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Measurement and modeling of mm-wave channels – from pathloss to dynamic directional models

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Motivation

Why channel modeling?

- Forms basis of system design
- Needed for standardization
- Insights for deployment scenarios

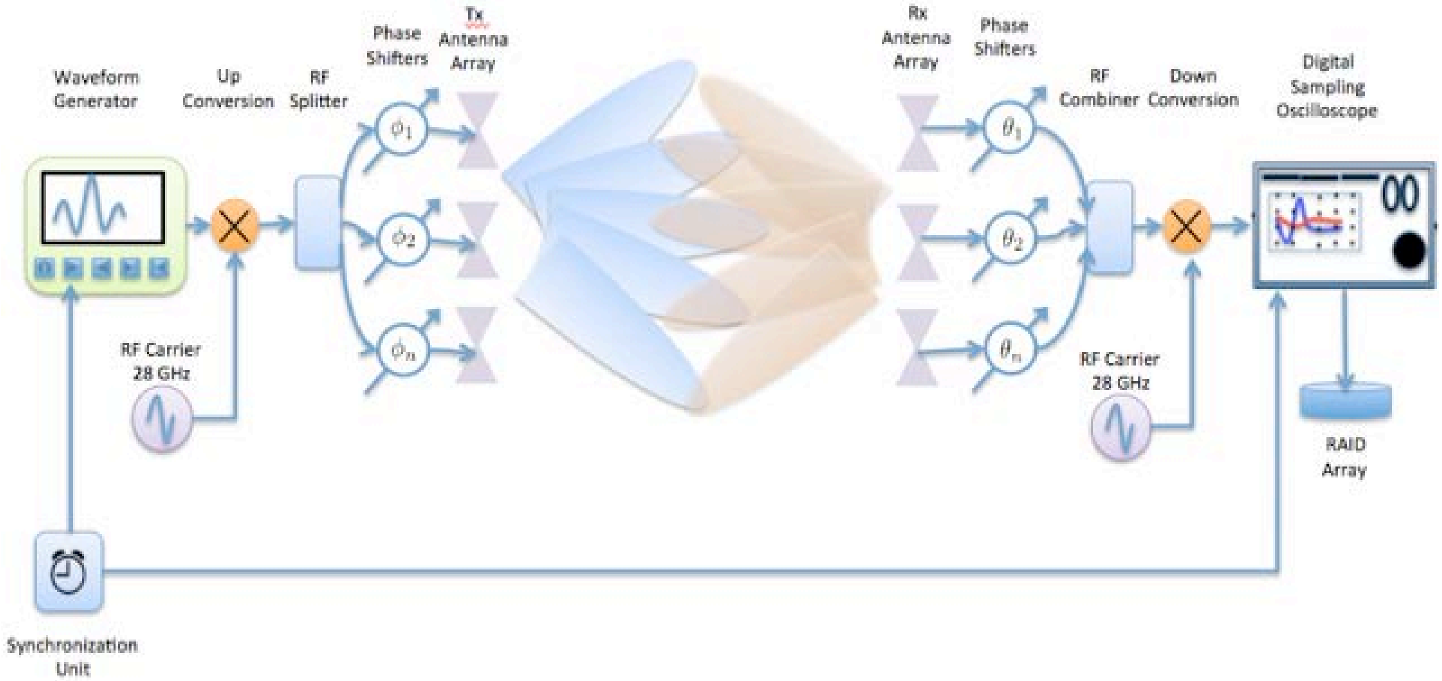
What are main challenges?

