Exploiting Real World Channels for Increased Capacity

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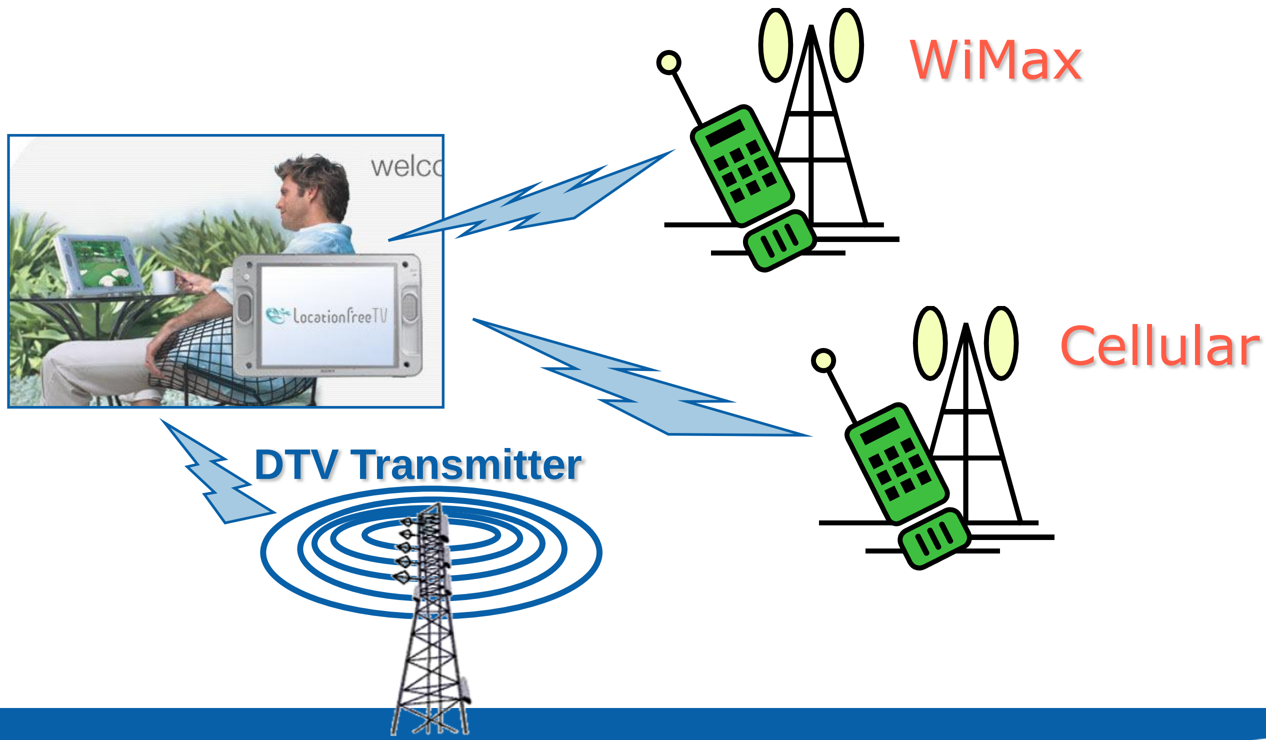
Agenda

- Introduction
  - Usage models
  - Ecosystem Changes
- Communications Model/Environment
- Channel Model – Backgrounder
- Directional Channel Model Example
- Performance and Design Guidelines
- Summary and Conclusions

