UNIVERSITY OF CAMBRIDGE

Radio Propagation Modelling

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Why is it needed?

- To predict coverage between nodes in a wireless network
- Path loss is different from environment to environment, e.g., in-building is different to outdoors.
- Knowledge of path loss enables system parameters to be defined, e.g., transmit power, receiver sensitivity and antenna gains.
- Path loss models include:
  - Empirically based – obtained from measurements
  - Analytical – solution of EM equations
  - Simulation – e.g., based on ray tracing or FDTD

Definition of Path Loss

- We will define path loss as a positive number expressed in dB. In which case the expression for received power (in dBm) is:

$$P_{RX}=P_{TX}+G_{TX}+G_{RX}-P_L$$

  Where P_{TX} is the transmit power in dBm, G_{TX} and G_{RX} are the transmit and receive antenna gain (in dBi) respectively, and P_L is the instantaneous value of the path loss.

- The receiver will cease to detect the received data correctly when the received signal power (P_{RX}) falls below the specified receiver sensitivity level, $P_{RX(min)}$

Analytical Path Loss Models

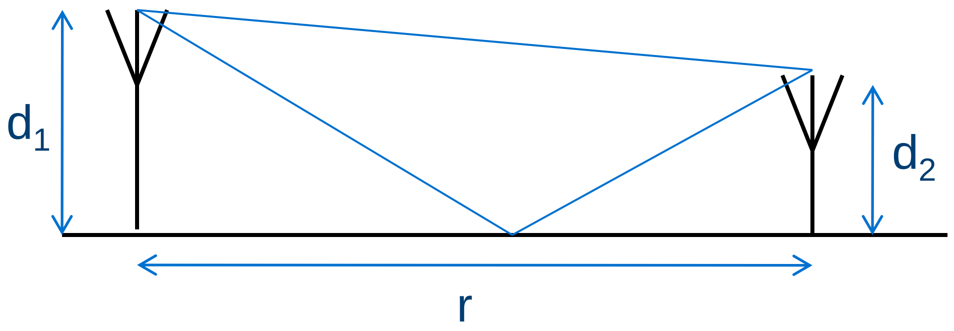
- The path loss (PL) is a is a function of antenna separation and depends upon the propagation environment. For example,
  - In 'free space' it is given by:

$P_L = 10\log_{10}(4\pi r/\lambda)^2$ i.e., 20dB/decade with distance

Where r is the antenna separation (in m), and λ is the wavelength

Analytical Path Loss Models

- Other analytical path loss models are available, e.g., for the so called 'flat earth' or '2-ray' model.

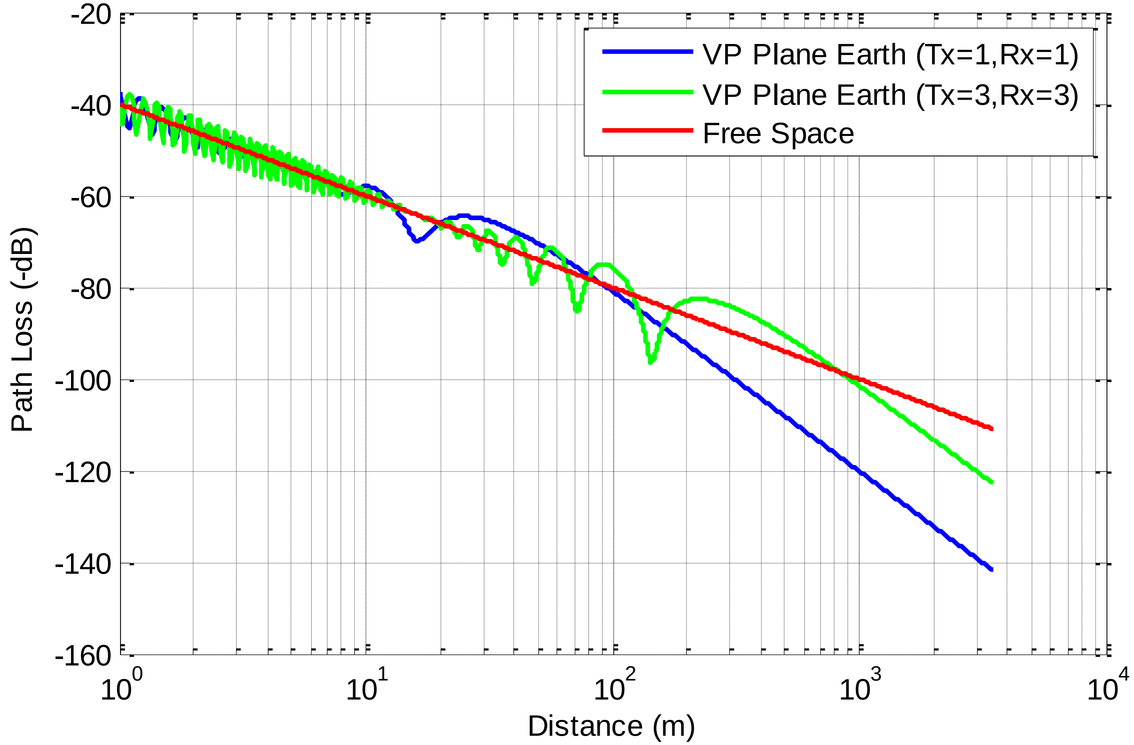


- Provided $r >> d_1, d_2$, then the path loss is given by:

$$P_L = 10 \log_{10}(r^2/d_1 d_2)^2 \quad \text{i.e., 40dB/decade with distance}$$

- We can also handle the case where $r >> d_1, d_2$ is not satisfied by explicitly including the variation of the ground reflection coefficient as a function of distance, wavelength and polarisation.

