Realistic Cooperative MIMO Channel Models for 4G and Beyond

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Outline

I. Background Information and Motivation

II. Point-to-Point MIMO Channel Models

III. Challenges for Cooperative MIMO Channel Modelling

IV. Visiting Fellowship Research Programme and Plan

I. Background Information and Motivation

- **Multiple-input multiple-output (MIMO): a key 3G/4G/B4G technology**
  - Use multiple antennas at both the transmitter (Tx) and receiver (Rx)
  - Exploits the spatial dimension of mobile propagation channels.
  - **Main benefits**: spatial multiplexing gain and spatial diversity gain (and power gain).
  - Widely used in various standards, e.g., LTE, IMT-Advanced, WINNER, COST259, COST273, Wi-Fi (802.11n), WiMAX (802.16a, 802.16e).

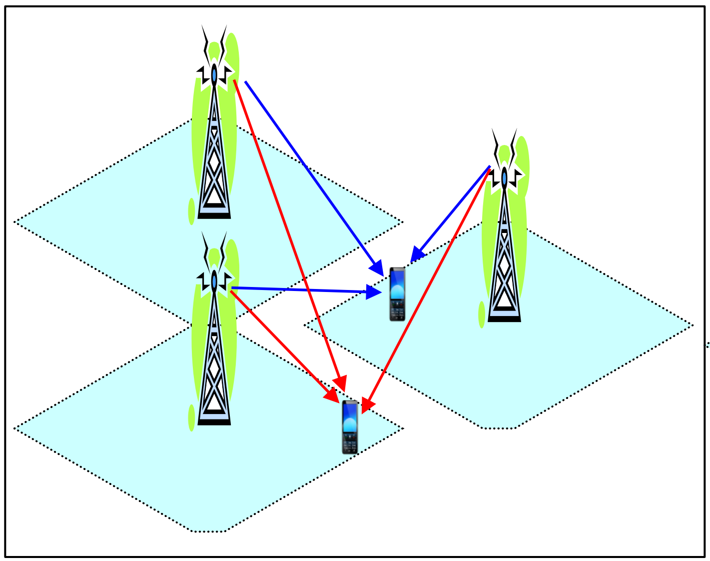
Fig. 1. A conventional MIMO wireless communication system

MIMO in Cellular Systems

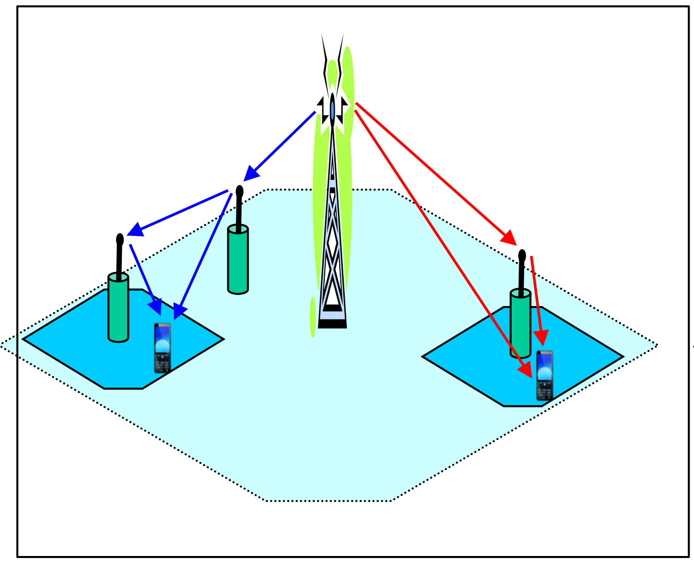
- **Conventional MIMO**: point-to-point (P2P) MIMO, single-user MIMO, or collocated MIMO
  - Only employs antennas belonging to a local terminal
  - **Collocated** antennas at the BS+ **Collocated** antennas at each user
  - Independent MIMO signal processing between the BS and each user.
- **Cooperative MIMO:** distributed MIMO, network MIMO, or virtual antenna array (VAA)
  - Utilises distributed antennas that belong to other terminals
  - **Collocated (or Distributed)** antennas at the BS + **Distributed** (**or Collocated**) antennas at multiple users
  - Joint MIMO signal processing among multiple BSs and/or multiple users
  - **Disadvantages**: increased system complexity, large signalling overhead
  - **Advantages**: increased capacity, cell edge throughput, and coverage

