MIMO Radio Channel Models

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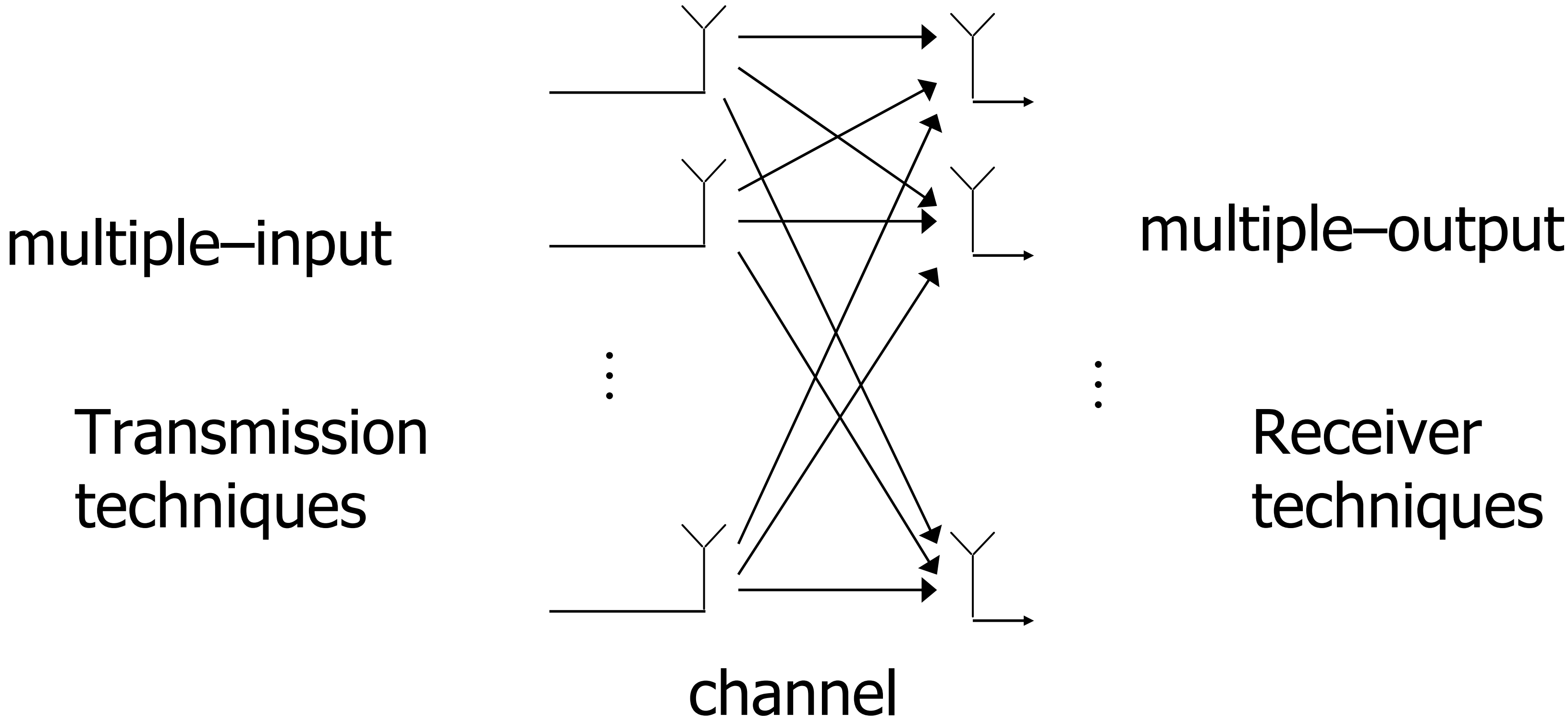
Contents