Flat Earth Path Loss



- Flat earth (or ‘2-ray’) and free space path loss at 2.4GHz
  - Vertical polarisation (VP), dry soil

Other Path Loss Modelling Approaches

- Empirically based path loss models can be determined for particular environments of interest, e.g., outdoor microcells, tunnels. However,
  - Requires an extensive measurement campaign
  - Is costly
  - And is only applicable to the range of parameters actually measured, e.g., frequency, antenna spacing, dimensions of environment
- Consequently, EM based models are also popular, e.g.,
  - Ray tracing
  - Finite difference time domain (FDTD)

EM Based Modelling

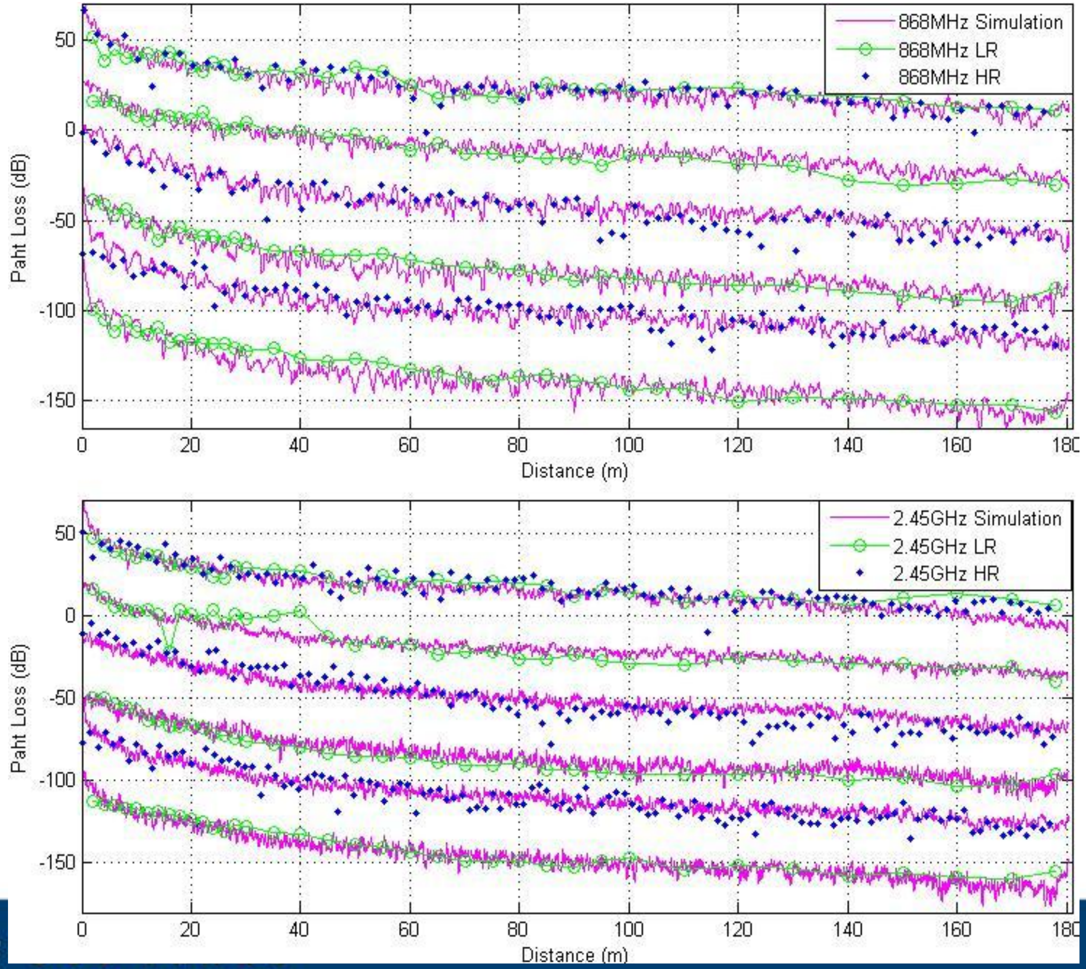
- Need to have detailed plans of the deployment site and material electrical parameters
- Computationally heavy – particularly FDTD
- Ray tracing needs to be carefully tuned for the particular application, otherwise problems can result
- Can predict path loss over a wide range of parameter values, i.e., no additional measurements required