Three Types of Cooperative MIMO Schemes

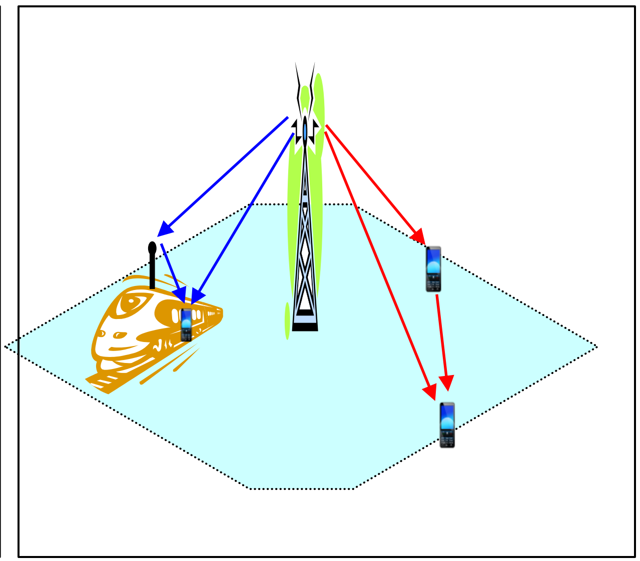
- **Coordinated multipoint transmission (CoMP)**: coordinate the transmission and reception of signal from/to one user in several geographically separated points (BSs)
- **Fix relays**: low-cost and fixed radio infrastructures without wired backhaul connections
- **Mobile relays**: mobile stations as relays, not deployed as the infrastructure of a network
  - **Moving networks** & **Mobile user relays**



CoMP



Fixed relay



Mobile relay

What Are Realistic MIMO Channel Models?

- **Simplest** MIMO channel models can use multiple uncorrelated processes.
- In practice, spatial correlations are often observed, which greatly influences the link capacity of MIMO systems.
- **Criteria for realistic MIMO channel models**:
  - **Accuracy**:
    - should consider spatial-temporal correlation properties
    - should consider channel variations of multiple users/links and multiple cells at the system level (instead of only at the link level), among other characteristics
  - **Simplicity**: easy and efficient to use
  - **Flexibility/Generality**: sufficiently flexible/generic to cover all the required test enbironments and scenarios (e.g., specified by 3GPP LTE or IMT-Advanced).

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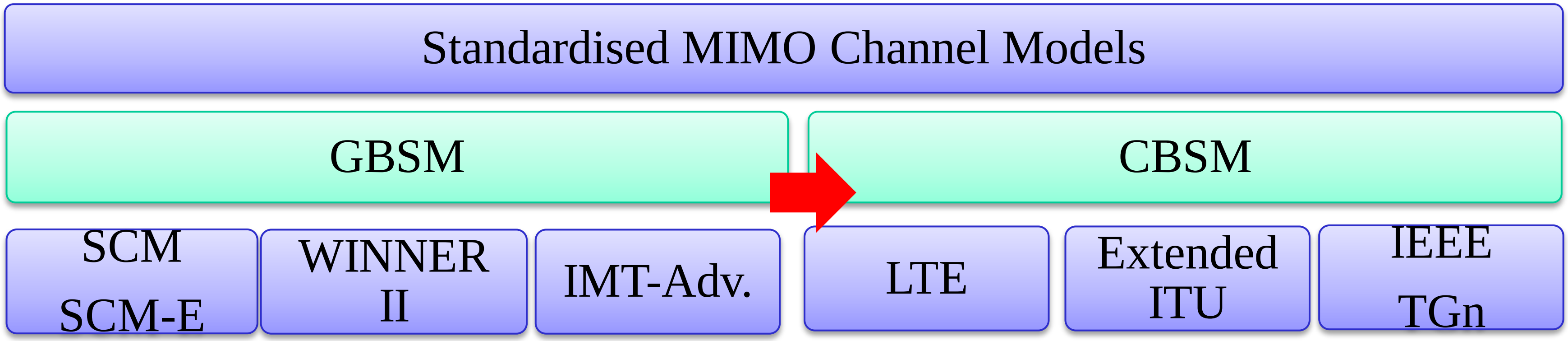
II. Point-to-Point MIMO Channel Models