Scope: Communications in Multiple–Input Multiple–Output (MIMO) Channel

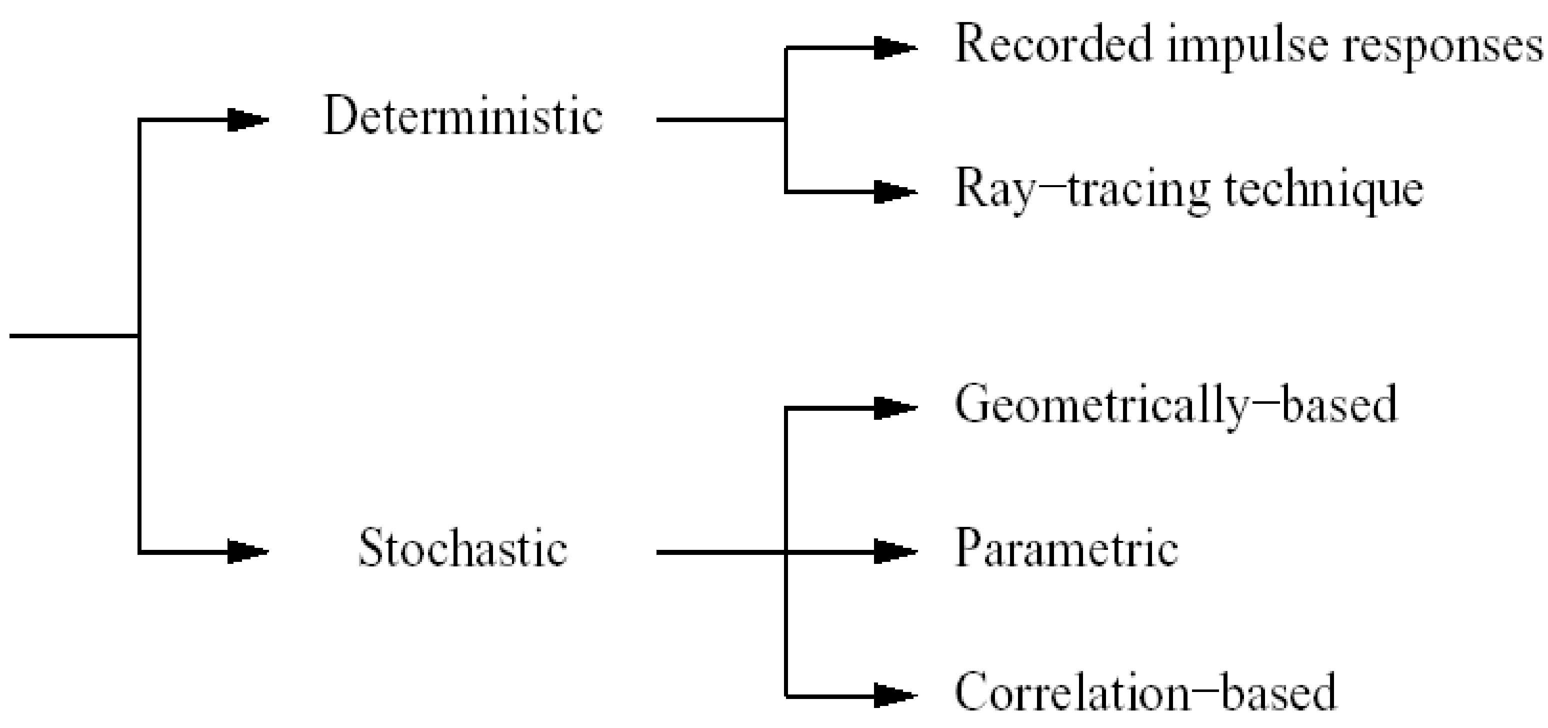


Transmission techniques

Receiver techniques

Channel models

Introduction: Channel models

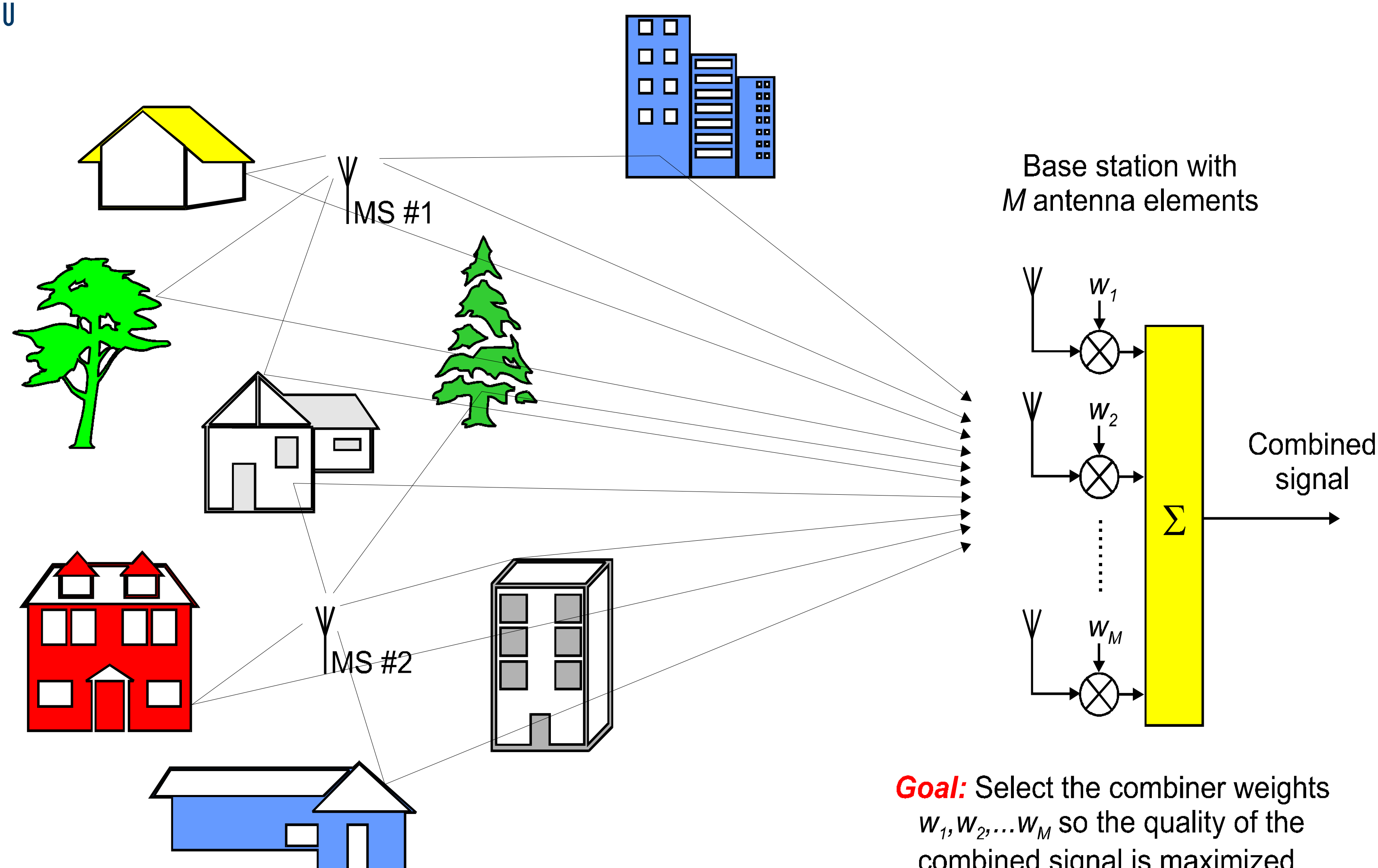


Introduction …

- Deterministic (geometric) modelling
  - e.g. specific micro/pico cell environment
  - can be used as basis for stochastic modelling
  - example: local area sample of the Codit model
- Stochastic modelling
  - often based on large measurement campaign
  - e.g. the so-called Metra MIMO model in 3GPP
  - example: typical correlation matrices for certain environments
  - Geometry based, parametric

"Radio channel model should be based on physical propagation environment"

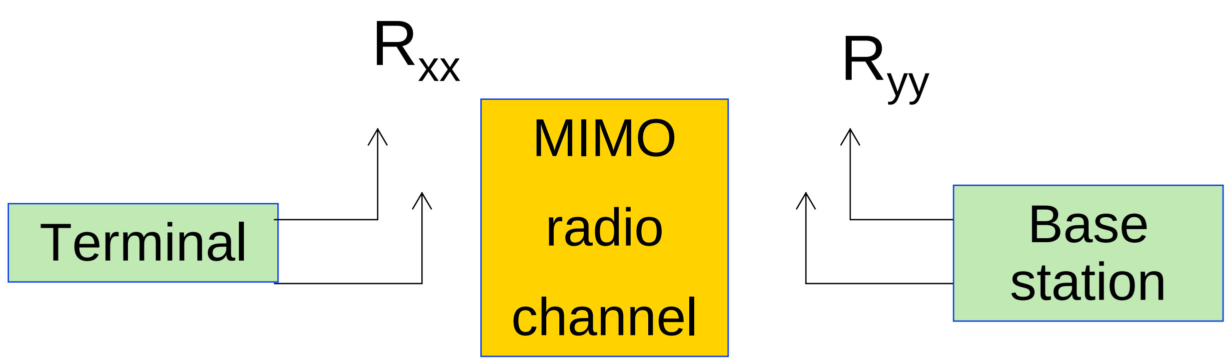
Antenna Array Principle