FDTD Modelling

- Finite Difference Time Domain (FDTD) is a time domain iterative solution to Maxwell's equations
- Full 3D FDTD model takes too long to run and uses too much memory
  - Problem reduced to 2D
  - Results need to be corrected to yield results corresponding with a 3D model – so called 'modified 2D FDTD'
  - Correction factors (CFs) determined for well known free space and flat earth models
    - Concept extended to tunnels
    - CF determined by comparison with measurements

FDTD Modelling

- Good match between measurements and 2D FDTD simulations



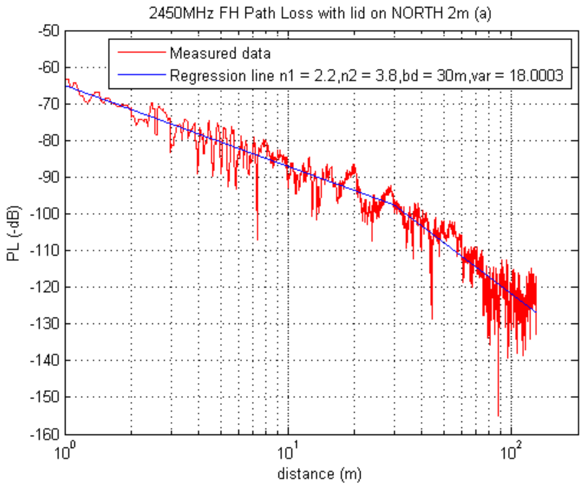
Aldwych tunnel 866MHz

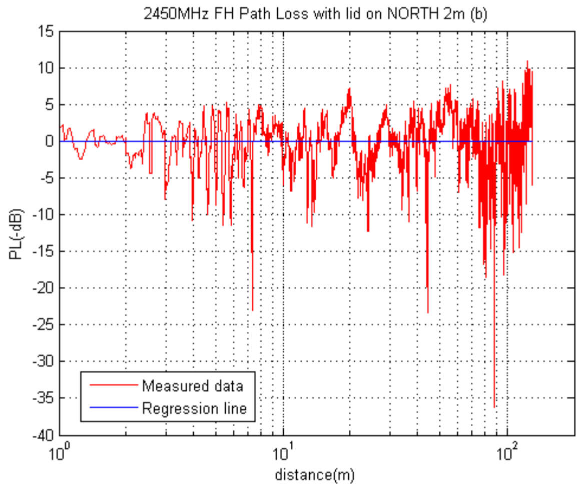
Aldwych tunnel 2.45GHz

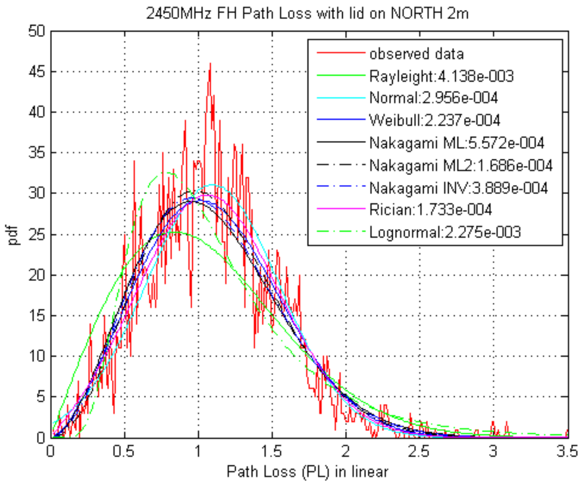
Empirical Modelling

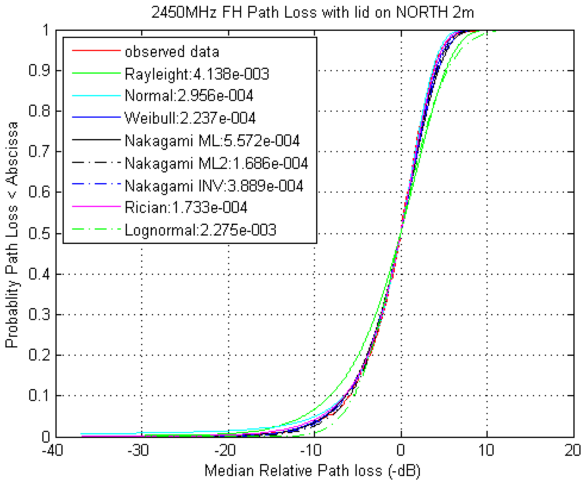
- Measurements performed at 2 frequencies (868 MHz and 2.45 GHz) for various antenna positions
  - Continuous wave battery powered transmitter
  - Half-wave sleeve dipole antennas
  - Anritsu portable spectrum analyser to measure receive signal power
  - Sampled values of received power logged on a laptop
- Fit dual-slope regression lines to data to determine mean path loss
- Fit parameterised probability distribution to data variation around the estimated mean level, e.g., Rician, Rayleigh distribution