- Many measurement campaigns have been done, but many open issues:
  - Statistically meaningful amount of data
  - Detailed statistics of multipath
  - Dynamic evolution of channels

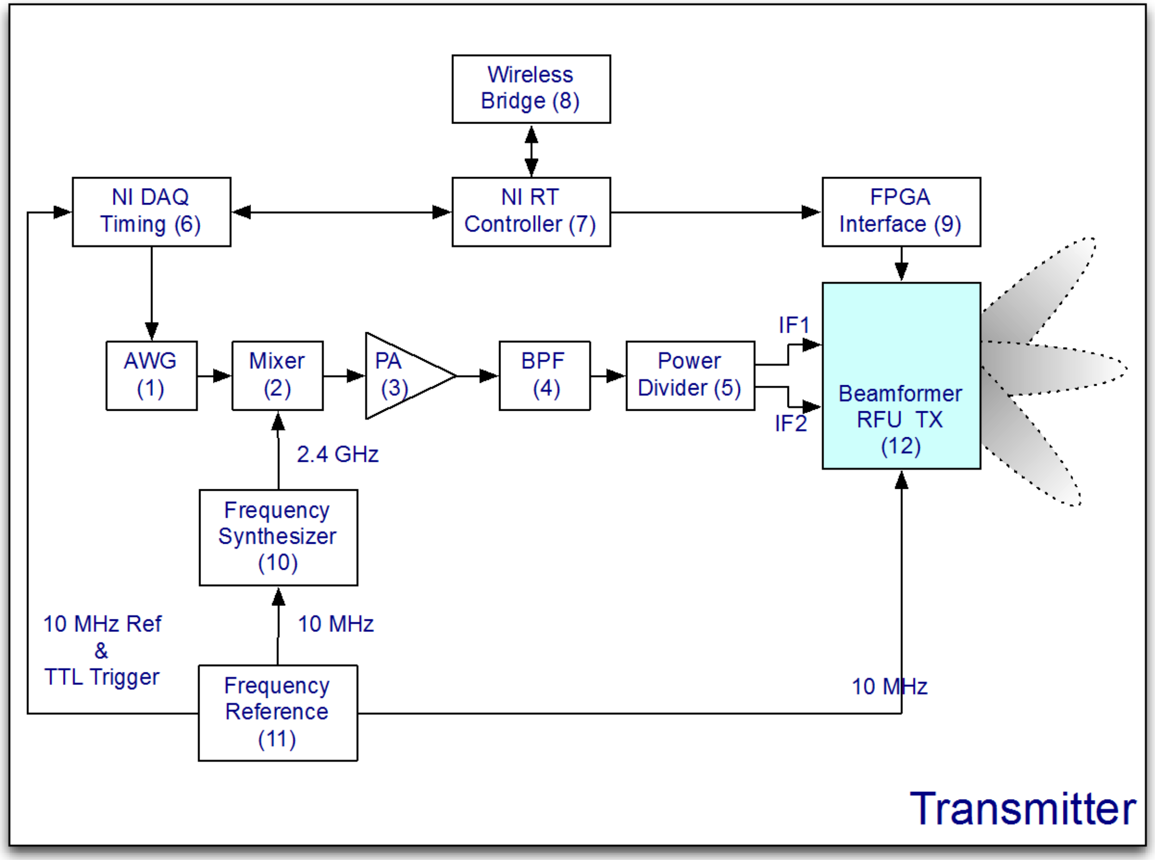
The USC/Samsung channel sounder

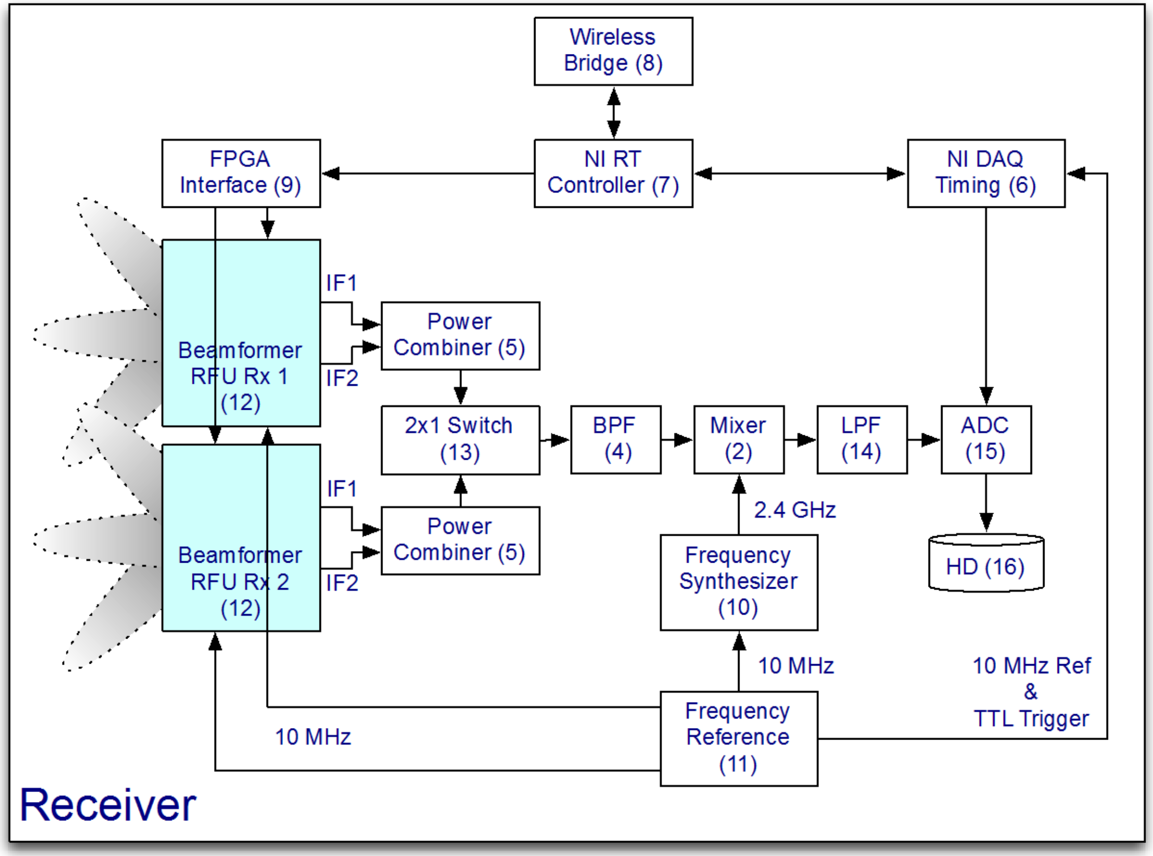
Goals and design principles

- Enable dynamic directional channel sounding: phased array
- Enable capturing of large amount of data: high speed baseband/streaming design
- Enable high-resolution evaluations (accuracy and resolution ~1°): precision calibration and low phase noise design
- Enable large distance range: high power, separate amplifier for each antenna



Block diagram of the sounder





Calibration

Challenges

- No separation of antenna calibration and RF calibration possible
- Calibration can depend on AGC settings, but large dynamic range
- Even small offsets (~1mm) of rotation axis from array phase center impact calibration at mm-wave frequencies

Solutions

- Developed set of new calibration methods to solve all these issues

High-resolution evaluations

Standard evaluation does not allow to resolve multipaths well

- Typical measurements have 10-30 degree beamwidth
- All MPCs falling within one beam appear to have same direction
- Leads to erroneous conclusions about channel sparsity, clustering, etc.