Goal: Select the combiner weights $w_1, w_2, \ldots w_M$ so the quality of the combined signal is maximized

Spatial modelling of 2D radio channel

- Parameters:
  - number of Tx/Rx antennas & their spacing/ geometry
  - number of scatterers/multipath components and their
  - azimuth directions
  - power
  - delay
  - fading characteristics
- In case of large antenna separation/ low correlation parallel 1D channel models can be applied --> R_{xx}



Some radio channel parameters

- Coherence time (vs. time-selective fading):

  $t_c \sim= 1/\ B_d = 1/\text{Doppler spread}$

  e.g. 2GHz, 15m/s: $f_{d,max} = v/\lambda = 15/0.15\ \text{Hz} = 100\ \text{Hz}$

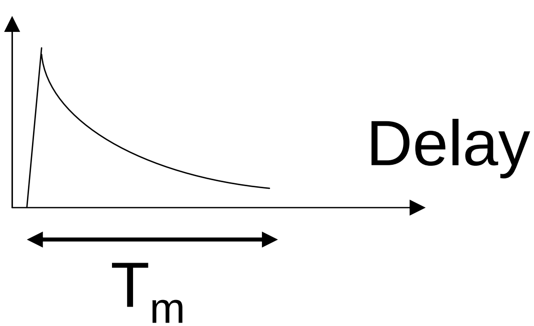
  $\Rightarrow B_d = 200\ \text{Hz} \quad \Rightarrow t_c = 5\ \text{ms}$

- Coherence bandwidth (vs. frequency selective fading):

