Reliable, Secure and Universal Mobile Radio Communications

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Mobile Radio: a brief history

- 1932 – Start of Mobile Radio Communications
- 1965 - IMTS Improved Mobile Telecommunications Systems
- 1983 - 1G Analog Systems (AMPS, TACS, NORDIC etc.)
- 1991 - 2G Digital Systems (DAMPS, GSM, CDMA)
- 2001 – 3G IMT-2000 (Several variations)
- 2007 – 3.5G Systems (GPRS, EDGE)
- 2008 – 4G Systems (Not yet defined)

Current Status

- 3G cellular (IMT-2000) systems designed to offer cellular users a significantly higher data-rates services using wideband (5MHz bandwidth) DS-CDMA technology:
  - indoor: 2Mbps
  - pedestrian: 384kbps
  - vehicular: 144kbps
- Demands for broadband wireless services (internet related) are increasing
- High-speed downlink packet access (HSDPA) of ~14Mbps/5MHz will soon appear. Even ~14Mbps data rate capability of 3.5G will sooner or later become insufficient.

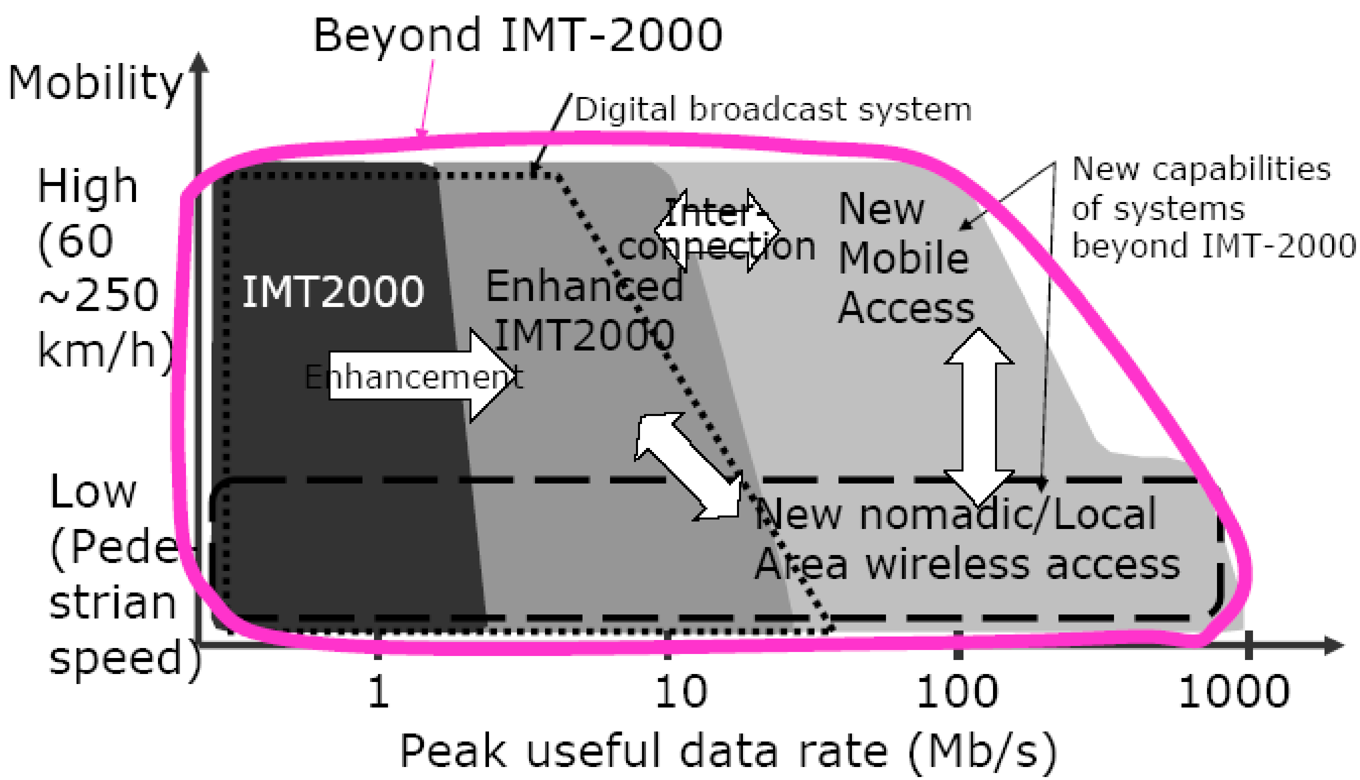
Defining 4G

- Identification of the killer services in the next decade is difficult.
- Internet based services will dominate 4G. The current IEEE 802.11n draft includes link rates up to 600 Mb/s.
- Wireless visual communications: a promising application