Solution

- Maximum-likelihood estimator (RiMax), with suitable modifications for mm-wave
- Mathematics are highly complex
- But: we developed accelerations that allow evaluations of many measurement points in reasonable time

Data model for Rimax

- Proposed data model of specular paths:

$$\mathbf{s}(\theta_{sp}) = \mathbf{B}_t \diamond \tilde{\mathbf{B}}_{TV} \diamond \tilde{\mathbf{B}}_{RV} \diamond \mathbf{B}_f \cdot \gamma_{VV} \in \mathbb{C}^{M\times 1}, \qquad (1)$$

- Proposed data model of DMC and noise:

$$\mathbf{n}_{\text{dan}} \sim \mathcal{CN}(0, \mathbf{R}_{\text{dan}}) \qquad (2)$$

$$\mathbf{R}_{\text{dan}} = \mathbf{R}_t \otimes \mathbf{R}_T \otimes \mathbf{R}_R \otimes \mathbf{R}_f + \sigma^2 \mathbf{I} \qquad (3)$$

- Parameter initialization
  Solution: a tensor-based method for SP, a modified method based on [1].

- Joint optimization of SP and DMC parameters via nonlinear optimization methods, such as Levernberg Marquardt, Gauss-Newton algorithm.
  Difficulty: Efficient method to compute Jacobian matrix, Fisher Information Matrix and Score function.

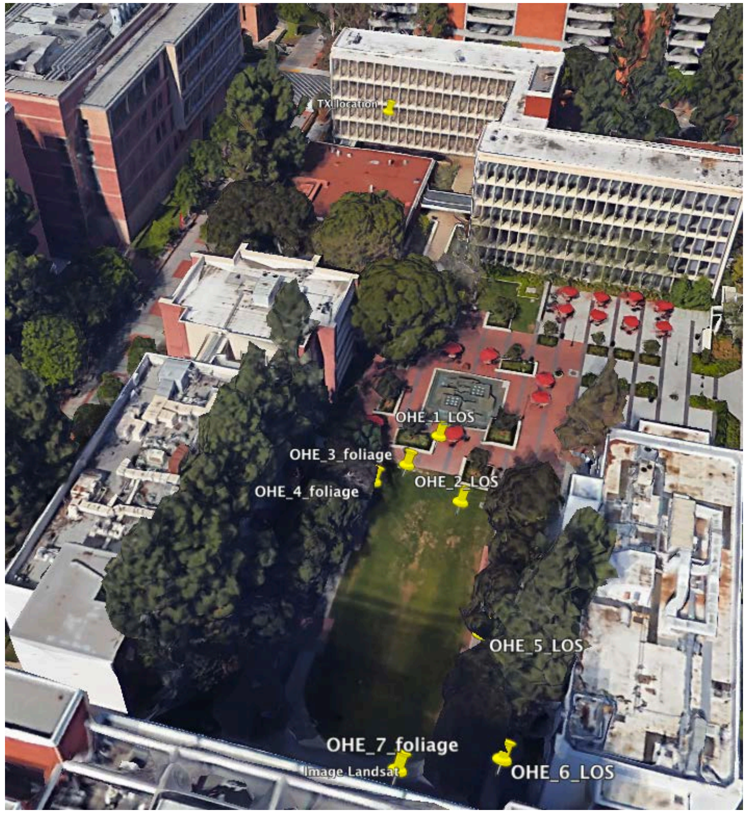
- Assume repeated sequential switching, T_0 is the duration of one MIMO snapshot.
- The newly added basis matrix:

$$\mathbf{B}_t(\nu) = \begin{bmatrix} e^{j(-\frac{T-1}{2})\nu_1} & \dots & e^{j(-\frac{T-1}{2})\nu_P} \\ \vdots & \ddots & \vdots \\ e^{-j\frac{T-1}{2}\nu_1} & \dots & e^{j\frac{T-1}{2}\nu_P} \end{bmatrix} \qquad (4)$$

- Weighted Tx/Rx array Matrix: $\tilde{\mathbf{B}}_{TV} = \mathbf{B}_{TV} \odot \mathbf{A}_{t,T}$

$$\mathbf{A}_{t,T}(\nu) = \begin{bmatrix} e^{j\frac{t_{T,1}}{T_0}\nu_1} & \dots & e^{j\frac{t_{T,1}}{T_0}\nu_P} \\ \vdots & \ddots & \vdots \\ e^{j\frac{t_{T,M_T}}{T_0}\nu_1} & \dots & e^{j\frac{t_{T,M_T}}{T_0}\nu_P} \end{bmatrix} \in \mathbb{C}^{M_T\times P} \qquad (5)$$

