Challenges in Millimetre Propagation Channel Measurement and Analysis

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mmWave systems

- To provide high throughput in small geographic area
- Various applications such as access, backhaul link, single/multi-user, V2X
- Interference and mobility becomes more of a challenge
- Super directional links using beamforming

(Source of figure and contents: Professor Robert W. Heath Jr., Millimeter Wave MIMO Communication, http://www.profheath.org/)
mmWave technology specific

- Propagation loss is high compared to sub-6 GHz setups
- Wireless link is directional to compensate for the propagation loss
- Few multipath exist in the channel, i.e. the link relies on one/two/three multipath
- Multipath blockage can happen easily
Wireless system design at PHY and higher layers are directly affected by wireless channel characteristics:

- PHY algorithms and architectures
- MAC schemes
- Radio circuits / power amplifier
- Antennas single-multiple, 2D/3D arrays
- Form factor

Reliable **channel models** are used in the system and network design
Requirements for mmWave channel modelling

- Path loss
- Spatial spread (angular characteristics)
- Delay spread with high resolution
- Polarization characteristics
- Time variance
- Blockage
- Penetration
mmWave channel characterization

Main points to be considered

- Coverage is most important feature to be extracted out of mmWave channel analysis
  - What can be the cell size for each band
  - How the coverage changes when it is LoS or nLoS
  - How much indoor coverage can be achieved from an outdoor base-station
- How much the link can rely on the nLoS components
- What are the main scatterers in the desired scenarios
- How to model the components close to the LoS in the delay or angular domain
- How to model the spatial scatterings with the required resolution for the mmWave systems
- What is the polarization characteristics of the main components
Requirements for mmWave channel model

- In general a good channel model should do a sensible trade-off between simplicity and accuracy
- mmWave channel model needs to cover the **wide range of frequencies** and to be consistence over this range
- Requires very **high resolution in delay** domain as the system bandwidth is large
- **Very good spatial resolution** (3D) is required as mmWave systems use very directional links, e.g. by employing pencil beams
- **Time variance of the channel**, including the continuous variations over time or especially considering the blockages in the channel and change of the scenario between LoS/nLoS needs to be appropriately modelled
- It has to be **independent from the antenna characteristics**, such as directivity and frequency response, i.e. the antenna effects has to be de-embedded
- Needs to take into account **scatterings from objects**, especially when these are close to LoS in delay or angular domain
- **Polarization characteristics** of the channel need to be modelled accurately
Current channel models for mmWave

- **METIS** channel model
  - The stochastic model as an extension of **WINNER+** and **3GPP-3D**
  - Deterministic model
  - Hybrid model
  - Parameters extracted based on measurement campaigns

- **NYU** channel model
  - Similar approach to the **3GPP-3D**
  - Based on measurement campaigns at various bands

- **mmMagic** H2020 project
  - Working on the channel modelling
  - Results expected to be published yet
mmWave channel characterization/modelling

- Common approach
  - Use the existing, extensively researched, sub-6 GHz channel models as the baseline
  - Extend them to mmWave frequencies and scenarios
  - Extract the missing parameters out of appropriate measurements data
  - Perform measurements when the required data is not available in the literature
Suitable measurement

- The scenario of the interest has to be emulated similar to the real scenario, i.e. in terms of link range, antenna height, etc.
- Required delay resolution is typically 0.5 ns or higher, i.e. measurement bandwidth more than 2 GHz
- Multipath has to be resolved in time and spatial domain, i.e. directional measurement and data analysis
- Spatial (angular) resolution of the measurements are to be high enough for the mmWave systems, e.g. 1 degrees resolution
- Measurements have to be 3D
- Full polarimetric measurements are recommended to capture polarization characteristics of the channel
- Blockage and time variance of the channel need to be captured and properly modelled
- Antenna characteristics need to be de-embedded from the channel
- To capture most scatterings in the channel large sounding dynamic range is required
Wireless channel – A linear system

- For any instance in time domain the channel response is the input-output relation of a linear time-invariant system.

\[ x(t) \rightarrow y(t) \]
In theory, an infinite bandwidth impulse would be transmitted periodically over the radio channel to measure the time variant channel impulse response, \( h(\tau,t) \), at the receive side of the radio channel.
Channel sounding

A known signal to the receiver is released in the channel.

- Channel attributes are inherent in the received signal.
- Which attribute of the channel is of interest? Which one is of less importance?!