Empirical Modelling



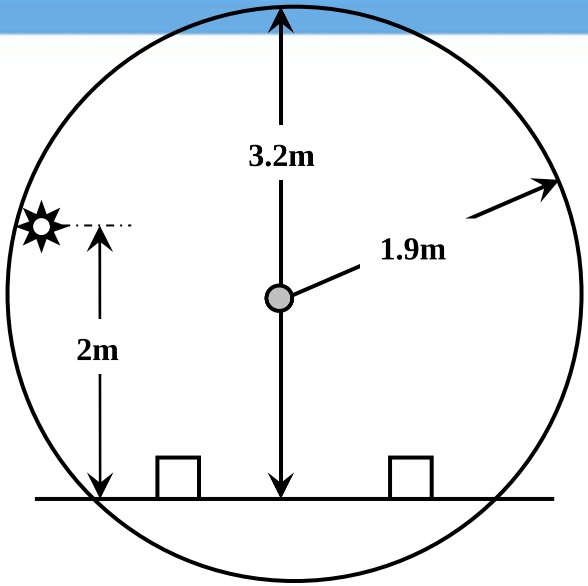






Radio Propagation Characteristics in Tunnels - Qualitative Results

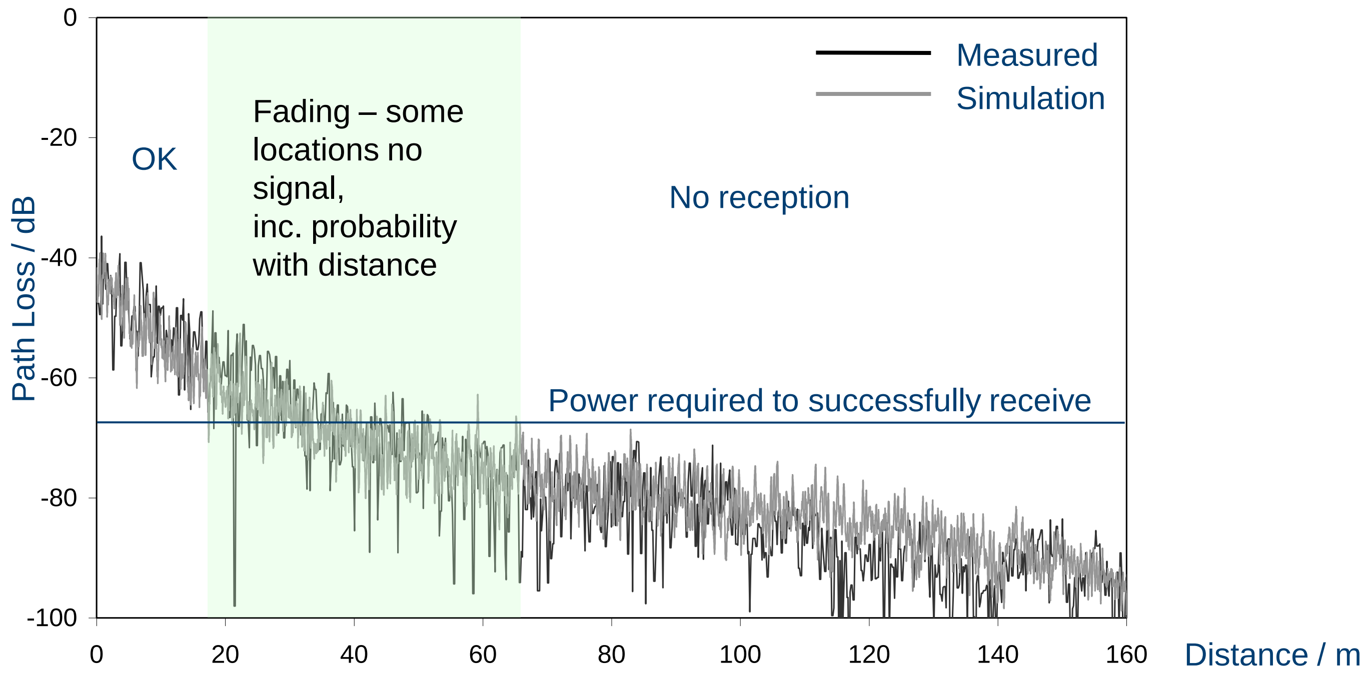
Investigated Factors	PL Performance
Antenna Position	CC case > **Side cases**
Operating Frequency	CC case: 868MHz > 2.45GHz **SS case: 868MHz ≈ 2.45GHz**
Material	CC case: Cast Iron ≈ Concrete **SS case: Cast Iron > Concrete**
Course	**Straight ≈ Curved**
Diameter	Only for concrete tunnels 868MHz: 5.1m > 3.8m 2.45GHz: 5.1m ≈ 3.8m



Investigated Factors	Fading Effects
Antenna Position	CC case < Side cases
Operating Frequency	868MHz < 2.45GHz
Material	Cast Iron > Concrete

