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Algorithms for Radio Networks

Introduction and Basics

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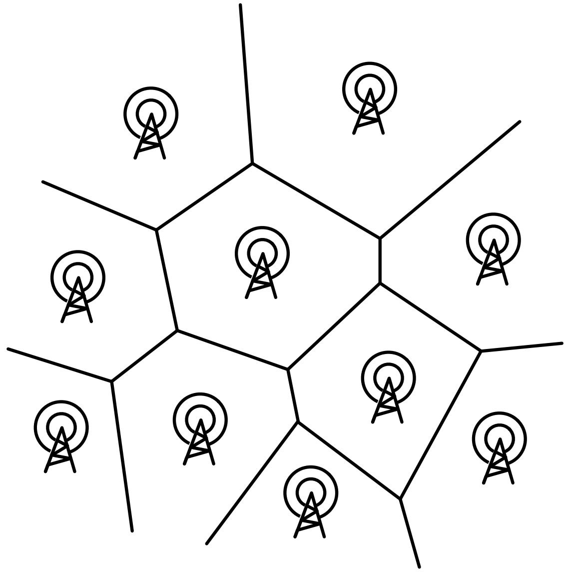
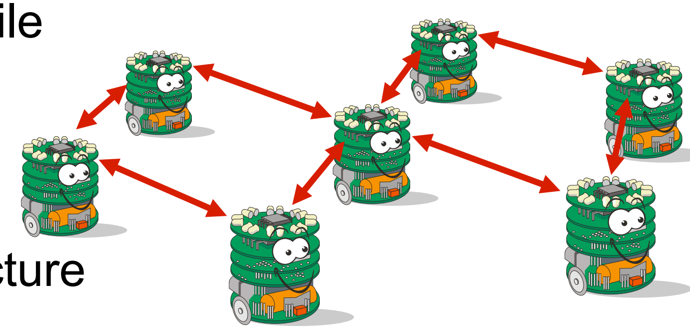
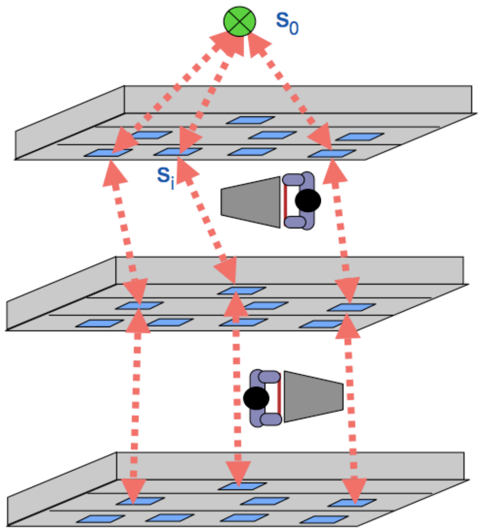


Networks Types

- **Cellular networks**
  - one or more access stations
  - each access station covers a cell
  - e.g. mobile telephones, WLAN
- **Mobile ad hoc networks**
  - self-configuring network of mobile nodes
  - nodes serve as end-points or routers
  - without any dedicated infrastructure
- **Wireless sensor network**
  - connecting sensors and actuator units wireless communicating with one or more base stations
  - base station is more powerful than other nodes