	1G	2G	3G	4G
Access	Analog	Digital	Digital	Up to 1Gb/sec
	FDMA	TDMA,DS-CDMA	DS-CDMA	OFDM,CDMA
Core network	CS	CS & PS	CS & PS	Broadband IP
Services	Voice	Voice, data	Voice, Video	???

G4 Vision – Up to 1Gb/sec Transmission Rate

~1Gbps wireless access



ITU-R WP8F (Ottawa, June 2002) :

Towards 4G systems

- 4G Objectives
  - Universality - Voice, Data and Video Transmissions
  - High Transmission Rate in Packet Mode
  - High Capacity and High Spectral Efficiency
  - Low latency, streaming Data Transport
  - Service Dependent QoS and Security

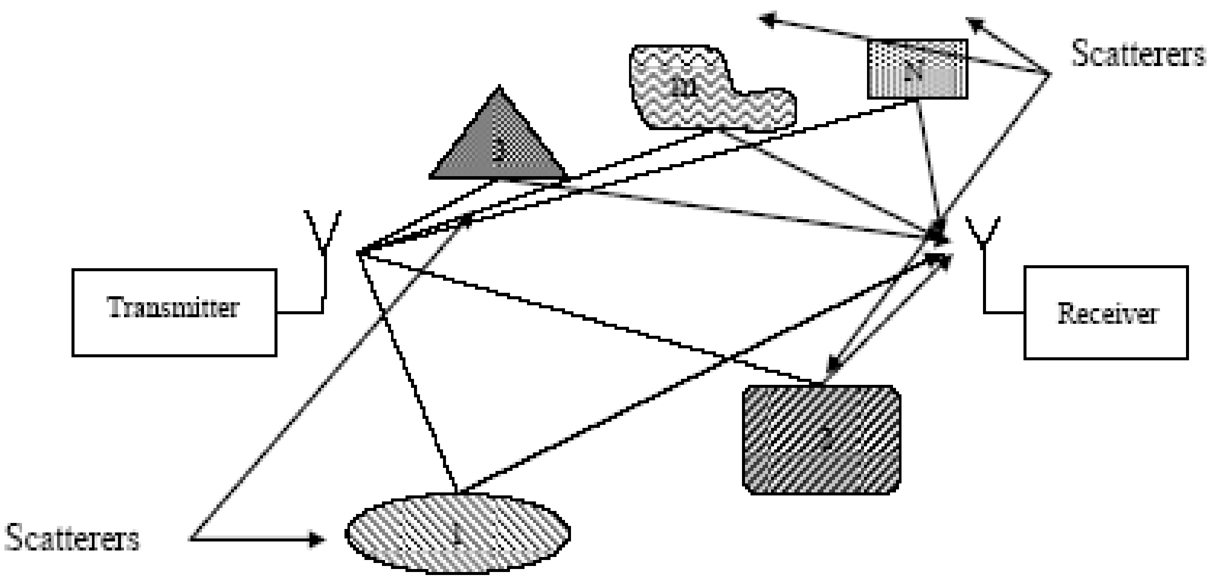
Communication System and Channel

- Transmitter Blocks
  - Data, Source Coding, Encryption, Coding,
  - Modulation Format & Transmission Strategies
    - QPSK, MPSK, MQAM,
    - CDMA, OFDMA, MIMO, Diversity, etc.
  - Protocols
- Receiver Blocks
    - Diversity, Smart Antennas
    - Demodulation, MUD, ODFM
    - Decoders, Decryption
  - Protocols

Communication System Design Principle

- Without good insight into mobile radio channel characteristics, an efficient, reliable, secure, and universal communication system cannot be designed.
- All 4G objectives (universality, high speed transmission, security and encryption, and coding for reliability) can be met if channel characteristic is fully understood and exploited.

