Millimetre Wave Wireless Access:  
The Path to 5G Enhanced Mobile Broadband

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5G: The Networked Society

• Broadband experience: everywhere; anytime
• Smart vehicles, transport & infrastructure

Target Specs:
• 10Gbit/s Peak, 100Mbit/s where ever needed
• X100 – x1000 Capacity
• X10 battery life
• Reduced Latency (1ms)

• 5G Requires
  • Enhanced Spectrum Efficiency .. Massive MIMO for sub-6GHz
  • New Spectrum ...... Millimetre wave bands
mmWAVE Propagation Versus sub-6GHz

\[ P_r = P_t + G_t + G_r + 20 \log_{10} \left( \frac{\lambda}{4\pi R} \right) \]

35 dB more loss at 60 GHz than 1 GHz
Measurement Equipment

Keysight Technologies based:

- Waveform generation and up-conversion:
  - M8190A Arbitrary Waveform Generator & M9009T Waveform Creator Software.
  - Either E8277D Vector Signal Generator (<44GHz), SiversIMA (60, 70 & 80GHz) transceivers or Silicon Image 6310 devices.

- Down-convertor and waveform analysis:
  - PXIe Quad Downconverter (<50GHz), SiversIMA transceivers (60, 70 & 80 GHz) or Silicon Image 6310.
  - MS0S804A Mixed Signal Oscilloscope and 89601B Vector Signal Analysis Software.
Spatial Dynamics of the mmWave channel. All measurements were performed at 60GHz with a bandwidth of 2GHz. Investigations:

- Transition from LoS to NLoS (through the mechanism of corner diffraction).
- “Large-scale” effects which refer to the spatial evolution of propagation parameters, such as delay and angular spreads, over longer distances of travel (in the order of a few metres).
  - Spatial measurements at intervals of 50cm with the receiver rotating through 360 degrees in azimuth.
- “Small-scale” effects which refer to rapid channel variations over very short distances of travel (in the order of only a few centimetres or even millimetres) over which the propagation parameters such as delay and angular spreads remain unchanged.
  - Diffuse scattering (specular path, cross-polar discrimination and non-specular paths).
Transition from LoS to NLoS – corner diffraction
Measurement Scenario
Corner Diffraction – Measurement & Modelled
mmWAVE Propagation: Diffuse Scattering
mmWAVE Propagation: Diffuse Scattering

K-factor (dB) | Coherence distance (cm)
--- | ---
Incident angle (= reflected angle) 75° | 75° | 45° | 30° |
Rough wall | 0.2 | 3.6 | 5.0 |
| | 2 | 2 | 1 |
LoS is blocked and user moves 2 metres further away.

- **Analogue beamforming**: exhaustive search:
  - **AP**: 32 antenna elements and forms 64 beams;
  - **User**: 8 antenna elements and forms 16 beams;
- **Specular reflection**: Signal power of reflected path from a given surface is calculated (Fresnel reflection);
- **Diffuse scattering**: Small-scale fluctuations added to mean signal power (modelled as K-factor variation with coherence distance term);
  - Rough wall: K-factor = -3dB, coherence distance < 1cm;
  - Smooth wall: K-factor = 5dB, coherence distance = 5cm;
**mmWAVE Beamforming Analysis**

- **Specular reflection:**
  - Reflected signal from concrete (rough ~6 dB higher plasterboard (smooth) due to the dielectric constant
- **Diffuse scattering:**
  - Diffuse signal power from concrete has higher average power (larger dynamic range & shorter coherence distance)

- 24 dB beamforming gain possible with optimum beam direction at both AP and UE
- Pointing angle for specular reflection (red) is nearly constant, but the optimal diffuse pointing angle (blue) varies rapidly.

![Scattered Reflection Ray Power](image1)

![Angle of the Selected Beam at User Array](image2)
Full 3D Dynamic Scene visualised with Ray Geometry and (Beam Patterns)

Visualisation of Power Delay Profile as user moves

Visualisation of Spatial Channel Response
Anite 2 x F8 Radio Channel Emulators

Anite F8 Channel Emulators: Wi-Fi, LTE-A and mmWave

Anite F8 Channel Emulators: EPSRC Experimental Equipment Award
Open Research Questions

Antenna Element Design, Polarisation, Array Geometry, Beamformer, …. testing

Integration with Software Enabled Networks

Rapid and Accurate Propagation Prediction & Planning tools

Beamformer Algorithm Optimisation: Urban, sub-urban ….. specialist deployments