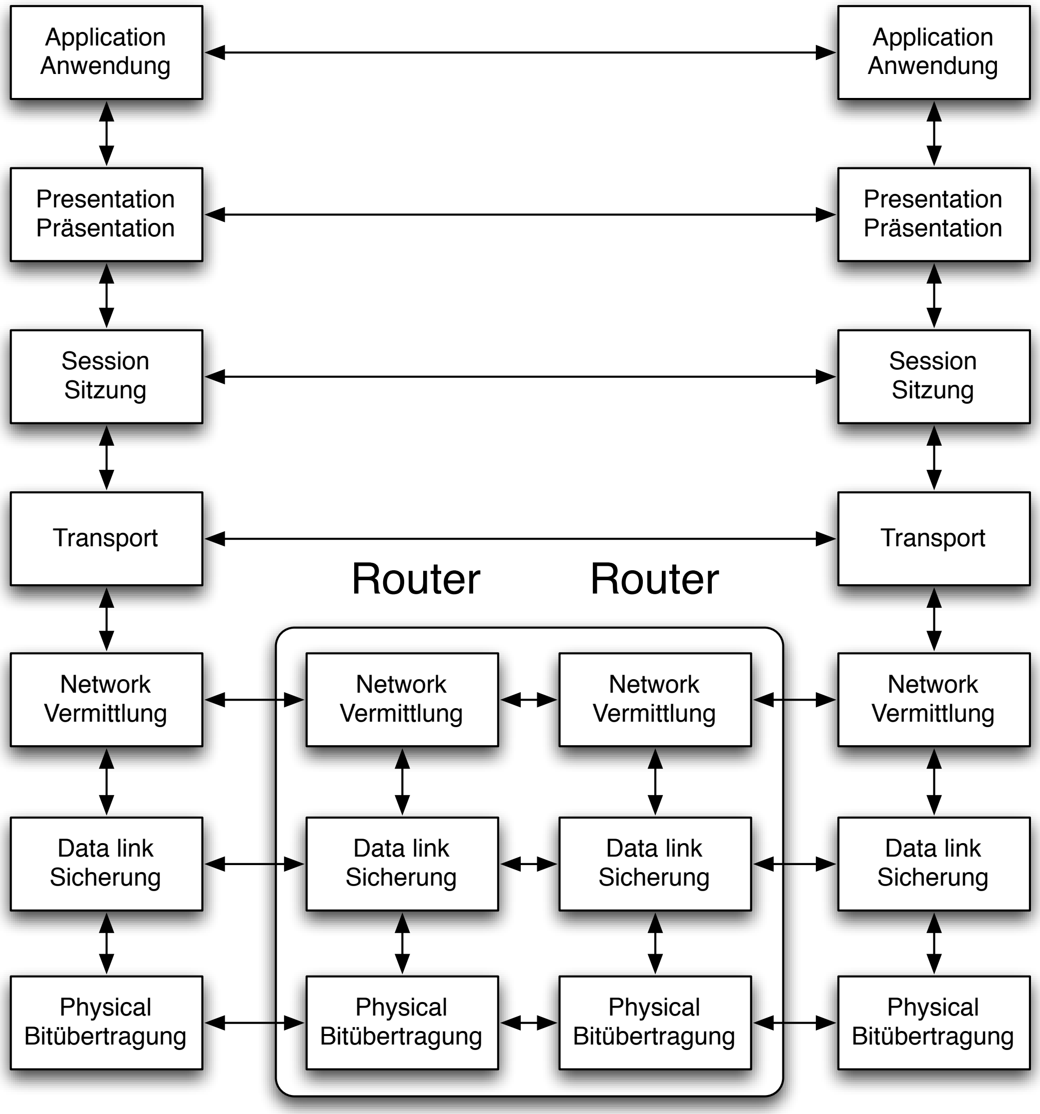


Popular Wireless Networks

- **GSM, GPRS, EDGE**
  - Global System for Mobile Communications
  - General Packet Radio Service
  - Enhanced Data Rates for GSM Evolution
  - Smart phones, PDAs, Laptop/netbook modem, Tablet PCs
- **UMTS**
  - Universal Mobile Telecommunications Systems
  - 3rd generation mobile communication standard
- **LTE**
  - Long Term Evolution
  - 4th generation standard
- **IEEE 802.11 a/b/g/n/ac**
  - Wireless Local Area Network (WLAN)
  - Wireless networking of computers, cameras, printers, etc.
  - Mostly as cellular networks
  - But also allows ad-hoc mode between two nodes
- **IEEE 802.15.4 + Zigbee**
  - Wireless Personal Area Network (WPAN)
    - Standard for wireless sensor networks
    - Zigbee Alliance
      - defined higher protocol layers