  $f_c \sim= 1/\ T_m = 1/\text{Delay spread}$

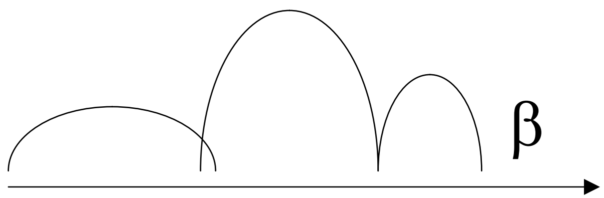
  e.g. typical urban: $f_c = 1/(2\ \mu s) = 500\ \text{kHz}$

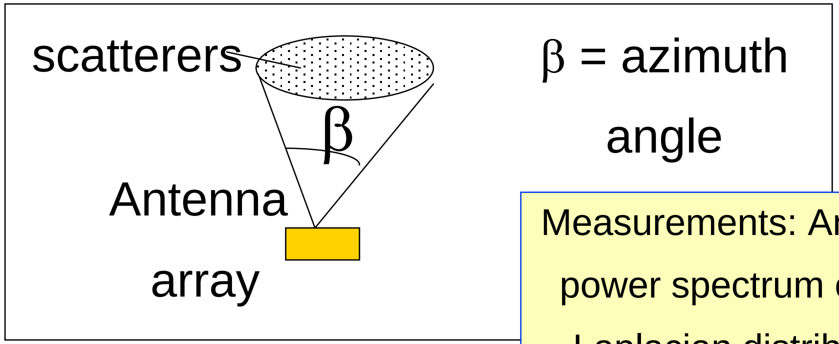
- Delay spread



Some radio channel parameters

- Angular spread, α





Measurements: Angular power spectrum often Laplacian distributed

- Angular spread of received paths is defined as the square root of the sample second central moment

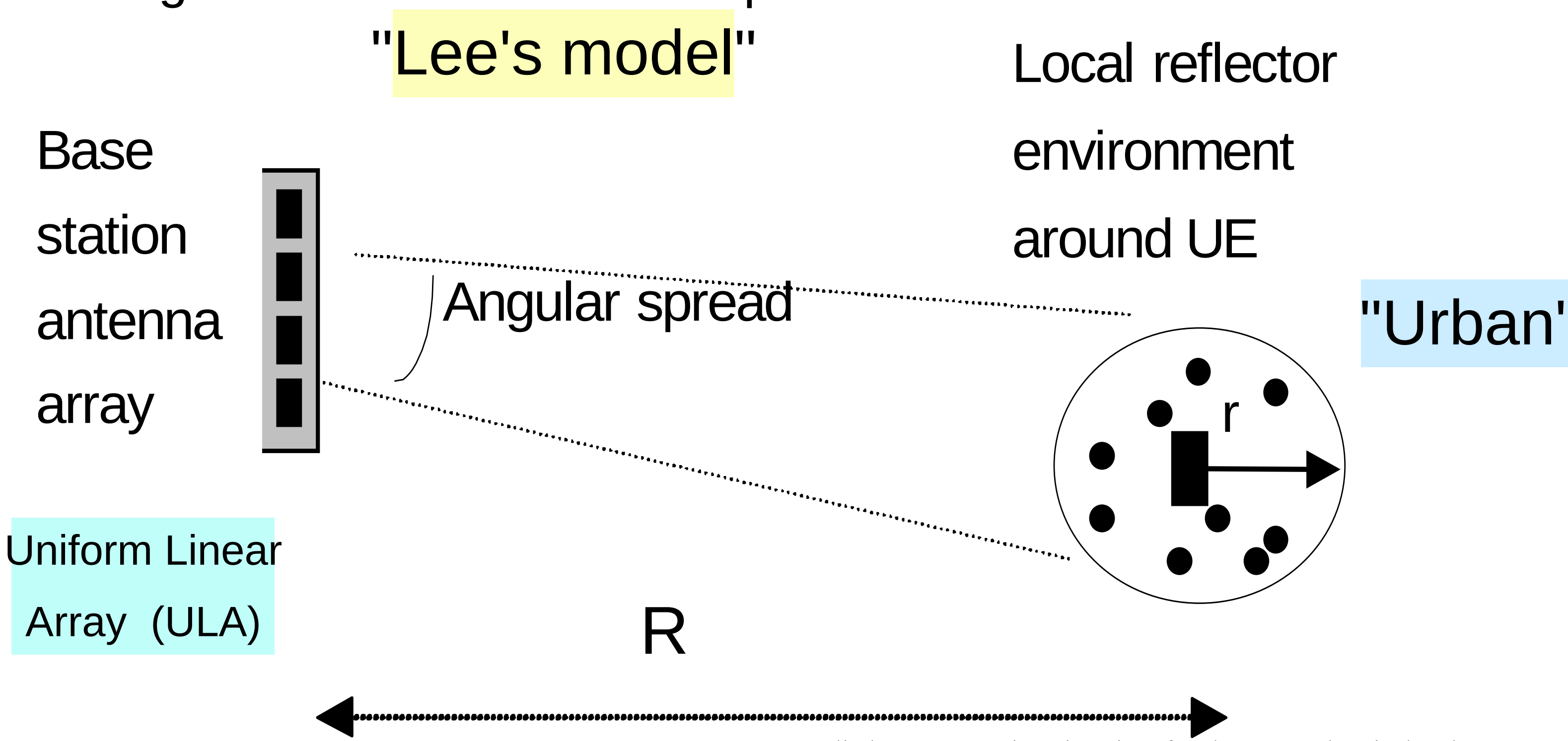
- $$\hat{S}_{\beta} = \sqrt{\sum_{n=1}^{N} \frac{\left(\beta_n - E\{\beta\}\right)^2 P(\beta_n)}{P_{\beta,total}}}$$ where