Fading

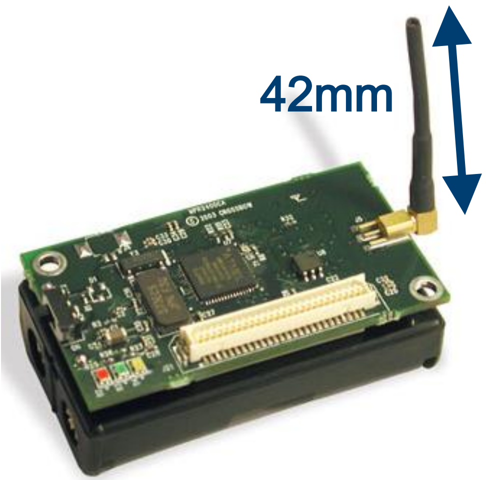
- As we have seen, the received signals exhibit so called ‘Multipath fading’
  - Destructive or constructive interference between multiple arriving signals at the receive antenna owing to reflections in the environment

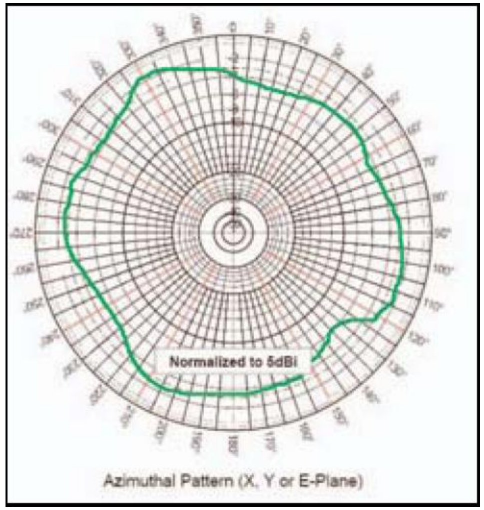


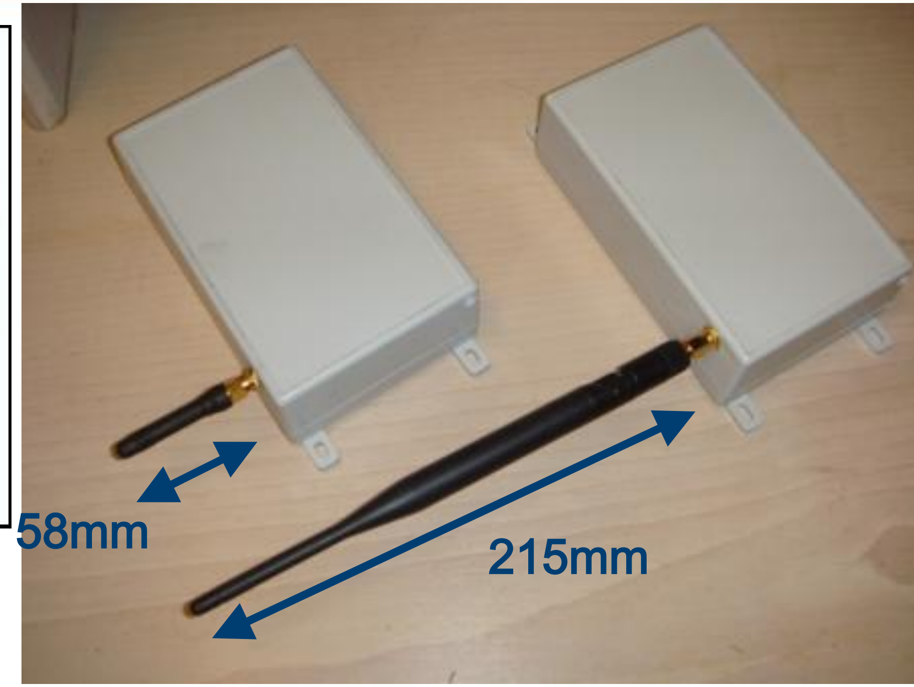
Current Approaches to Overcome Fading

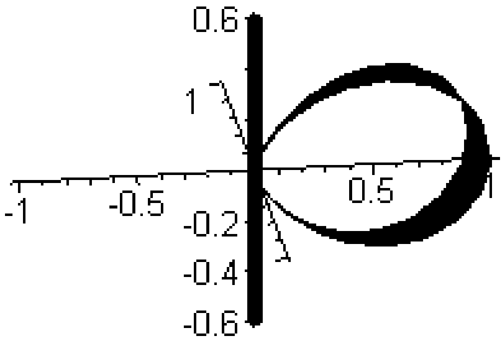
- Increase transmit power
  - Battery life penalty
- Improve receiver sensitivity
  - Cost implications
- Relay/multihop networks
  - Cost, installation time
- Increase antenna gain
  - Size, cost, robustness issues