A Typical Radio Propagation Scenario



Characterizing the Channel

- A communication channel is completely characterized by its impulse response.

Time-Invariant channel

$$h(\mathbf{r}_{Tx},\mathbf{r}_{Rx},\tau,\phi,\psi)=\sum_{l=1}^{L}h_l(\mathbf{r}_{Tx},\mathbf{r}_{Rx},\tau,\phi,\psi)$$

Receiver and transmitter locations

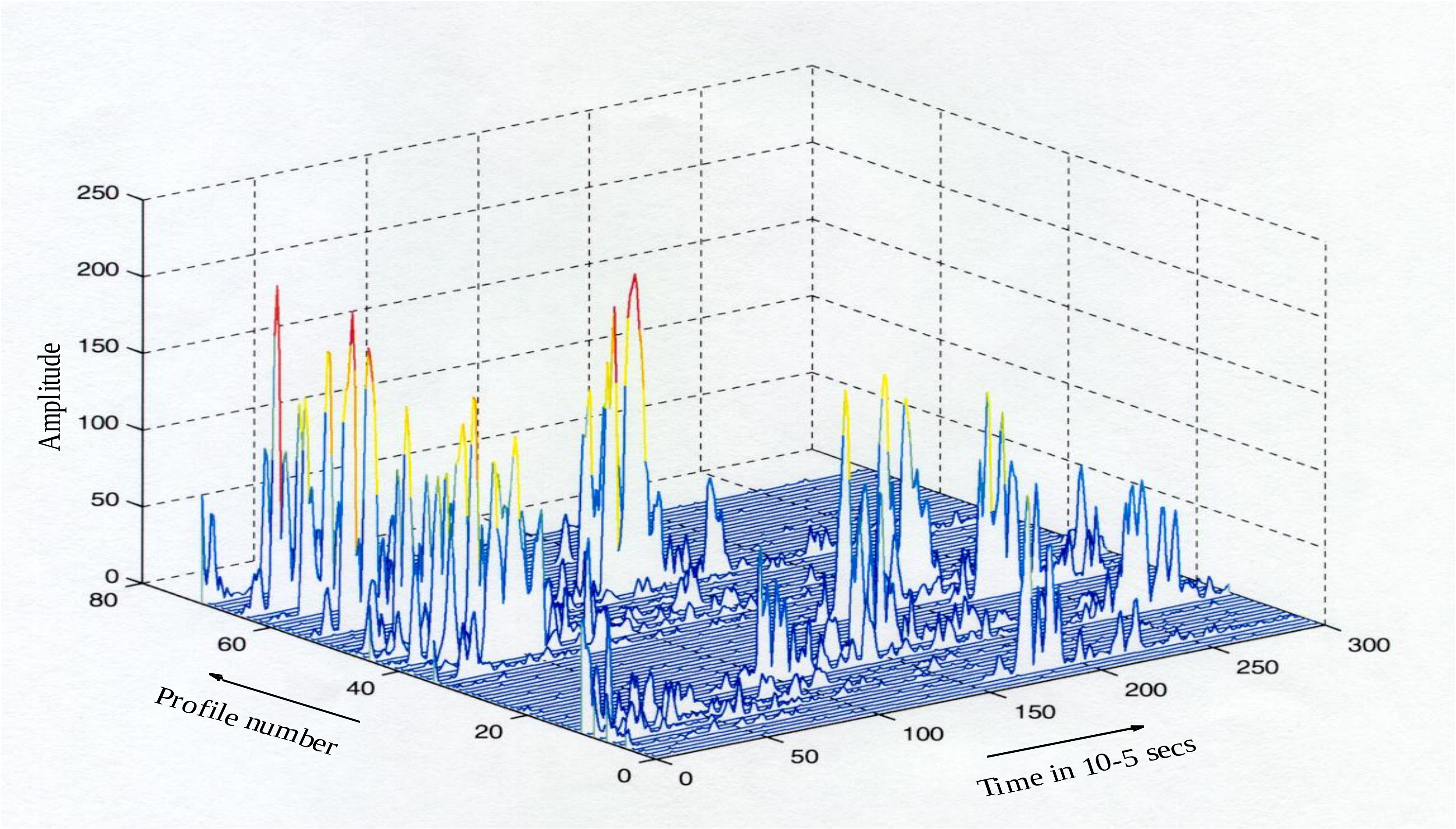
Excess delay, DOD, and DOA

L = Multipath components (MPC)