- $E[\beta]$ is the mean or expected value of angles of arrival β_i,
- $P(\beta_i)$ is the power of signal coming from scatterer i and
- $P_{\beta,total}$ is the total power

Angular spread is the standard deviation of angles of arrival weighted with path powers

Codit: Wide Band Channel Model

- macro-cell channel model (BTS antenna well above the surroundings)
- short term variation -UE moving over small areas (tens of λ)
- local area samples (WSSUS model)
- long term variation of mean power has not been considered



Codit: Wide Band Channel Model, cont'd

- Complex field E_i from one scatterer *i:*

$$E_i(t) = a_{i0} e^{j\left(\varphi_{i0} + kvt\cos\theta_{i0}\right)} + \sum_{l=1}^{N_{waves}} a_{il} e^{j\left(\varphi_{il} + kvt\cos\theta_{il}\right)}$$

- a_{il} is the partial wave amplitude for subpath *l*
- φ_{il} is a random phase term
- k is the wave number (=2π/λ)
- v is the mobile terminal (UE) velocity
- λ is the wavelength of the carrier
- θ_{il} denotes the incident angle between the scatterer i and the UE velocity vector
- N_{waves} is the number of partial waves (per scatterer)

Codit: Wide Band Channel Model, cont'd

Time-variant channel impulse response function from multiple scatterers at different delays:

$$h(t,\tau) = \sum_{i=1}^{N} E_i(t) \cdot \delta(\tau - \tau_i)$$

- *N* is the number of scatterers
- δ is the Dirac delta function
- τ_i time delay associated with a particular scatterer

Codit: Wide Band Channel Model, cont'd

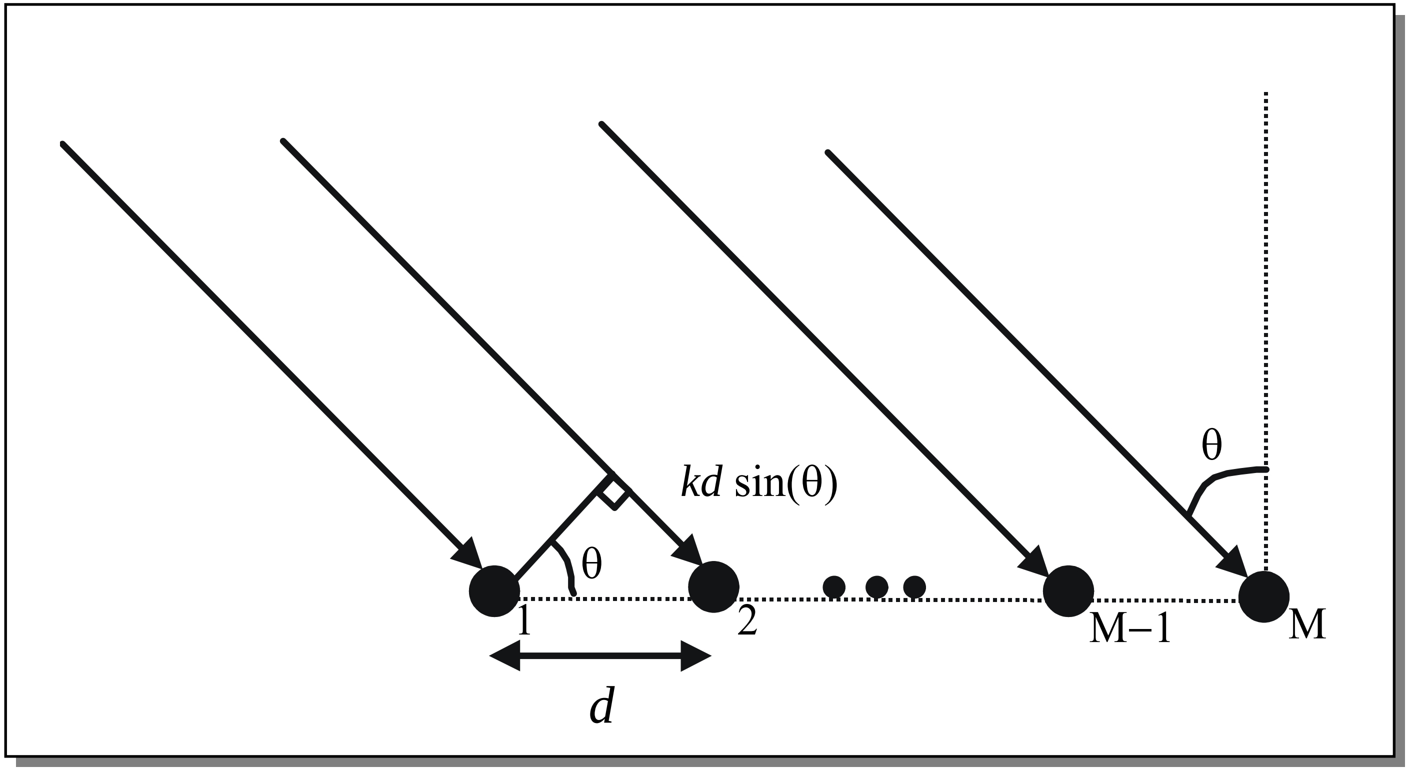
- Spatio-temporal channel impulse response at antenna element m of a ***uniform linear array***:

$$h_m(t,\tau) = h(t,\tau)e^{j\frac{2\pi}{\lambda}(m-1)d\sin\beta}$$

- d denotes the inter-element spacing

– β is the azimuth direction of the reflector

Uniform Linear Array (ULA)



- Delay difference => phase difference:
- $\Delta l = d \cdot \sin\theta$
- $\Delta\varphi = 2\pi \cdot d \cdot \sin\theta / \lambda = k \cdot d \cdot \sin\theta$
- $k = 2\pi / \lambda$

Stochastic Models – COST 259

- Cost 259 comprehensive attempt to model directional channels (COST 259-DCM)
- Cost direct channel model has a three-level top-bottom structure consisting of
  - the cell type(macro-, micro- or pico-cell),
  - the Radio Environment (RE) and
  - the Local Parameters (LPs) of the detailed propagation scenario.
- A given set (cell type/RE/LP) fully characterizes a simulation environment
- COST259-DCM is a model framework enabling to tune the parameters of a specific implementation

Stochastic Models – GBSM

- Geometrically-Based Stochastic Models (GBSM) assume a stochastic distribution of scatterers around the two ends of the connection.
- The channel model is derived from the positions of the scatterers, by applying the laws of
  - Specular reflection,
  - diffraction and
  - scattering of electro-magnetic waves.
- The shape of the scattering area often accounts for a given kind of scenario.
- Usually, macro-cells are simulated by distributing scatterers around the UE,
- Micro-cells involve ellipses whose foci are the Node B and the UE location.
- Scatter density and cluster are user defined parameters
- Most GBSM are single-bounce models, since they only account for a single specular reflection at the scatterer surface
- Example: the above desribed Codit model

Parametric Stochastic Models – PSM

- Parametric Stochastic Models (PSM) describe the received signal as a superposition of waves.
- A common implementation of these models takes the form of a tapped delay line,
- Each tap reflects a propagation path.

Parametric Stochastic Models – DD

- The Double Directional Channel Model (DDCM) is an example of a PSM.
- Its parameters can be given as a delay-angle distribution or through a spatial scatterer distribution
- The DDCM can be implemented as a tapped delay line model, where each of the N resolvable multipath components has
  - complex gain,
  - delay, and
  - (DoD, DoA) pair,

  regardless of the number of bounces.
- Both Tx and Rx antenna characteristics are excluded
- Example: SAGE algorithm assumes this model

Parametric Stochastic Models – DD

- Where δ is the delta function, θ is the elevation and Φ is the azimuth.
- ξ is a 2x2 matrix whos elements are the complex gain of the orthogonal polarisations and the cross coupling between polarisations

$$\mathbf{H}(t,\tau,\phi_{Tx},\theta_{Tx},\phi_{Rx},\theta_{Rx}) = \sum_{k=1}^{N} \xi_k(t) \quad \delta\left[\phi_{Tx}-\phi_{Tx,k}(t)\right]\delta\left[\theta_{Tx}-\theta_{Tx,k}(t)\right] \delta\left[\phi_{Rx}-\phi_{Rx,k}(t)\right]\delta\left[\theta_{Rx}-\theta_{Rx,k}(t)\right] \delta\left[\tau-\tau_k(t)\right],$$

