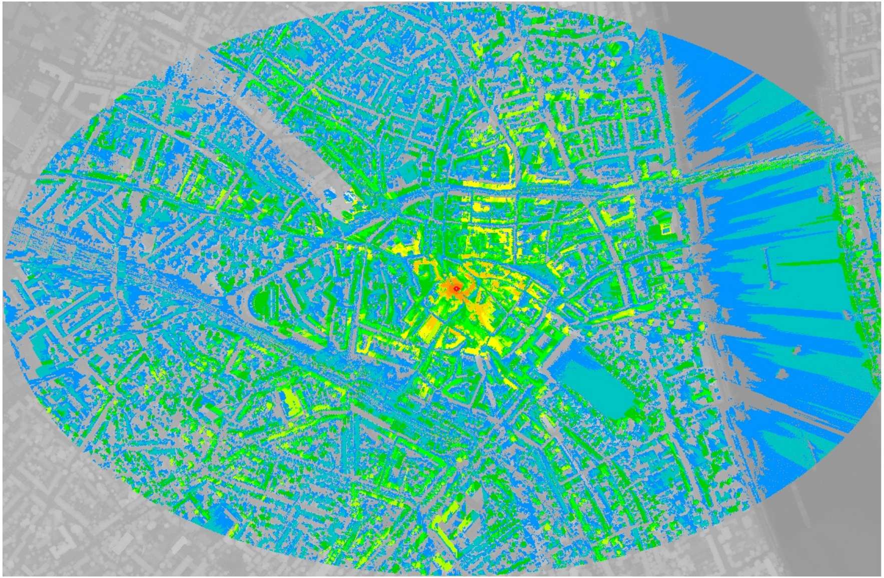
H-BRS 868 MHz without topography data



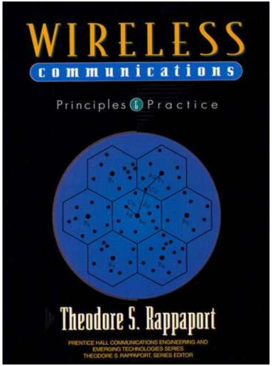
H-BRS 868 MHz with topography data



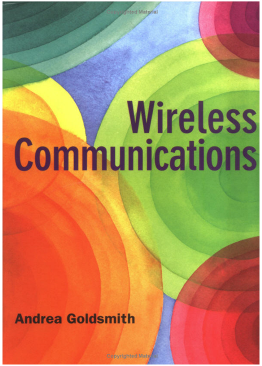
City Center of Bonn with LiDAR Data



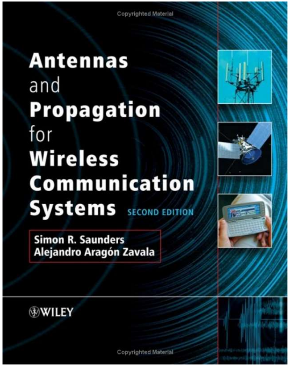
Books to be recommended



Rappaport [6]



Goldsmith [3]



Saunders [8]

Reading for next week

Tegola Tiered Mesh Network Testbed in Rural Scotland

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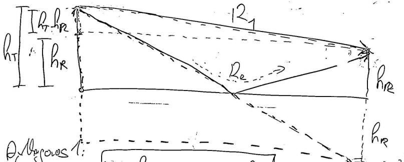
Abstract: Many rural and remote communities around the world see them selves on the wrong side of the digital divide. In particular, there is evidence to suggest that there is a growing digital divide between urban and rural areas in terms of broadband Internet access with people living in rural areas having fewer choices and pay higher prices for slower speeds. This is true even in developed countries. Motivated by the above observations, there has been an increasing interest in deploying and researching low cost rural wireless networks with active community participation. This paper presents an overview of our efforts in this direction in deploying a rural WiFi based long distance mesh network testbed in the Scottish Highlands and Islands. We highlight the unique aspects of our testbed that differentiate it from other existing rural wireless testbeds. We also outline some of the research issues that are currently being investigated in this project [1].

Appendix: Proofs



Taylor Series approximation

$$\sqrt{1+\varepsilon} \approx 1+\frac{\varepsilon}{2}$$

Pythagoras 1:

$$R_1 = \sqrt{d^2 + (h_T - h_R)^2} = d\left[1 + \frac{(h_T-h_R)^2}{d^2}\right]^{\frac{1}{2}} \approx d\left[1 + \frac{1}{2}\left(\frac{h_T-h_R}{d}\right)^2\right]$$

Pythagoras 2:

$$R_2 = \sqrt{d^2 + (h_T + h_R)^2} = d\left[1 + \frac{(h_T+h_R)^2}{d^2}\right]^{\frac{1}{2}} \approx d\left[1 + \frac{1}{2}\left(\frac{h_T+h_R}{d}\right)^2\right]$$

$$\Delta R = R_2 - R_1 = d\left[1 + \frac{1}{2}\left(\frac{h_T+h_R}{d}\right)^2\right] - d\left[1 + \frac{1}{2}\left(\frac{h_T-h_R}{d}\right)^2\right]$$

$$= \frac{d}{2}\left(\frac{h_T+h_R}{d}\right)^2 - \frac{d}{2}\left(\frac{h_T-h_R}{d}\right)^2$$

$$= \frac{1}{2}\frac{(h_T+h_R)^2}{d} - \frac{1}{2}\frac{(h_T-h_R)^2}{d}$$

$$= \frac{(h_T+h_R)^2 - (h_T-h_R)^2}{2d}$$

$$= \frac{\cancel{h_T^2} + 2h_T h_R + \cancel{h_R^2} - [\cancel{h_T^2} - 2h_T h_R + \cancel{h_R^2}]}{2d}$$

$$= \frac{4 h_T h_R}{2d} = \frac{2 h_T h_R}{d} \quad \text{q.e.d.} \Rightarrow \text{Phase } \Delta = \frac{4\pi}{\lambda} \cdot \frac{h_T h_R}{d}$$