- **Deterministic channel models**: all parameters are fixed
  - Channel measurements, e.g., stored measured channel impulse responses
  - Ray tracing technique

- **Stochastic channel models**: at least one parameter is stochastic
  - **Geometry Based Stochastic Models (GBSMs):**
    - **Purely geometric** (shape of scatterer region): one ring, two ring, elliptical, …
    - **Semi-geometric** (spatial scatterer distributions + clusters + user defined parameters): 3GPP SCM (extended), WINNER, IMT-Advanced, COST 259, COST 273, …
  - **Correlation Based Stochastic Models (CBSMs):**
    - **Kronecker Based Stochastic Model (KBSM)**: 3GPP LTE, 802.11n
    - **Joint correlation model**: Weichselberger model, Virtual channel representation

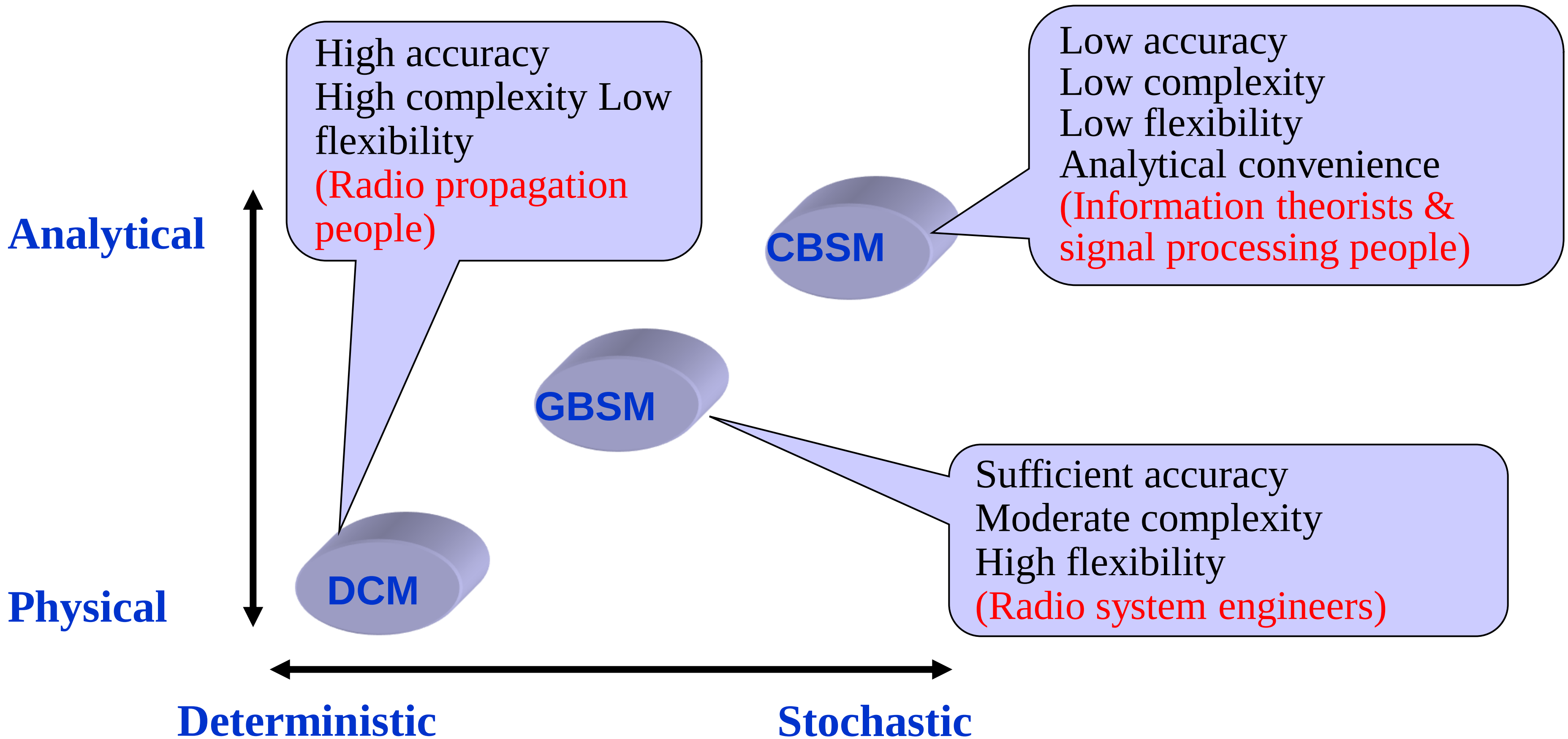
Standardised MIMO Channel Models

- **GBSMs:**
  - **COST 259** (1996-2000): very general, 13 radio environments
  - **COST 273** (2001-2005): updated radio environments and model parameters
  - **3GPP Spatial Channel Model (SCM)**: 5 MHz system bandwidth, 3 environments
  - **WINNER**: related to both the COST 259 model and 3GPP SCM-Extended (SCME) – additional 5 GHz centre frequency, 100 MHz system bandwidth
  - **IMT-Advanced**: similar to WINNER
- **CBSMs/KBSMs**:
  - **3GPP LTE, extended ITU, IEEE TGn**



Trade-Offs of MIMO Channel Models

- Deterministic approach ←→ Stochastic approach
- Physical intuition ←→ Analytical traceability



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III. Challenges for Cooperative MIMO Channel Modelling

- Standardised cooperative MIMO channel models are not yet available.
- Can be constructed from the existing (standardised) P2P MIMO channel models + additional features/models
- Additional features to be addressed (**challenges**):
  - **Heterogeneity** of multiple links
  - **Correlation** of multiple links
  - **Mobile-to-mobile (M2M)** channel models