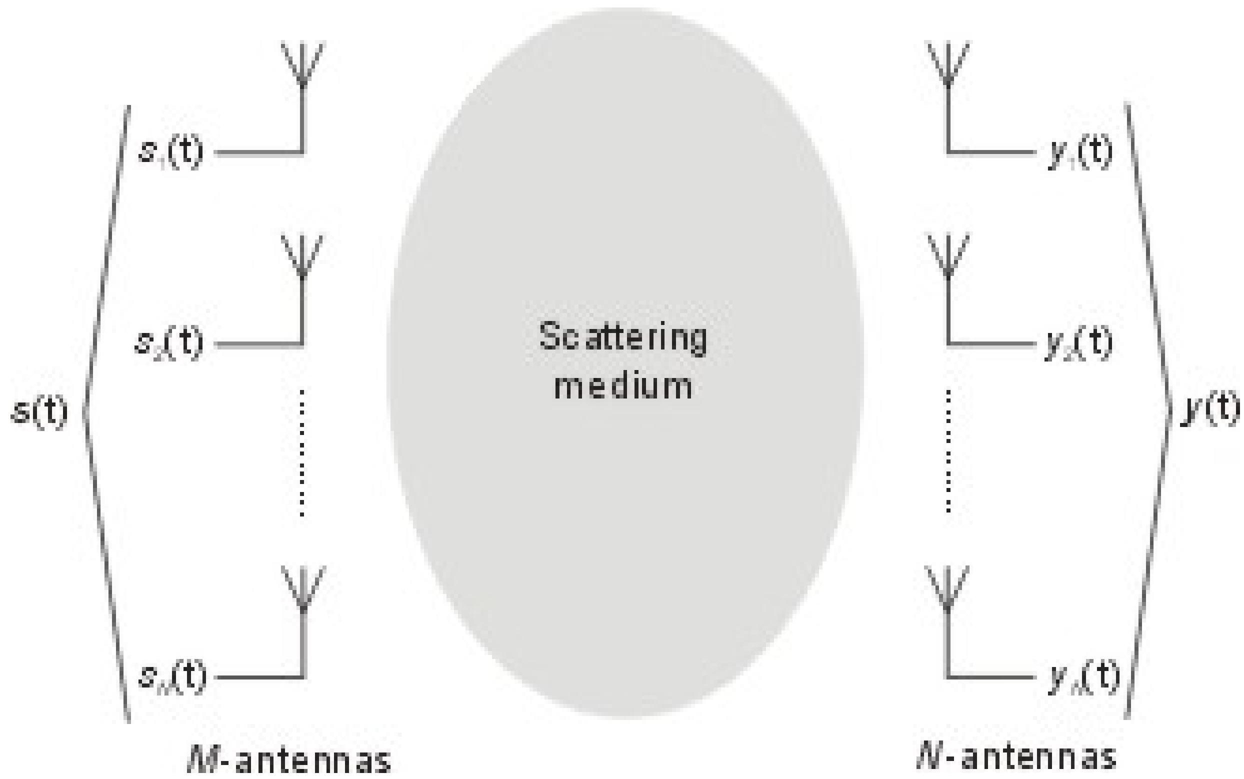
METRA Channel Model - Overview

- Stochastic model filed in 3GPP in February 2001
- Used by major manufacturers for MIMO model
- Model is a tapped delay line where each of the taps is a matrix
- Size of each matrix depends on the number of active elements in transmit and receive ends
- Embeds the full correlation information of the channel into two correlation matrices defined independently
- A Kronecker product is performed to combine the matrices to fully characterize the correlation properties of the MIMO channel

METRA Channel Model – Overview (2)

- One main strengths of the MIMO stochastic model is that it relies on a small set of parameters to fully characterize
- Specifically
  - power gain of the MIMO channel matrix,
  - two correlation matrices describing the correlation properties at both ends of the transmission links,
  - the associated Doppler spectrum of the channel paths.
- Parameters can be extracted from measurement results,
- Parameters can also be derived from single-input/multiple-output (SIMO) results already published in the open literature.

System Model - 1



System Model - 2

- M antennas at base station and N antennas at mobile

$$H = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \cdots & \alpha_{1,N} \\ \alpha_{2,1} & \alpha_{2,2} & \cdots & \alpha_{2,N} \\ . & . & . & . \\ \alpha_{M,1} & \alpha_{M,2} & \cdots & \alpha_{M,N} \end{bmatrix}$$

- Where α_{ij} is the complex transmission coefficient from antenna *i* to antenna *j*.
- The relationship between y(t) and s(t) is

$$y(t) = H(t)\, s(t)$$

System Model - 3

- all antenna elements have same polarization and radiation pattern
- The spatial complex correlation coefficient at the BS between antenna m_1 and m_2 is given by

$$\rho_{m_1 m_2}^{BS} = \langle \alpha_{m_1 n}, \alpha_{m_2 n} \rangle$$

assumed that the spatial correlation coefficient at the MS is independent of *n*

- The spatial complex correlation coefficient at the MS between antenna n_1 and n_2 is given by

$$\rho_{n_1 n_2}^{MS} = \langle \alpha_{m n_1}, \alpha_{m n_2} \rangle$$

assumed that the spatial correlation coefficient at the BS is independent of *m*

System Model - 4

- define

$$R_{BS} = \begin{bmatrix} \rho^{BS}_{1,1} & \rho^{BS}_{1,2} & \cdots & \rho^{BS}_{1,M} \\ \rho^{BS}_{2,1} & \rho^{BS}_{2,2} & \cdots & \rho^{BS}_{2,M} \\ . & . & . & . \\ \rho^{BS}_{M,1} & \rho^{BS}_{M,2} & \cdots & \rho^{BS}_{M,N} \end{bmatrix}_{MxM}$$

$$R_{MS} = \begin{bmatrix} \rho^{MS}_{1,1} & \rho^{MS}_{1,2} & \cdots & \rho^{MS}_{1,N} \\ \rho^{MS}_{2,1} & \rho^{MS}_{2,2} & \cdots & \rho^{MS}_{2,N} \\ . & . & . & . \\ \rho^{MS}_{N,1} & \rho^{MS}_{N,2} & \cdots & \rho^{MS}_{N,N} \end{bmatrix}_{NxN}$$