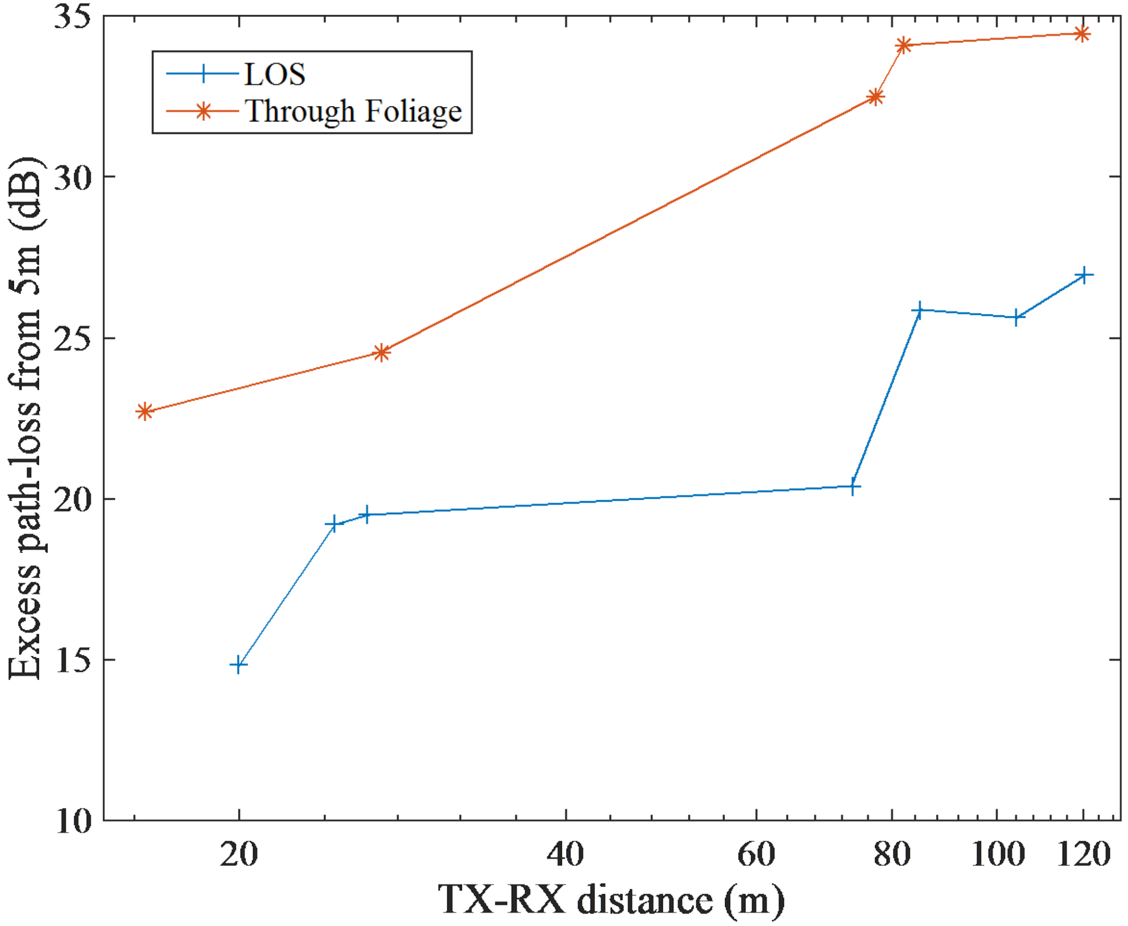
Sample results – foliage attenuation (I)