ISO/OSI Reference model

- **7. Application**
  - Data transmission, e-mail, terminal, remote login
- **6. Presentation**
  - System-dependent presentation of the data (EBCDIC / ASCII)
- **5. Session**
  - start, end, restart
- **4. Transport**
  - Segmentation, congestion
- **3. Network**
  - Routing
- **2. Data Link**
  - Checksums, flow control
- **1. Physical**
  - Mechanics, electrics



TCP/IP-Layer of the Internet

Application	Telnet, FTP, HTTP, SMTP (E-Mail), ...
Transport	TCP (Transmission Control Protocol) UDP (User Datagram Protocol)
Network	IP (Internet Protocol) + ICMP (Internet Control Message Protocol) + IGMP (Internet Group Management Protoccol)
Host-to-Network	LAN (e.g. Ethernet, 802.11n etc.)

Signals, Data and Information

- **Information**
  - Human interpretation,
  - e.g. Beautiful weather
- **Data**
  - Formal presentation
  - e.g. 28 degrees Celsius, rainfall 0cm, 0% cloud cover
- **Signal**
  - Representation of data by physical variables,
  - e.g. Current flow through thermal sensor, the video signals from camera
- **Examples of signals:**
  - Current, voltage
  - In the digital world signals representing bits

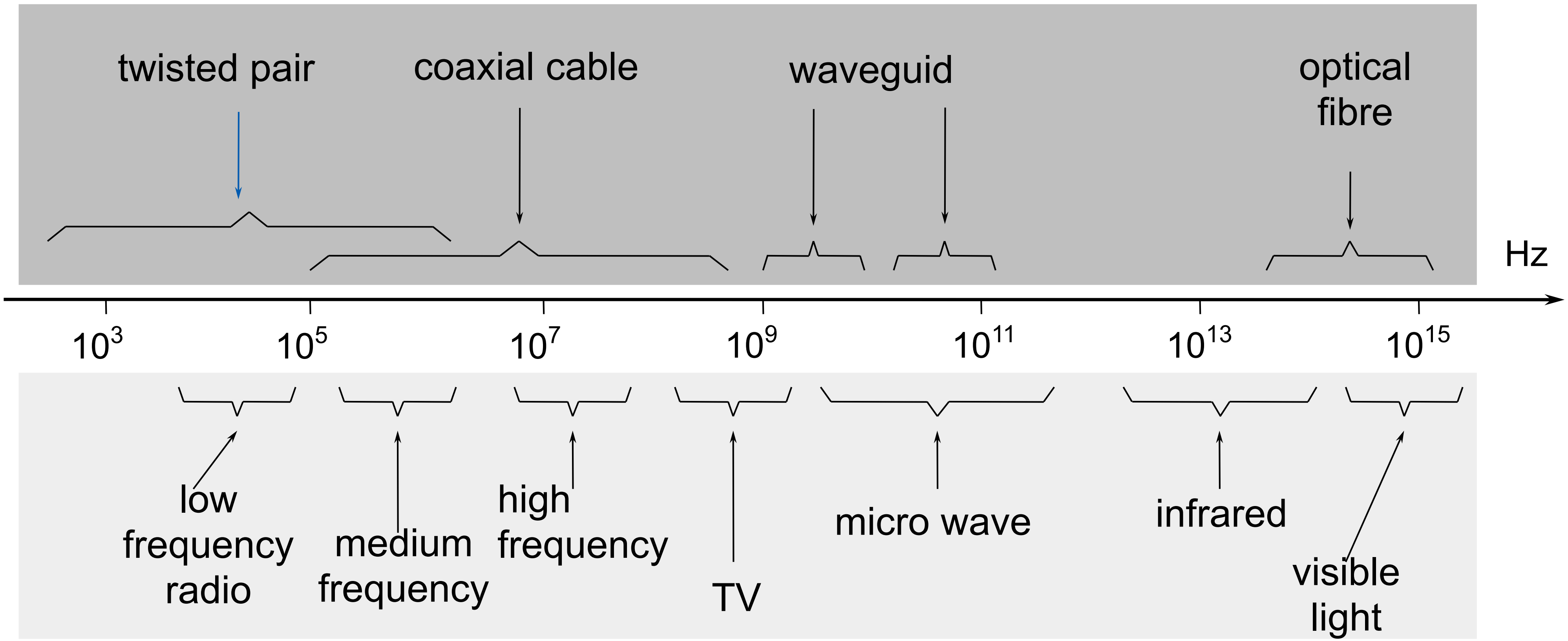
Physics – Background

- **Moving particles with electric charge cause electromagnetic waves**
  - frequency f : number of oscillations per second
    - unit: Hertz
  - wavelength λ: distance (in meters) between two wave maxima
  - antennas can create and receive electromagnetic waves
  - the transmission speed of electromagnetic waves in vacuum is constant
  - speed of light $c \approx 3 \cdot 10^8$ m/s
- **Relation between wavelength, frequency and speed of light:**