Challenge 1: Heterogeneity of Links in Cooperative MIMO

- **Cooperative MIMO operates over heterogeneous links/channels**

CoMP

- BS-MS channels: fixed-to-mobile (F2M) channels

Fixed relay

- BS-RS (fixed to fixed-F2F) channels
- RS-RS (F2F) channels
- BS-MS (F2M) channels
- RS-MS (F2M) channels

Mobile relay

- BS-RS (F2M) channels
- RS-RS (M2M) channels
- BS-MS (F2M) channels
- RS-MS (M2M) channels

- **The heterogeneity of multiple links can be characterised by**
  - Multiple scenarios
  - Different line-of-sight (LoS) probability
  - Different dynamics of time evolution

Scenarios Defined in Existing Channel Models

SCM (3):

- Suburban Macro (NLOS)
- Urban macro (NLOS)
- Urban Micro (LOS / NLOS)

SCM-E(3):

- Suburban Macro (LOS / NLOS)
- Urban macro (LOS / NLOS)
- Urban Micro (LOS / NLOS)

LTE (6):

- Extended Pedestrian A (EPA) 5Hz
- Extended Vehicular A model (EVA) 5Hz
- Extended Vehicular A model (EVA) 70Hz
- Extended Typical Urban model (ETU) 70Hz
- Extended Typical Urban model (ETU) 300Hz
- High-speed train scenario (TBD)

IMT-Advanced (5):

- Indoor hotspot (LOS / NLOS)
- Urban micro-cell (LOS / NLOS/ O to I)
- Urban macro-cell (LOS / NLOS)
- Rural macro-cell (LOS / NLOS)
- Suburban marco-cell (LOS / NLOS)

LTE-Advanced (4)

- Indoor
- Microcellular
- Base Coverage Urban
- High Speed

Scenarios Defined in Existing Channel Models (cont.)

WINNER II (14): --Most comprehensive!

- A1 – Indoor office (LOS/NLOS)
- A2 - Indoor to outdoor (NLOS)
- B1 – Urban micro-cell (LOS/NLOS)
- B2 – Bad urban micro-cell (LOS/NLOS)
- B3 – Indoor hotspot (LOS/NLOS)
- B4 – Outdoor to indoor (NLOS)
- B5 – Stationary feeder (LOS/NLOS)
- C1 – Suburban macro-cell (LOS/NLOS)
- C2 – Urban macro-cell (LOS/NLOS)
- C3 – Bad urban macro-cell (LOS/NLOS)
- C4 – Urban macro outdoor to indoor (NLOS)
- D1 – Rural macro-cell (LOS/NLOS)
- D2 – Moving networks (LOS/NLOS)

IEEE 802.16j (9) – Consider relays!