Received signal plus some info from environment are recorded for off-line processing.
mmWave channel sounding requirements

- Covering multiple mmWave bands
- Providing high time delay resolution on the order of cm’s
  - sounder with a large transmission bandwidth
- Covering high Doppler shifts, especially for outdoor applications
  - sounding setup and waveform with a large repetition rate
- Providing large measurement dynamic range
  - High receiver sensitivity
  - Efficient power amplifier
- Assisting very good spatial (angular) resolution
  - Large antenna array with fast switching system
  - Narrow beam directional antenna with precise rotating system
Common channel sounders 1

- Vector Network Analyser (VNA),
- The desired bandwidth is excited with a narrow band signal moving across the bandwidth and the frequency transfer function is measured
- Wide bandwidth
- High cable loss limits the dynamic range / link range
- Measurement is slow (due to sweeping the full band)
Common channel sounders 2

- arbitrary waveform generators for signal generation at the transmitter, spectrum analysers as receivers which covers all receiver functions including down converting
- A sounding signal with outstanding autocorrelation properties, such as Frank-Zadoff-Chu sequences is used
- Exceptional properties such as minimum phase noise, long-term stability and repeatability of the transmit signal and low noise figure and linearity at the receiver signal analyser
Custom designed channel sounders

- TU Ilmenau [1]
- Durham University [2]
- NYU Wireless [3]

Sounding techniques

- Pseudo random binary sequence (PRBS) waveform
- Frequency swept method (FMCW)

To get the spatial (angular/directional) dispersion of the channel

Required setup

- Directional antenna + rotator
- Single antenna + precise positioner
- Array antenna at one or both link ends (linear / planar / cylindrical / spherical)
Directional measurement

- To get the spatial spread of the channel with high resolution:
  - Large, calibrated, well shaped antenna array with appropriate switching network is required
    - Switching between antennas has to be fast enough to capture all signals from all antenna elements in the coherent time of the channel
    - Both polarizations can be considered in the design
    - Not cost effective
  - Scanning the channel by means of directional antennas and rotating table
    - Slow measurement since the channel has to be scanned at each azimuth
    - Polarization measurement can be achieved by changing the antenna polarization, but consumes more time
    - 2D measurement
To get the polarimetric characteristics of the channel, such as XPR
A combination of both polarization antennas has to be used in the setup
Sounding hardware specs - synchronization

- Synchronization is critical in channel sounding
  - Common clocks (by connecting a cable)
  - Rubidium atomic clocks are normally used to improve the synch performance for longer links (drifts after few hours >> Cesium clocks for better performance)

- Tx/Rx synchronization in the remote operation mode
  - Initial synchronization is accomplished by a back-to-back calibration procedure
  - Frequency references are kept synchronized
    - Separate Rubidium/Cesium reference sources at both Tx and Rx are required and the local oscillator (LO) signals have to be generated at both sides
Back to back calibration
- overall device frequency response is measured and stored for equalisation purposes
- AGC dependent back-to-back calibration when possible is advantageous

Absolute device power
- operating the transmitter with its nominal output power to a reference attenuator

Figure courtesy of M. Landmann.
a switched AGC in well-defined calibrated steps to cover a range of up to 50...60 dB

The AGC setting has to be implemented on the basis of instantaneous peak value estimation

In case of multi channel measurements the AGC timing control must be synchronised to the multi-channel operation to avoid uncontrolled transients

When measuring the cross polarised channels AGC needs to adjust the gain for each channel separately to provide best resolution

Calibration per AGC setting is required
Power amplifier
- Nonlinearity of the power amplifier requires appropriate calibration
- In case of multi-antenna measurements with switch, the arrangement of antenna switches and amplifiers in the RF signal path always requires a trade-off between sensitivity and phase stability
  - If there is a single PA used for all channels, the corresponding antenna switch has to handle the full output power
  - the advantage of using a single PA for all channels is that the PA always has the same frequency response (except phase drift)

Receiver sensitivity
Phase noise
Measurement data analysis

• Post processing to derive desired attributes of the channel
• Interpretation of the results and propagation micromechanism identification
• Contribute to channel models
mmWave channel studies at 5GIC

- To complement the existing models and activities on the mmWave channel elsewhere we target to derive:
  - Accurate prediction of the coverage in urban scenarios
  - Indoor coverage from an outdoor base-station
  - High resolution spatial model of the channel
  - Polarization characteristics of the urban channel

- Measurements have been performed and are in progress for the required scenarios

- Data analysis of the measured data and modelings are in progress
5GIC mmWave channel measurements

Small cell propagation channel measurement campaigns at various mmWave bands

- Wideband, directional, full polarimetric measurement and analysis
- Small-cell scenario on the campus of University of Surrey and University of Durham
- Measurements at BRE in planning

Collaboration with Rohde and Schwarz
5GIC mmWave channel measurements

- Wideband sounding setup
- Directional measurements using narrowbeam antennas and rotating table
- Full polarimetric by repeating measurements
Measurement setup

R&S SMW200A
Vector Signal Generator

R&S FSW67
Signal and Spectrum

Receiver horn antenna mounted on the rotating table pole:
- 22.8 dBi @ 32 GHz
- 25 dBi @ 39 GHz
- Beamwidth: 8 degs

8.2 dBi @ 32 GHz
10 dBi @ 39 GHz
Beamwidth: 54 degs
Main scatterers/reflectors in the channel can be identified

The interactions in the channel need to be modelled

Further extensions are required for better resolution in space and for 3D measurements
Thank you!

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