Time-variant channel

$$h(\mathbf{r}_{Tx},\mathbf{r}_{Rx},t,\tau,\phi,\psi)=\sum_{l=1}^{L}h_l(\mathbf{r}_{Tx},\mathbf{r}_{Rx},t,\tau,\phi,\psi)$$

Mobile Radio Channel Impulse Response



The Mobile Radio Channel

- Path loss - signal attenuation over distance
- Random terminal mobility and propagation over irregular terrain makes the mobile radio channel challenging.
  - Radio wave propagation - Time spread
    - Reflections, scattering, shadowing, and diffraction cause multipath propagation and time spread.
  - Terminal mobility – Frequency Spread
    - Random time variant signal amplitude and phase - signal fading characterized statistically.

Path Loss and Tx Power

- Links for 100 Mb/s ~1 Gb/s are severely power-limited
  - Peak power is proportional to "$f^{2.6}$ x R"
  - Peak transmission power for 100 Mb/s in 5GHz band is about 135,000 times that of 8 kb/s in 2GHz band, e.g., 1W ➡ 135kW.
  - Cell size should be reduced by about 29 times (e.g., 1,000m ➡ 34m cell)
- Necessity of fundamental change in wireless access network architecture is indicated.

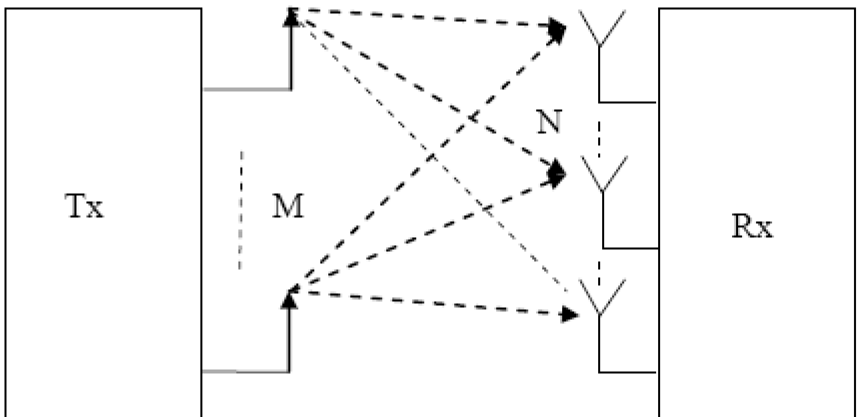
Delay spread and coherence bandwidth – Indoors example

- Delay spread varies between 9 *nsec* to 220 *nsec* depending on the environment.
- Coherence bandwidth varies between 720 KHz and 17 MHz.
- Data rate dynamically varies as the channel is non-stationary
- Insufficient channel capacity to sustain high speed transmissions of 100 Mb/sec ~ 1 Gb/sec.

High Speed Transmission Strategies

- Creating Bandwidth
  - Using Signal Processing
    - Interference and multipath cancellation/combining
      - Antenna diversity, equalization, coding
      - CDMA and OFDMA - MUD
      - Rake with diversity, equalization and coding
      - Adaptive filtering and adaptive antenna arrays
      - Interference mitigation
  - Learning from Conventional techniques of multiplying capacity
    - Multi-input Multi-output (MIMO)
    - MIMO with signal Processing