$$\lambda \cdot f = c$$

Electromagnetic Spectrum

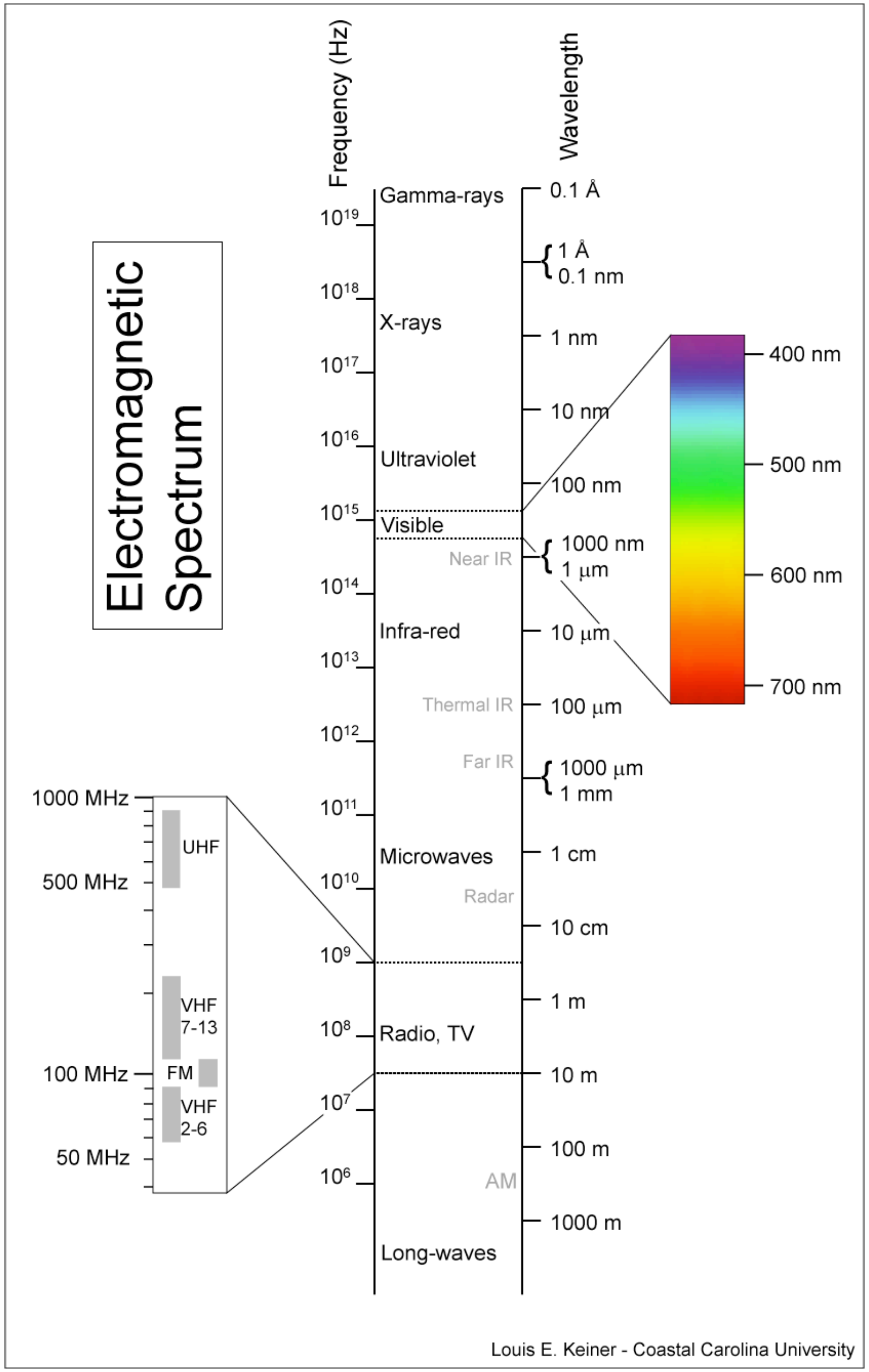
guided media



guided media

Bands

- **LF** **Low Frequency**
- **MF** **Medium Frequency**
- **HF** **High Frequency**
- **VHF** **Very High Frequency**
- **UHF** **Ultra High Frequency**
- **UV** **Ultra Violet light**



Bands for Wireless Networks

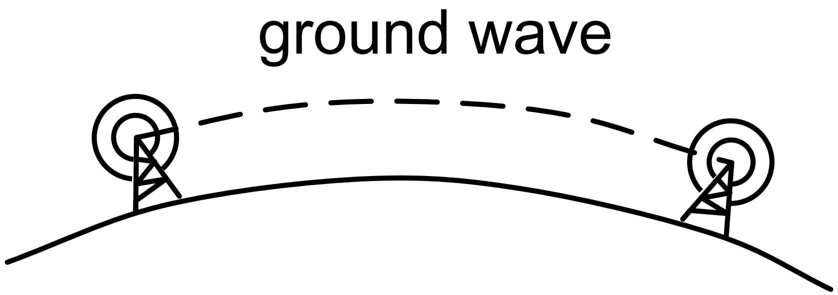
- **VHF/UHF for mobile radio**
  - antenna length
- **SHF for point-to-point radio systems, satellite communication**
- **Wireless LAN: UHF to SHF**
  - planned EHF
- **Visible light**
  - communication by laser
- **Infrared**
  - remote controls
  - LAN in closed rooms