Reflection Coefficient

Refl. Results

$$E = E_0 e^{-j\beta R_1} (1 \pm e^{-j\Delta})$$

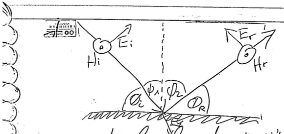
↓ Euler

$$= E_0 e^{-j\beta R_1} [1 \pm \cos\Delta \mp j\sin\Delta)$$

$$|E| = E_0 \sqrt{1 + \cos^2(\Delta) + 2\cos(\Delta) + \sin^2(\Delta)}$$

Path difference

Appendix: Proofs



„vertical polarization" „$\parallel$"

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin(\phi_t) - \eta_1 \sin(\phi_i)}{\eta_2 \sin(\phi_t) + \eta_1 \sin(\phi_i)}$$

Statements: 1. For all lossless insulators $\mu_1 = \mu_2 = \mu_0$ $\eta_i = \sqrt{\frac{\mu_0}{\varepsilon_i}}$

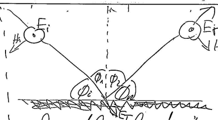
2. One Medium is free space.

$$\Gamma_{\parallel} = \frac{-\varepsilon_r \sin(\phi_i) + \sqrt{\varepsilon_r - \cos^2(\phi_i)}}{\varepsilon_r \sin(\phi_i) + \sqrt{\varepsilon_r - \cos^2(\phi_i)}}$$

Observation: Two Factors 1) angle of incidence 2) ε_r

Let $\phi_i \Rightarrow 0$ long distance between the [illegible]

$$\Gamma_{\parallel} = \frac{-\varepsilon_r \cdot 0 + \sqrt{\varepsilon_r - 1}}{\varepsilon_r \cdot 0 + \sqrt{\varepsilon_r - 1}} = 1$$



„horizontal polarization" „$\perp$"

$$\Gamma_{\perp} = \frac{E_R}{E_i} = \frac{\eta_2 \sin(\phi_i) - \eta_1 \sin(\phi_t)}{\eta_2 \sin(\phi_i) + \eta_1 \sin(\phi_t)}$$

$$\Gamma_{\perp} = \frac{\sin(\phi_i) - \sqrt{\varepsilon_r - \cos^2(\phi_i)}}{\sin(\phi_i) + \sqrt{\varepsilon_r - \cos^2(\phi_i)}}$$

$$\Gamma_{\perp} = \frac{0 - \sqrt{\varepsilon_r - 1}}{0 + \sqrt{\varepsilon_r - 1}}$$

$$\Gamma_{\perp} = -1$$

$E_i = E_T + E_R$

$\eta_i = \sqrt{\frac{\mu_i}{\varepsilon_i}}$

$\frac{\sin(\phi_2)}{\sin(\phi_1)} = \frac{\eta_2}{\eta_1}$ Snells law

$\sqrt{\mu_1 \varepsilon_1} \sin(90 - \phi_i) = \sqrt{\mu_2 \varepsilon_2} \sin(90 - \phi_t)$

$\phi_i = \phi_r$

$E_r = \Gamma E_i$

$E_t = (1 + \Gamma) E_i$

Constant R

Appendix: Proofs

$$\frac{P_R}{P_T} = \left(\frac{\lambda}{2\pi d}\right)^2 + \left|1 + R e^{jk\cdot\frac{2h_T h_R}{d}}\right|^2$$

$$b = \left(\frac{\lambda}{2\pi d}\right)^2 \quad a = k\cdot\frac{2h_T h_R}{d} \quad R = -1$$

$$\frac{P_R}{P_T} = b\cdot\left|1 - e^{ja}\right|^2 \quad ; \quad e^{ja} = \cos(a) + j\sin(a)$$

$$\frac{P_R}{P_T} = b\cdot\left|1 - \cos(a) + j\sin(a)\right|^2 \quad ; \quad |x + jy|^2 = x^2 + y^2$$

$$= b\cdot\left((1-\cos(a))^2 + \sin^2(a)\right)$$

$$= b\cdot\left(1 - 2\cos(a) + \cos^2(a) + \sin^2(a)\right) \quad \Big| \ \cos^2(x) + \sin^2(x) = 1$$

$$= b\cdot\left(2 - 2\cos(a)\right) = 2\left(1 - \cos(a)\right)$$

$$= 2\left(\frac{\lambda}{2\pi d}\right)^2\cdot\left(1 - \cos\left(k\cdot\frac{2h_T 2h_R}{d}\right)\right)$$

Two Ray Proof

Thank you for your attention.
Are there any questions left?

Room K331
Rathausallee 10
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Sankt Augustin

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