- Type A: Macro-cell suburban, ART to BRT for hilly terrain with moderate-to-heavy tree densities. (LOS/NLOS)
- Type B: Macro-cell suburban, ART to BRT, for intermediate path-loss condition (LOS/NLOS)
- Type C: Macro-cell suburban, ART to BRT for flat terrain with light tree densities (LOS/NLOS)
- Type D: Macro-cell suburban, ART to ART LOS
- Type E: Macro-cell, urban, ART to BRT (NLOS)
- Type F: Urban or suburban, BRT to BRT (NLOS)
- Type G Indoor Office LOS/NLOS
- Type H Macro-cell, urban, ART to ART (LOS)
- Type J Outdoor to indoor NLOS

ART: above roof-top; BRT: below roof-top

A Cooperative MIMO Channel Model Based On WINNER II

Cooperative MIMO	**Link type**	**Description**	**Recommended scenario**
CoMP	BS-MS	MS indoor	C2 (NLoS)
		MS outdoor	C2 (LoS)
Fixed relay	BS-MS	Indoor or outdoor	C2
	BS-RS	Various RS locations	B5 (LoS/NLoS)
	RS-RS	Various RS locations	B5 (LoS/NLoS)
	RS-MS	Indoor-to-indoor	A1 (LoS/NLoS)
		Indoor-to-outdoor	A2 (NLoS)
		Outdoor-to-outdoor	B1 (LoS/NLoS)
Moving network	BS-MS	Indoor	C2 (NLoS)
	BS-RS	LoS for RS	C2 (LoS)
	RS-MS	Indoor	B3 (LoS/NLoS)
Mobile user relay	BS-MS	Indoor or ourdoor	C2
	MS-MS	LoS	B5b (**not a M2M scenario**)

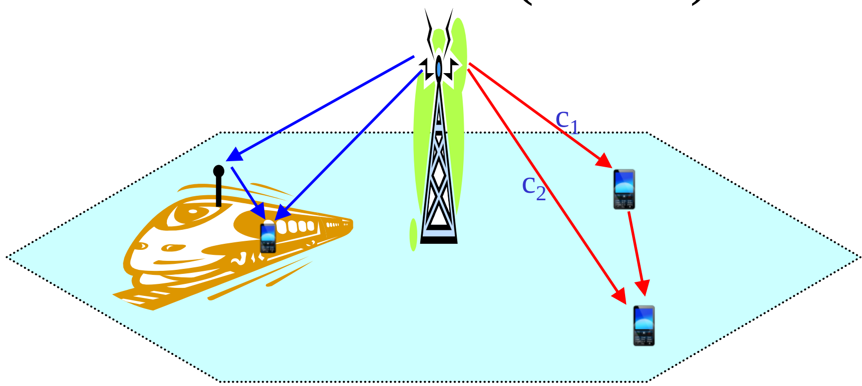
LoS Probability and Scenario Transition

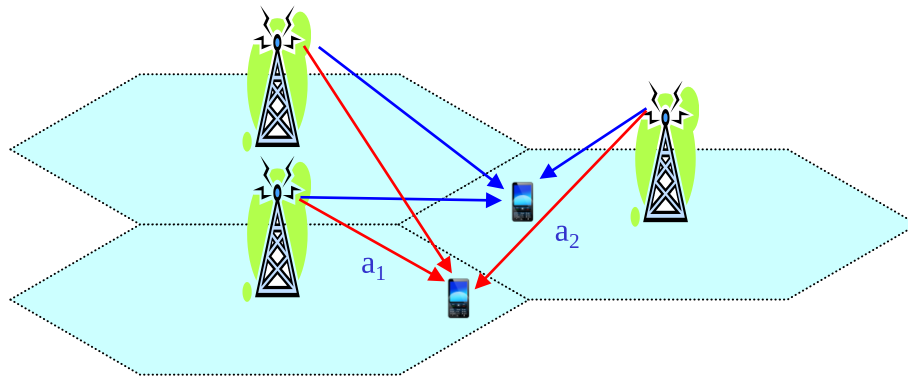
- **LoS probability**
  - LoS probability depends on various environment factors (e.g., terrain features and distance).
  - Different links in a cooperative transmission may have different LoS probabilities.
- **Time evolution of fading channels**
  - Time evolution behaviour, e.g., transitions between different scenarios and LoS/NLoS conditions, may have significant impact on system performance.
  - Different links in a cooperative transmission may have different time evolution dynamics.