MIMO - the Capacity Multiplier

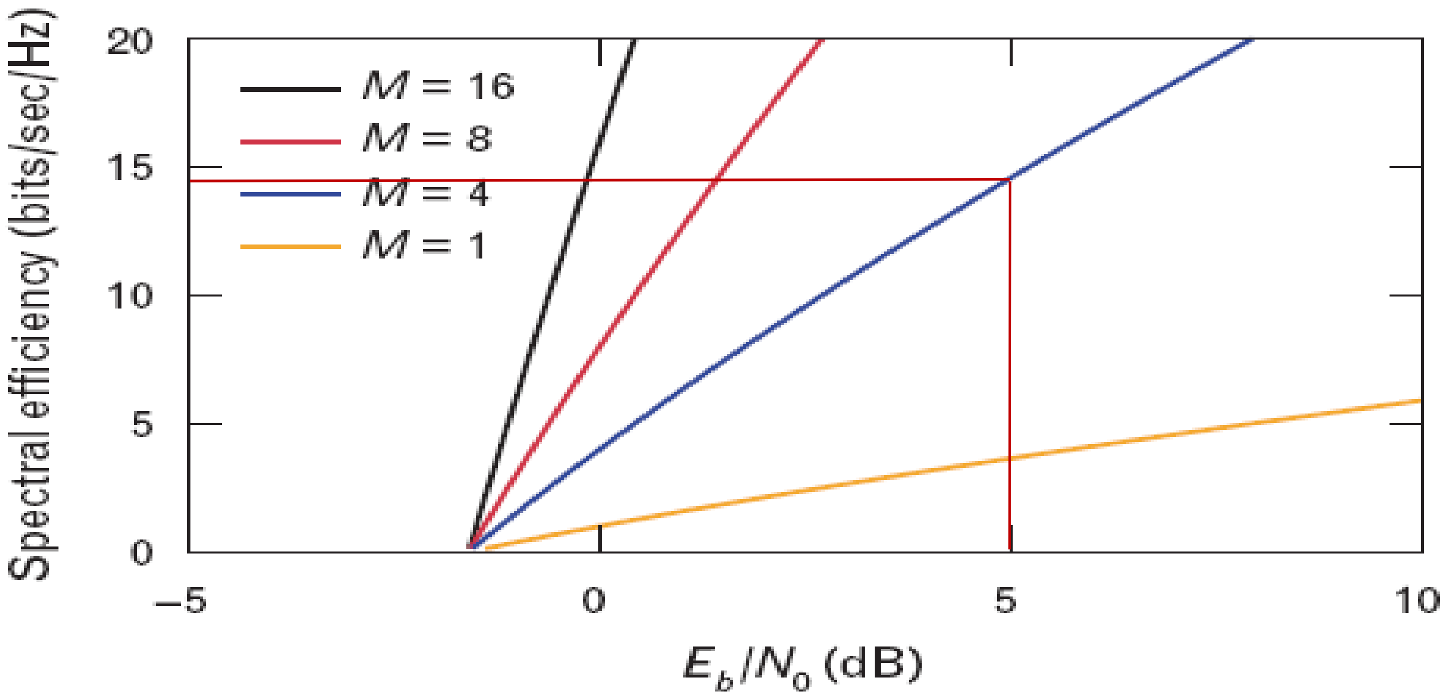


NxM MIMO System

$$\mathbf{H}(t,\tau)=\begin{bmatrix} h_{11}(t,\tau) & h_{12}(t,\tau) & \cdots & h_{1M}(t,\tau) \\ h_{21}(t,\tau) & h_{22}(t,\tau) & \cdots & h_{2M}(t,\tau) \\ \vdots & \vdots & \cdots & \vdots \\ h_{N1}(t,\tau) & h_{N2}(t,\tau) & \cdots & h_{NM}(t,\tau) \end{bmatrix}$$