System Model - 5

- If the correlations are independent of *n* and *m* as stated earlier then
- the spatial correlation matrix of the MIMO radio channel is the Kronecker product of the spatial correlation matrix at the MS and the BS and is given by

$$R_{MIMO} = R_{MS} \otimes R_{BS}$$

Limitations of the Metra Model

- In certain circumstances, model does not deliver the expected capacity improvements

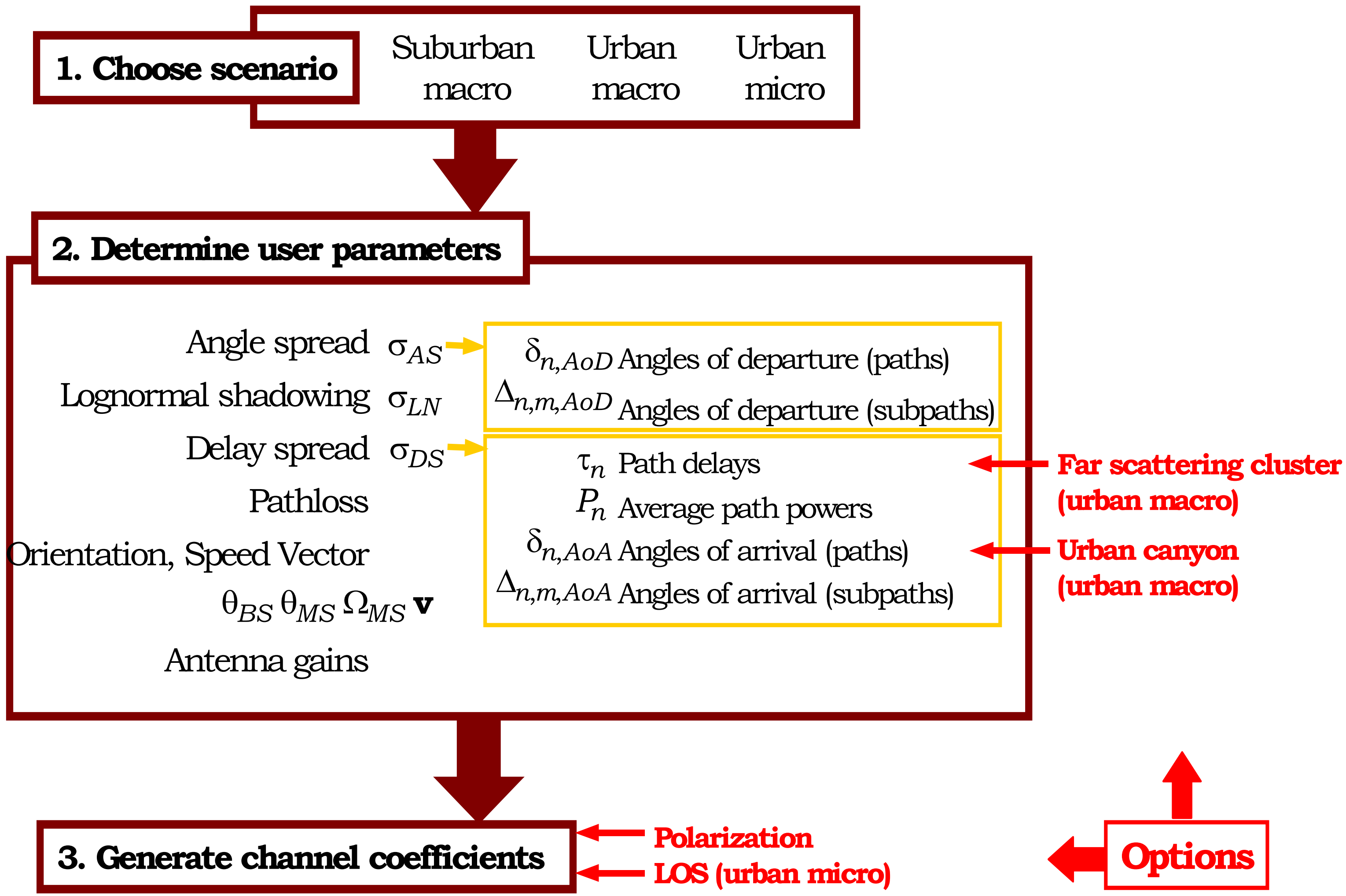
- Such a key-hole behaviour could be experienced
  - in hallways,
  - tunnels, or
  - for very large distances between the UE and Node B.

- In these waveguide-like situations , the channel matrix does not have full rank

Spatial Channel Model(SCM) of 3GPP/3GPP2

- **3rd Generation Partnership Project;Technical Specification Group Radio Access Network:**
- **Spatial channel model for Multiple Input Multiple Output (MIMO) simulations (Release 6)**
- **To compare the performance of candidate MIMO schemes at *system level***
- ***The link level models are defined only for calibration purposes***

Spatial Channel Model(SCM) of 3GPP / 3GPP2



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