	SCM	**WINNER-II**	**IEEE 802.16j**
LoS probability model	Urban microcell only	Scenario-dependent	Scenario-dependent
Scenario transition	Quasi-stationary	Non-stationary	No

Challenge 2: Correlation of Multiple Links

- **Large-scale parameters**, such as shadow fading (SF), delay spread (DS) and azimuth spread (AS), may be correlated.
- **Intra-site correlation** (c1&c2) v.s. **Inter-site correlation** (a1&a2)



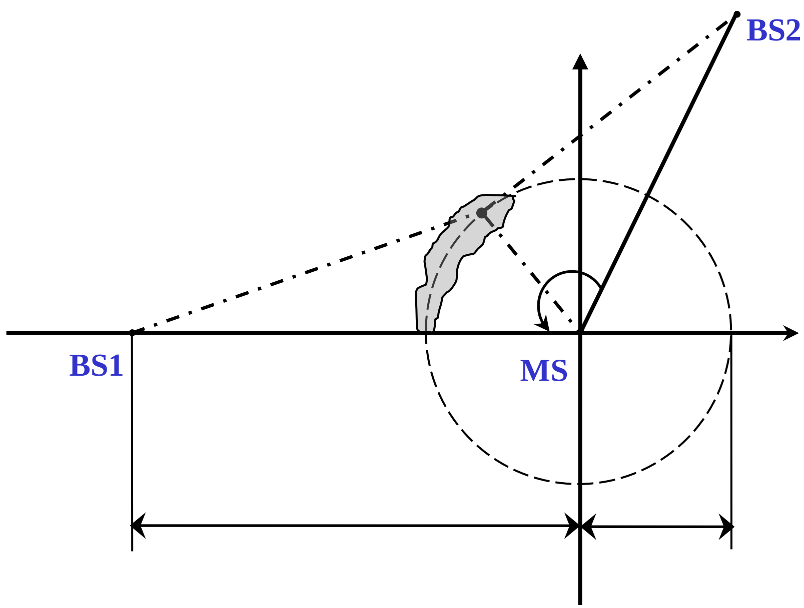


- **Shadow fading (SF) correlation** is an important phenomenon to model because it directly influence the macro diversity gain.

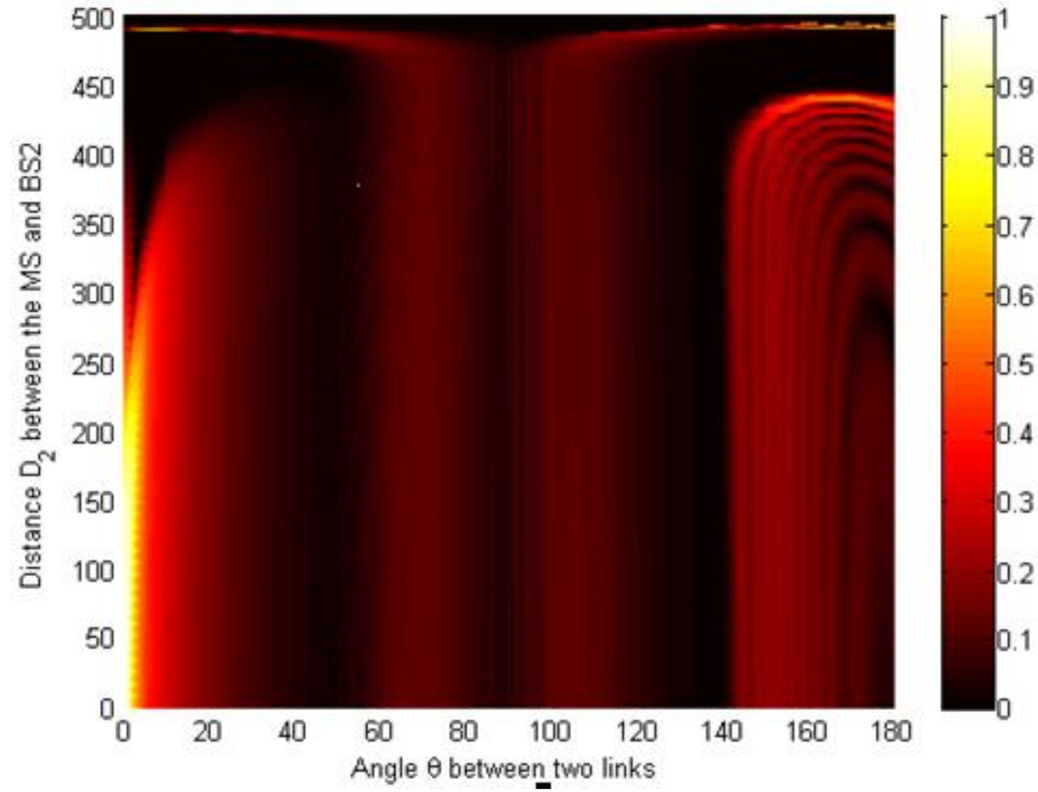
	SCM	WINNER-II	IEEE 802.16j
Intra-site SF correlation	0	Distance-dependent	Distance-dependent
Inter-site SF correlation	0.5	0	Distance-and-angle dependent
Correlation of other LSPs	Fixed values	Distance-dependent	Not considered