- TX Height: 11m; RX Height: 1.8m
- 7 RX locations; TX – RX separation varying from 72m to 120m

OHE_4 shadowed by trees, distance: 82m

Sample results – foliage attenuation (II)

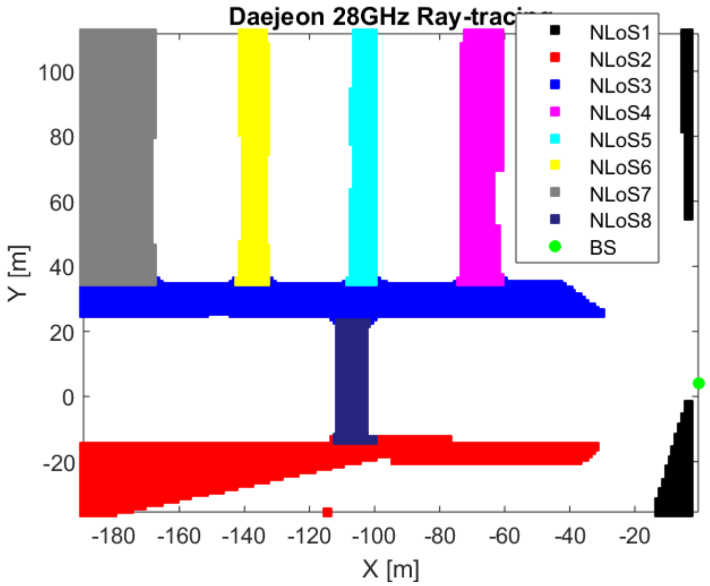


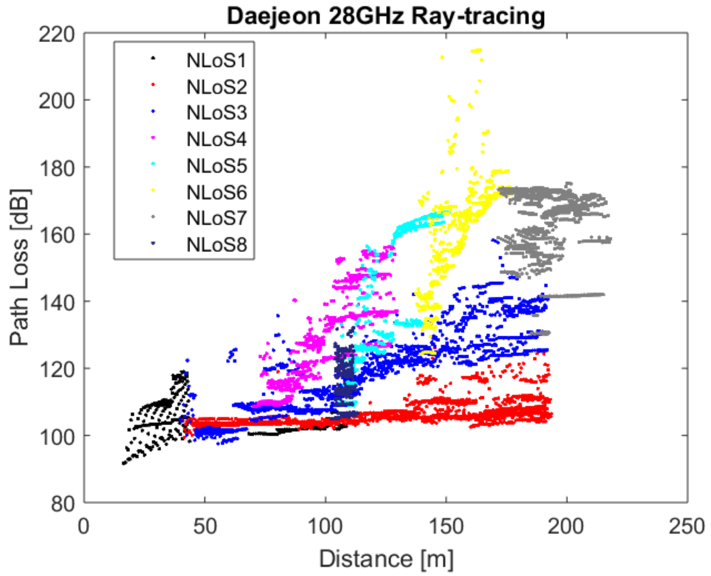
- Observed path-loss difference between LOS and shadowed by foliage varies from 5dB to 12dB for similar distances.
- Path loss exponent for LOS:1.2
- Path loss exponent through foliage: 1.5

Channel modeling

Pathloss model

- Model of older papers: pathloss increases moderately with distance, but very large variance
- Our insight: variations due to different pathloss coefficients in different streets





- Why is that important: (i) properly model spatial consistency (length of fading dips, frequency of handovers), (ii) can be combated with proper deployment

Summary

New channel measurements and models are critically important

- Current models, including 3GPP models, are not sufficient
- Need directional, dynamic measurements with statistically significant number of points
- Required for algorithm design and deployment

- Measurement, evaluation, and modeling must be considered jointly

- Sounder design must be aligned with evaluation methods and modeling requirements
- Applications decide environment and measurement parameters

Expect exciting new developments

- Even in areas as well-explored as pathloss….

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