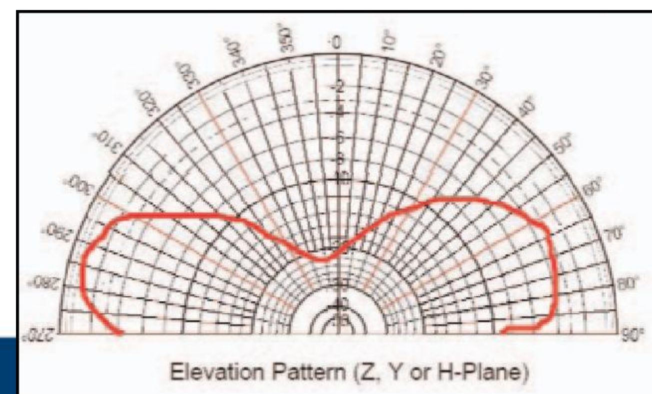
Antennas


42mm


Normalized to 5dBi
Azimuthal Pattern (X, Y or E-Plane)

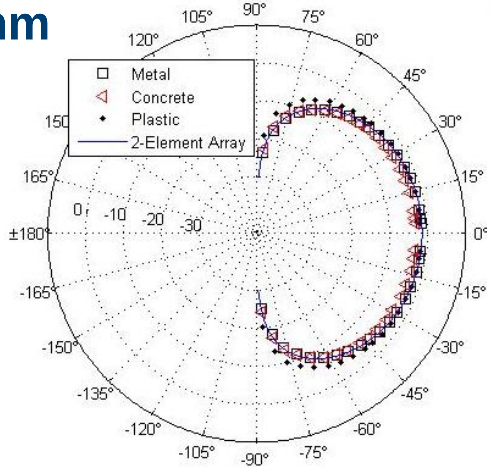

58mm
215mm


0.6
1
-1
-0.5
0.5
-0.2
-0.4
-0.6

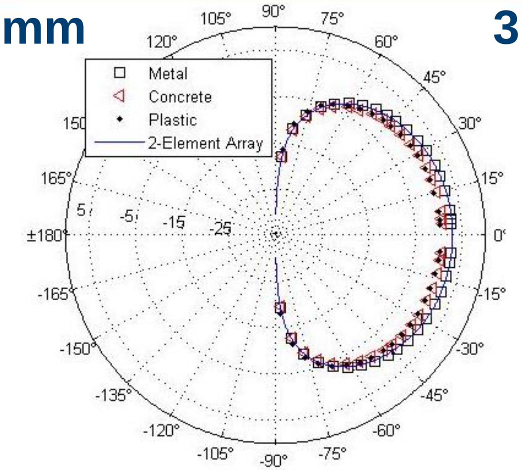

Elevation Pattern (Z, Y or H-Plane)