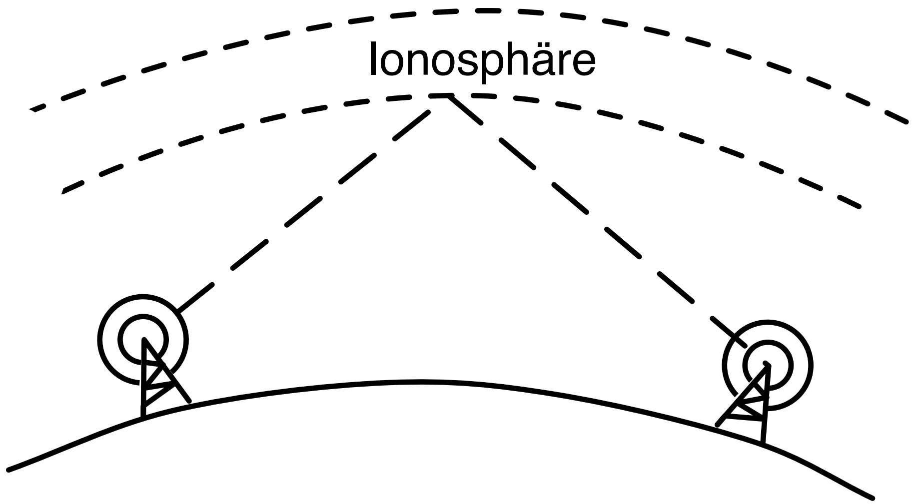
Propagation Performance

- **Straight-lined propagation in vacuum**
- **Received power decreases with $1/d^2$**
  - in theory
  - in practice higher exponents up to 4 or 5
- **Reduction because of**
  - attenuation in air (in particular HF, VHF)
  - shadowing and mountain effect
  - reflection
  - diffusion at small obstacles
  - diffraction

Frequency Dependent Behavior

- **VLF, LF, MF**
  - follow the curvature of the earth (up to 1000 km for VLF)
  - permeate buildings
- **HF, VHF**
  - absorbed by the ground
  - reflected by the ionosphere 100-500 km height
- **Over 100 MHz**
  - straight-line propagation
  - marginal penetration of buildings
  - good focus
- **Over 8 GHz absorption by rainfall**





Problems

- **Multiple Path Fading**
  - Signal arrives at receiver on multiple paths because of reflection, diffusion, and diffraction
  - Signal time variation leads to interferences
    - decoding faults
    - attenuation
- **Mobility problems**
  - Fast fading
    - different transmission paths
    - different phasing
  - Slow fading
    - increase of distance between sender and receiver

Noise and Interference

- **Noise**
  - inaccuracies and heat development in electrical components
  - modeled by normal distribution
- **Interference from other transmitters**
  - in the same spectrum
  - or in neighbored spectrum
    - e.g. because of bad filters
- **Effect**
  - Signal is disrupted

Signal Interference Noise Ratio

- **reception energy = transmission energy · path loss**
  - path loss ~ $1/d^{\gamma}$
    - $\gamma \in [2,5]$
- **Signal to Interference and Noise Ratio = SINR**
  - S = (desired) Signal energy
  - I = energy of Interfering signals
  - N = Noise
- **Necessary condition for reception**

$$\text{SINR} = \frac{S}{I+N} \geq \text{T}hreshold$$

Path Loss

- **Attenuatation**
  - Received signal power depends on the distance d between sender and receiver
- **Friis transmission equation**
  - distance: R
  - wavelength: λ
  - P_r: energy at receiver antenna
  - P_t: energy at sender antenna
  - G_t: sender antenna gain
  - G_r: receiver antenna gain

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

$$P_r(d) = P_r(d_0) \cdot \left(\frac{d_0}{d} \right)^2$$

Path Loss Exponent

- **Measurements**
  - γ path loss exponent
  - shadowing variance σ^2
  - reference path loss at 1m distance

Location	Average of γ	Average of σ^2[dB]	Range of PL(1m)[dB]
Engineering Building	1.9	5.7	$[-50.5, -39.0]$
Apartment Hallway	2.0	8.0	$[-38.2, -35.0]$
Parking Structure	3.0	7.9	$[-36.0, -32.7]$
One-sided Corridor	1.9	8.0	$[-44.2, -33.5]$
One-sided patio	3.2	3.7	$[-39.0, -34.2]$
Concrete canyon	2.7	10.2	$[-48.7, -44.0]$
Plant fence	4.9	9.4	$[-38.2, -34.5]$
Small boulders	3.5	12.8	$[-41.5, -37.2]$
Sandy flat beach	4.2	4.0	$[-40.8, -37.5]$
Dense bamboo	5.0	11.6	$[-38.2, -35.2]$
Dry tall underbrush	3.6	8.4	$[-36.4, -33.2]$

Karl, Willig, Protocols and Architectures for Wireless Sensor Networks, Wiley, 2005

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