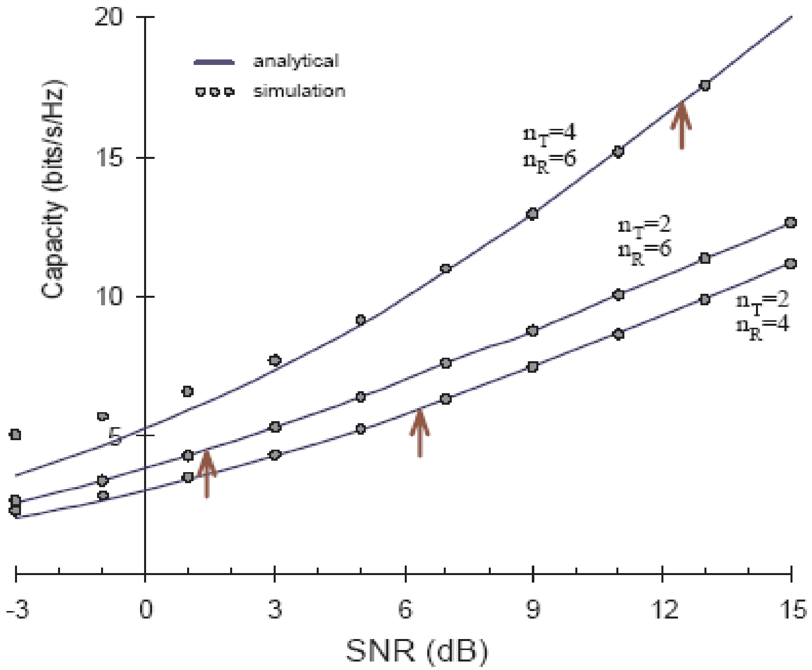
Spectral Efficiency of MIMO

- Basic assumption
  - Rich scattering, uncorrelated i.i.d. fading



MIMO and Channel Capacity

- Basic Assumptions
  - Rich scattering, uncorrelated i.i.d. fading

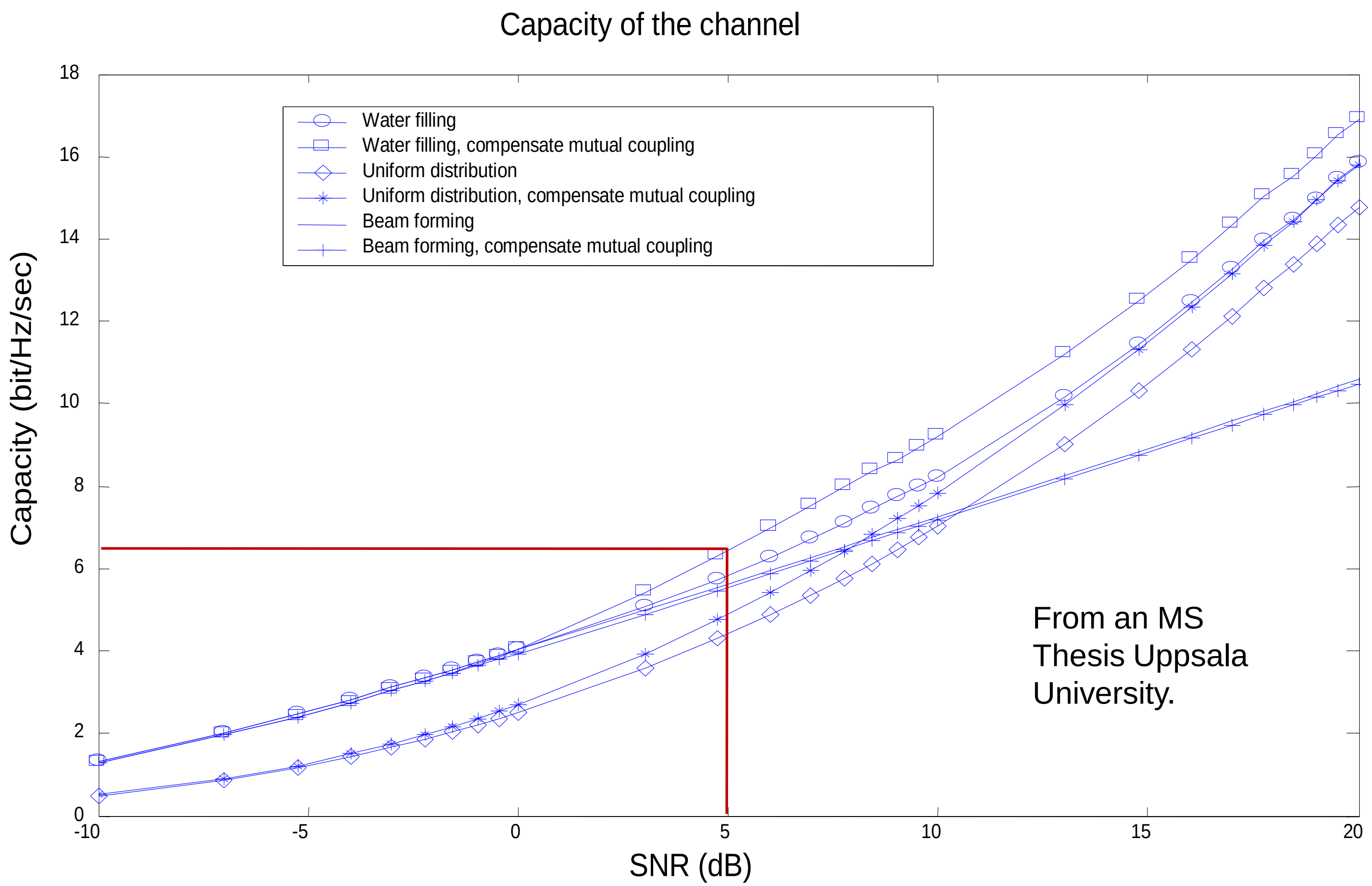


Antonia M. Tulino, Random Matrix Theory and Wireless Communications (2004)

Realistic Channel and Capacity

- Realistic Channels
  - Non i.i.d. distributions of the paths
  - Multipath fading instead of flat fading
  - Presence of path correlation
  - Paths may be subjected to correlated or uncorrelated interference
- Impact on Capacity
  - A significant reduction is expected since the condition of independence of paths is violated.
  - To evaluate the impact channel characterization is needed in order to ascertain degree of path correlation, channel multipath profile etc.

Impact of Channel Coupling on Capacity



Characterizing MIMO Channels

Antenna configuration
Bandwidth

Physical Models

Physically Motivated

(i) Deterministic (ray tracing, stored measurements)
(ii) Geometric based stochastic
(iii) Non-geometric stochastic (Saleh Venzuela, Zwick)

Analytical Models

MIMO Channel Matrix

(i) Correlation based (i.i.d., Kronecker, Weichselberger)
(ii) Propagation Motivated (Finite scatter, maximum entropy, virtual channel)

Standardized Models: 3GPP SCM, COST 259 and 273, IEEE 802.11 n, IEEE 802.16.e/SUI, Winner

Physical Channel Models

- Deterministic Physical Models
  - Aim at reproducing actual radio propagation process
    - Example – Stored Environment and Ray Tracing
- Geometry Based Stochastic Models
  - Single and Multiple Bounce Scattering
  - Placement of Scatterers in a Deterministic Way