Effect of Close to Wall Antennas

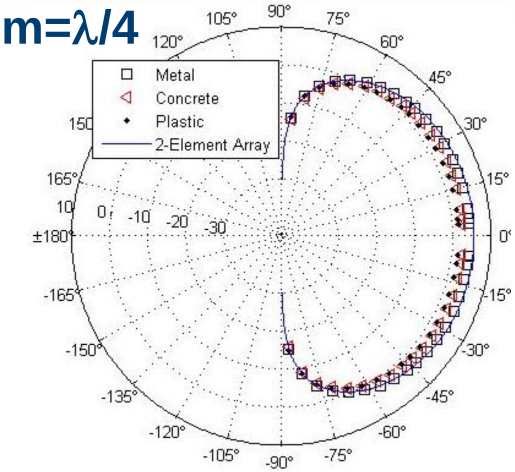
6mm

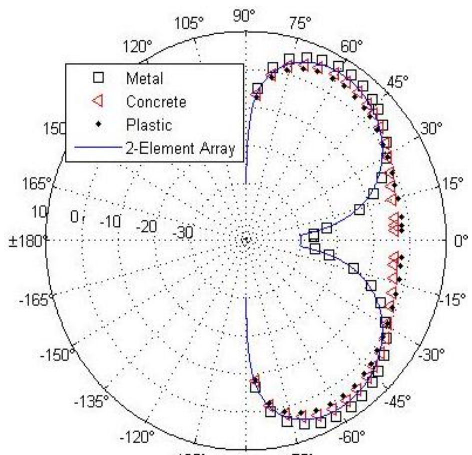


20mm

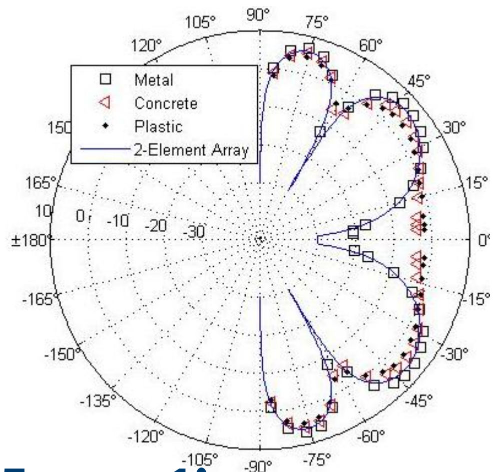


31.5mm=λ/4

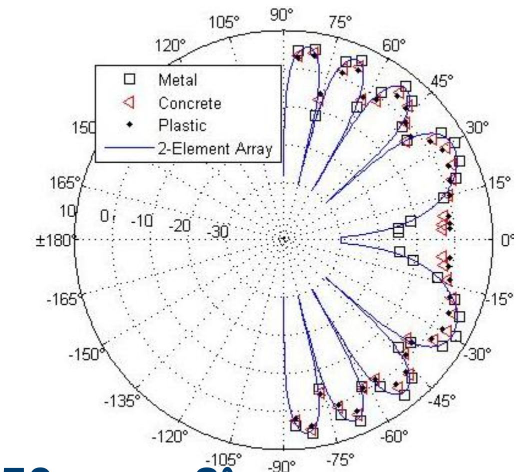




62.5mm = λ/2



125mm = 1λ



250mm = 2λ

Diversity to Overcome Fading

- Dependent on the environment – geometry, materials
  - Can be modelled stochastically – difficult to predict exact location
  - Fade positions static in a static environment
  - Possibly solutions include frequency or space diversity

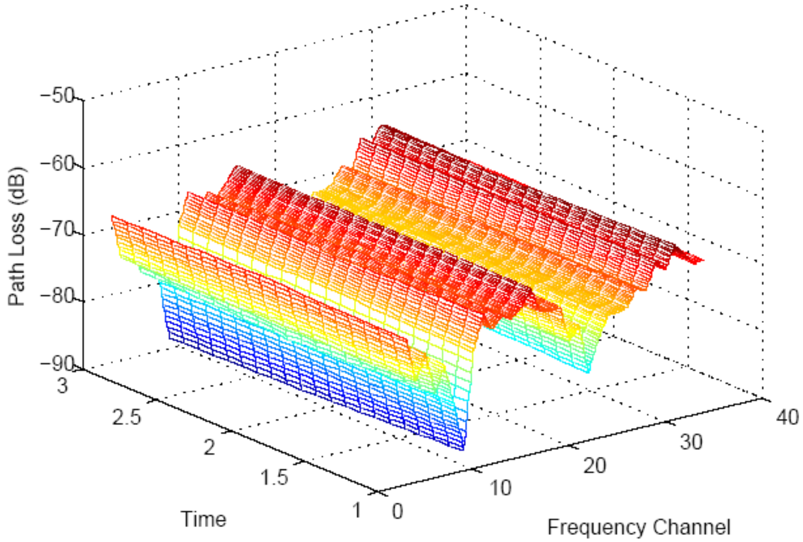
Frequency Diversity

- Measurements conducted every 10m in 90m cast iron lined tunnel
  - Measurements of received signal measured on 32 freq. channels, 5MHz spacing in 2.4GHz ISM band

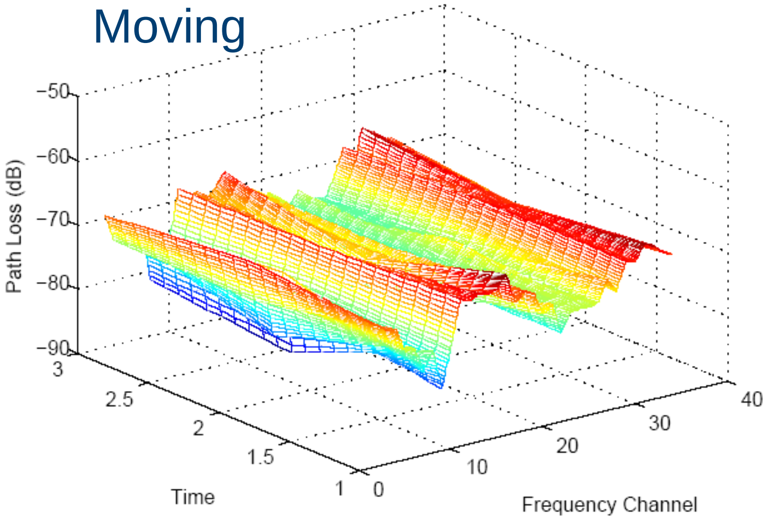
Frequency Diversity

- See change in path loss from channel to channel
- Note effect of changing environment