Small Scale Channel Correlation

- A simple GBSM illustrates that two inter-site links can have high small scale fading correlation.



A one-ring GBSM for a CoMP system.



Absolute values of small scale fading correlation coefficients of the two links in a CoMP system as a function of θ and D2 (D1=500 m, R=30 m).

Challenge 3: M2M Channel Modelling

- **Mobile-to-mobile (M2M) communications:**
  - Require the direct communication between two moving stations both equipped with low elevation antennas
  - Different from traditional fixed-to-mobile (cellular) communications
    - Only one station is moving.
    - Very often, the base station has highly elevated antenna (free of scatterers).

- **Challenges for M2M channel modelling:**
  - Greater dynamics (faster time-varying) and more severe fading than F2M channels
  - Non-stationarity of M2M channels
  - Impact of the density of moving scatterers on the channel characteristics
  - Impact of the elevation angle on the channel characteristics: 3D model

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- **WP1 (10/12/2010—09/01/2011, Southeast Univ.)**: Development of cooperative MIMO channel models that consider the correlations of multiple links and LSPs and can run multiple scenarios simultaneously, supported by measurement results
- **WP2 (01/04/2011—30/04/2011, ShandongUniv.)**: Development of realistic M2M channel models which can be used for cooperative MIMO systems using mobile relays
- **WP3 (01/05/2011—30/05/2011, Shandong Univ.)**: Development of a new realistic cooperative MIMO channel model (framework) with the above desirable features while having reasonable complexity
- **WP4 (after the visit)**: Investigation of the impacts of the proposed cooperative MIMO channel model and existing cooperative MIMO channel models on the performance of cooperative MIMO systems; **collaboration with industrial partners and contribution to standard proposals**

Some Relevant Publications

1. **C.-X. Wang**, X. Hong, X. Ge, X. Cheng, G. Zhang, and J. S. Thompson, "Cooperative MIMO channel models: a survey," *IEEE Communications Magazine*, vol. 48, no. 2, pp. 80-87, Feb. 2010.

2. **C.-X. Wang**, X. Cheng, and D. I. Laurenson, "Vehicle-to-vehicle channel modeling and measurements: recent advances and future challenges", *IEEE Communications Magazine*, vol. 47, no. 11, pp. 96-103, Nov. 2009.

3. X. Cheng, **C.-X. Wang**, D. I Laurenson, S. Salous, and A. V. Vasilakos, "An adaptive geometry-based stochastic model for non-isotropic MIMO mobile-to-mobile channels", *IEEE Trans. on Wireless Communications*, vol. 8, no. 9, pp. 4824-4835, Sept. 2009.

4. X. Cheng, **C.-X. Wang**, D. I Laurenson, S. Salous, and A. V. Vasilakos, "New deterministic and stochastic simulation models for non-isotropic scattering mobile-to-mobile Rayleigh fading channels," *Wireless Communications and Mobile Computing*, John Wiley & Sons, accepted for publication.

5. **C.-X. Wang**, X. Hong, H. Wu, and W. Xu, "Spatial temporal correlation properties of the 3GPP spatial channel model and the Kronecker MIMO channel model", *EURASIP Journal on Wireless Communications and Networking*, vol. 2007, Article ID 39871, 9 pages, 2007. doi:10.1155/2007/39871.

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Thank you for your attention!

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