- Non-geometric Stochastic Physical Models
  - Describe paths by statistical parameters only
  - Clusters of MPCs (Saleh-Venzuela) or Individual Paths (Zwick)

Analytical Channel Models

- MIMO Channel Matrix
  - Correlation Based Analytical Models
    - Multivariate complex Gaussian distribution of MIMO Channel coefficients (Rayleigh, Ricean, Nakagami, etc.)
    - The i.i.d. model – simplest model
    - The Kronecker Model
    - The Weichseleberger Model
  - Propagation Based Analytical Models
    - Finite Scatterer Model
    - Maximum Entropy Model
    - Virtual Channel Representation

Standardized Models

- COST Models
  - COST 259/273
    - COST 259 Directional Channel Model
    - COST 273
- 3GPP Spatial Channel Model (SCM)
  - Calibration Model
  - Simulation Model
- Wireless World Initiative New Radio (WINNER) Channel Models
  - IEEE 802.11n
  - SUI Models and IEEE 802.16a

Features Lacking in the Current Models

- Single versus double scattering
- Keyhole effect
- Diffuse multipath components
- Polarization
- Time variation

Research Directions

- Measurements in different environments – indoors, outdoors (urban, sub-urban, and rural)
- Analysis of measurement results (impulse response, correlation coefficients) and development of models, and channel matrices.
- Design and implementation of real time channel simulators
- Analysis of MIMO capacity for realistic channels
- Development of signal processing strategies for optimization and capacity enhancement

Research Directions

- Adaptive Techniques – modulation, error control, scheduling
- System design in full view of the radio link characteristics and backbone network characteristics – e.g. end to end solutions, error free protocols.