The Wireless Propagation Environment

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The radio channel

- The propagation channel is the cause of many of the problems and limitations of radio systems
- Understanding of its properties is therefore key to the understanding of radio systems
- A line of sight (LOS) path between transmitter and receiver is the normal basis for radio transmission systems
- But some systems rely on ‘bending’ of the radio waves for ‘over the horizon’ communications, some on refraction from the ionosphere, some even on scattering from meteorites!

Radio propagation modes and frequencies

extreme low

ELF <3kHz
VLF 3-30 kHz
LF 30-300 kHz
MF 300kHz-3 MHz
HF 3-30 MHz
VHF 30-300 MHz
UHF 300MHz-3GHz
SHF 3-30 GHz
EHF 30-300GHz
(mm-waves)
THz range >300 GHz

ultra high

Wavelength = c/f; (1 GHz is ~30cm)

c = 3e10

LOS microwave link

Repeaters may be used.
BT had 9000 microwave links for network edge and 1000 for its core network
1.4, 4, 5.8, 6, 18 and 38 GHz for 2 Mbit/s to different SDH delivery.
Some very long distances can work with no repeaters. How and why?

Effective isotropic radiated power (EIRP)

- Directional antennas mean that the power radiated is concentrated in the direction of the receiver
- This means that compared with an isotropic (omni-directional) radiator the transmitter has an apparently higher power
- The extent to which the antenna 'directs' the power is referred to as the antenna gain G
- The effective isotropic radiated power is then:

$$EIRP = Pt / G$$

G is not a "real" gain as the antenna is generally a passive device

Path loss

- Normally is the major source of loss (also called Free space loss or LOS)
- Due to the spatial separation between the TX and the RX
- In LOS case loss varies as (frequency)^2 & (distance)^2

receive power

$$C = \frac{P_T}{4\pi R^2} G_T a_e$$

$$= \frac{P_T}{4\pi R^2} G_T \frac{\lambda^2}{4\pi} G_R$$

$$= P_T G_T \left(\frac{\lambda}{4\pi R} \right)^2 G_R \quad [\mathrm{W}]$$

a_e= Antenna effective area
G= Antenna gain

$$L = \left(\frac{4 \cdot \pi \cdot d}{\lambda} \right)^2$$

$$L_{dB} = 20 \log_{10} f_{MHz} + 20 \log_{10} d_{km} + 32.44$$

d in km, f in MHz, which are required to be converted to m, Hz

The Mobile Communications Channel

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Figure 14: Panel Antennas and Corner Reflector Antennas

downlink has higher frequency than uplink

because downlink is usually from Base station,
which means it can afford more power

criterion to choose frequency
1. look for available f
2. characteristics for frequency whether is suitable for application

http://www.wipl-d.com/applications.php?cont=emc/mounted-antennas

Radio spectrum

dBm

If we take one milliwatt as a reference (i.e. P_2) then we have a unit of absolute power called the "dBm", which is defined as follows :

$$P_{dBm} = 10\log_{10}\left(\frac{P_1}{10^{-3}}\right)$$

Where P_1 is in watts.

Power (mW)	Power (dBm)
1mW	0 dBm
5 µW	-23dBm
10µW	-20dBm
1 µW	-30dBm
1nW	-60dBm
1pW	-90dBm
1 kW	60 dBm

Antenna gain and directivity

isotropic antenna

Directional antenna

$$P_r = \frac{P_T}{4\pi r^2}$$

$$P_r = G\frac{P_T}{4\pi r^2}$$

Typical Gain and Beam-width

Type of antenna	G_i [dB]
Isotropic	0
Dipole	2
Helix (10 turn)	14
Small dish	16
Large dish	45

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Phone radiation patterns in proximity of a human head

Novel dual-port antenna typology

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http://www.feko.info/applications/white-papers/design-and-optimisation-of-an-lte-mobile-phone-antenna

Path loss

Given two antennas, the power available at the output of the receiving antenna, P_r, is given by:

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

Where G_t and G_r are the antenna gains (with respect to an isotropic radiator) of the transmitting and receiving antennas respectively, λ, is the wavelength, and R is the distance between the antennas.

Path loss

The path loss, being the ratio of transmitted power to received power, is defined as follows:

$$L = \frac{P_T}{C} = \frac{1}{G_T G_R}\left(\frac{4\pi R}{\lambda}\right)^2$$

Replacing wavelength with frequency :

$$L = \frac{1}{G_T G_R}\left(\frac{4\pi R f}{c}\right)^2$$

If we assume both antenna are isotropic, i.e. Gt=GR=1, we can express the path loss equation in dB for convenience, as follows :

$$L_{dB} = 20\log_{10} f_{MHz} + 20\log_{10} R_{km} + 32.44$$

Path loss as a function of distance and frequency

not linear plot of axis x

Ref. JPL report 2005;

Estimation of Microwave Power Margin Losses Due to Earth's Atmosphere and Weather in the Frequency Range of 3–30 GHz

Effects of gaseous absorption

depend on environment

frequency used in 5G

Reference atmosphere surface parameters:

temperature	15 C
Pressure	1013 mb
water vapour	7.5 g/m^3

area in mountain is thiner than are in ocean, so the attenuation is lower

If we want confine the range of communication, we will use high attenuation.