Empty

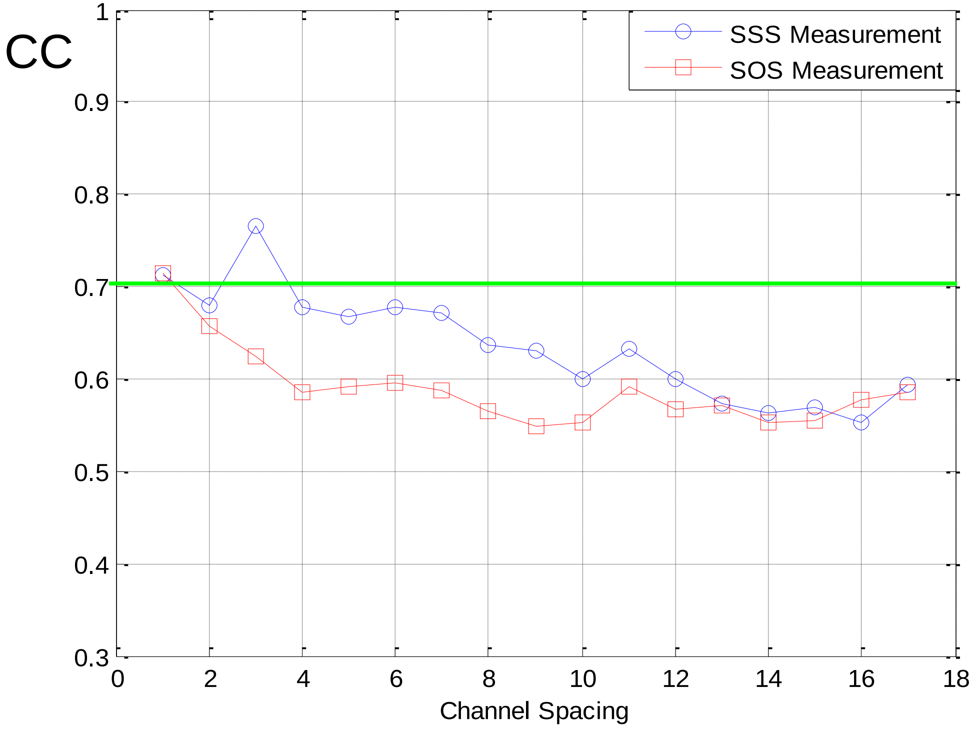


People Moving



Frequency Diversity (FD)

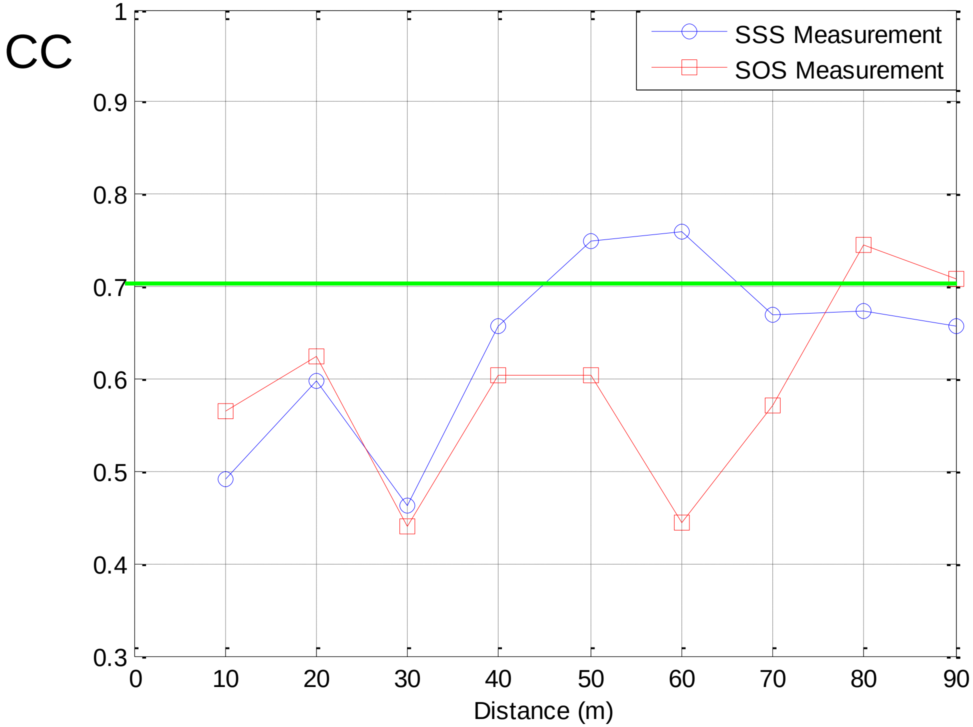
- Potential diversity gain quantified using correlation coefficient (CC)
  - Values <0.7 indicate worthwhile gain



- Hopping by 1 channel gives reasonable FD gain
- FD gain increases with channel separation
- Antennas on Same side (SSS) of tunnel wall experience less FD gain than antennas on opposite side (SOS)

Frequency Diversity (FD)

- Potential diversity gain quantified using correlation coefficient (CC)
  - Values <0.7 indicate worthwhile gain



- FH gain decreases with distance
- SOS in general experience greater FD gain than SSS

Frequency Diversity (FD)

- FD has the potential to achieve diversity gain in the tunnel environment
- Use of FD will improve link reliability and so ease deployment problems
- No additional hardware required, but will make media access control (MAC) layer more complicated
- Will give some immunity to radio frequency (RF) interference
- We will also be investigating the use of space diversity (SD)

Conclusions

- Propagation knowledge important when planning deployment
  - We have determined empirical and FDTD models
- Antenna gain, radiation pattern and location important
- Fading a problem
  - Difficult to accurately predict
  - Frequency Diversity may be applicable in some environments