Specific attenuation due to rain

[After ITU-R, 1996]

Spherical raindrops assumed (therefore no polarisation dependence)

Drop size (Major axis)	1mm	4mm	6mm
Drop shape (a/b)	0.9	0.8	0.7

water will scattering and absorb signal

Cloud attenuation

- Liquid clouds
  - small, spherical, water droplets (0 – 10 µm radius)
  - Significant attenuation above 20 GHz
  - Attenuation proportional to total water content (g/m^3)
  - No cross polarisation
- Ice clouds
  - small needles and plates (sub-millimetre in size)
  - Attenuation (dominated by scattering rather than absorption) negligible below 100 GHz
  - Severe cross polarisation

Liquid cloud specific attenuation

Frequency (GHz)	Attenuation (dB/km)
5.0	0.023
10.7	0.106
15.4	0.217
23.8	0.507
31.4	0.859
90.0	4.74

- Clouds occur in many types
- Thicknesses from 100 m to several km
- Attenuation modest but may be present for large fractions of time - significant for low availability systems

[Extracted from Table 7.1, Brussaard, G & Watson, P A: Atmospheric modelling and millimetre wave propagation, Chapman Hall, 1995] (0 °C g/m^3)

Radio versus cable

- Radio transmission fundamentally involves $1/d^2$ reduction in signal strength due to 'spreading/angular divergence' of the radio waves
- Cable systems, on the other hand, involve an exponential reduction in signal strength with distance
- Exp(-d) is a much more rapid rate of decay than $1/d^2$ so in principle radio systems should ultimately be more capable of providing greater 'single hop' range than cable – although in practice that will depend n the attenuation factor of the cable for any given link radio can propagate in anywhere
- Optical fibres have very low loss indeed (~0.2 dB/km) and in addition we have optical amplifiers available as a means of compensating for fibre loss, so that this 'in principle' ultimate advantage of radio over cable is not commonly applicable in practice

Radio Propagation mechanisms

reflection

scattering

diffraction

- **Reflection**
  - Propagation wave impinges on an object which is large as compared to wavelength (i.e the surface of the Earth, buildings, walls, etc.)
- **Diffraction**
  - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges when the dimension of edge is close to wave length
  - Waves bend around the obstacle, even when LOS (line of sight) does not exist
- **Scattering**
  - Objects smaller than the wavelength of the propagation wave (i.e. foliage, street signs etc.)

Multipath Propagation

power control system to adjust the power from base station depending on power received from devices,

there is feedback between base station and device to give information.

Multi-path propagation

- Multi-path propagation causes signals with different phases to add at the receiver
- This can be constructive or destructive - signal amplitude can go from maximum to minimum with a phase change of π /2
- Shadowing where there are obstructions between the TX and RX can occur and for access systems more complex arrangements relying on reflected paths are encountered.

signal 1 travels $\lambda/2$ farther than Yellow to reach receiver. For 1 GHz, λ=30cm.

Frequency selective fading

?

in real, the environment is statistical not deterministic

Two ray fading (Plane Earth Propagation)

$C = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad P_r = C \cdot F^2$

Received free-space field strength modified by factor *F*:

$$F = 1 + \rho e^{j\phi} e^{-j2\pi\left(\frac{d_2 - d_1}{\lambda}\right)} \cong \frac{4\pi h_T h_R}{\lambda R} \quad \text{for small argument}$$

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

Received free-space carrier power modified by factor $|F|^2$

P is the reflection coefficient, for earth~1

When d>> h_t and h_r

Plane-Earth propagation

$$= \frac{4h_T h_R}{\lambda}$$

For $R > R_{\max}$:

$$C = P_T + G_T - \underbrace{20\log_{10}\left(\frac{R^2}{h_T h_R}\right)}_{L_{PEPL}} + G_R$$

[Note the path loss is *subtracted*]

Multipath Propagation; Positives and negatives!!

- Enables communication even when transmitter and receiver are not in “line of sight”. This allows radio waves effectively to go through obstacles by getting around them, thereby increasing the radio coverage area.
- Using sophisticated digital signal processing the multipath signals can be used to substantially increase the usable signal power at the receiver.

- Increased signal loss.
- Multiple copies of a signal may arrive at different phases. If phases add destructively, the signal level relative to noise declines, making detection more difficult.
- Intersymbol interference (ISI). One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit, causing interference at the receiver.

When the transmitter and/or the receiver moves (as is the case in mobile systems), the channel becomes time varying and frequency dependent

Use of diversity

- Diversity techniques are often used to mitigate the the effects of the wireless channel.
- The principle of diversity is to transmit the same information on two or more sub-channels that fade independently from one another.
- Independently fading sub-channels are realised either in the time, frequency or space domains.
- Selection combining, equal gain combining or maximal ratio combining techniques recombine the information in the various sub-channels at the receiver.

Diversity Techniques

Time Diversity

Frequency Diversity

Space Diversity

most common used

receive same signal with different attena

Single Antenna Systems

Multiple Antenna Systems

Multiple Input Multiple Output systems (MIMO)

Summary

- Looked at the basic radio propagation concepts
- Seen how signal strength may vary and factors for such variation
- Looked at the causes and effects of fading
- Calculation of link budget e.g. path loss = Pt - Pr + …
- Concepts of diversity

Take home points..

Summary

- Looked at the basic ideas behind radio propagation
- Seen how signal strength may vary and factors for such variation
- Looked at the causes and effects of fading
- Related propagation to cellular architectures and frequency reuse
- Calculation of link budget