Consumers are increasingly Mobile and Nomadic

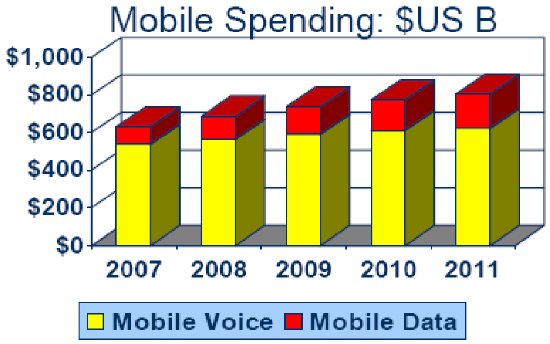
Mobile and Nomadic

Enabled by longer life Mobile PCs and Great displays

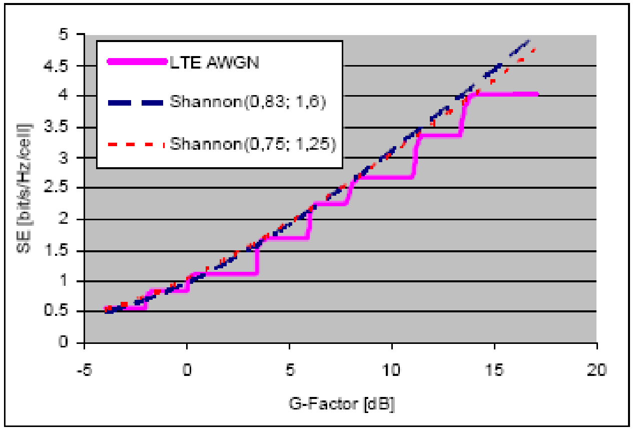


Ecosystem Changes

- World-wide Cellular Data Growth
  - Subscriptions for voice are saturating (yellow)
  - ARPU (ave. revenue per user) growth (red) from data (~ 17%-IDC)
- Achieving Shannon Bound – nearly achieved
- New Spectrum is limited at 700-800 MHz
- Old infrastructure is barely adequate – new infrastructure (towers) cost is huge
- Need to Increase the efficiency of data transmission (Increase Green Content) – avoic wasting power/time

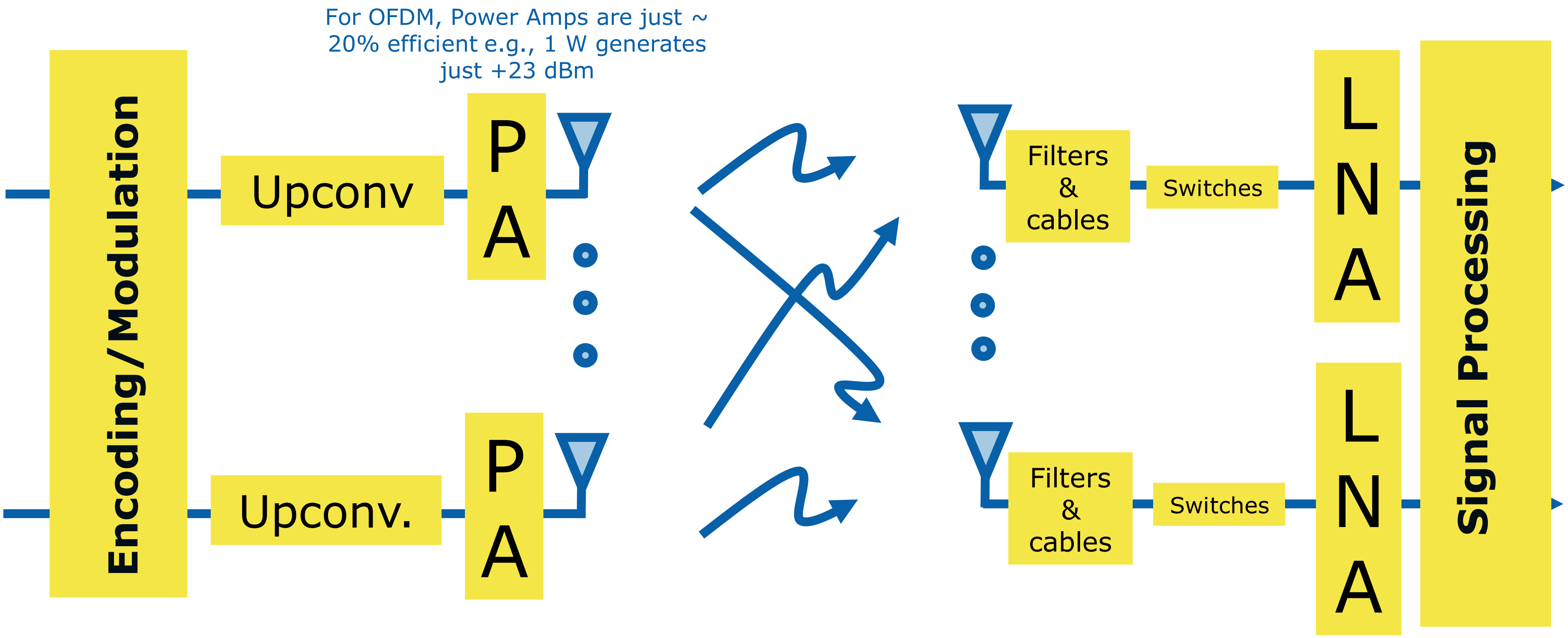


IDC



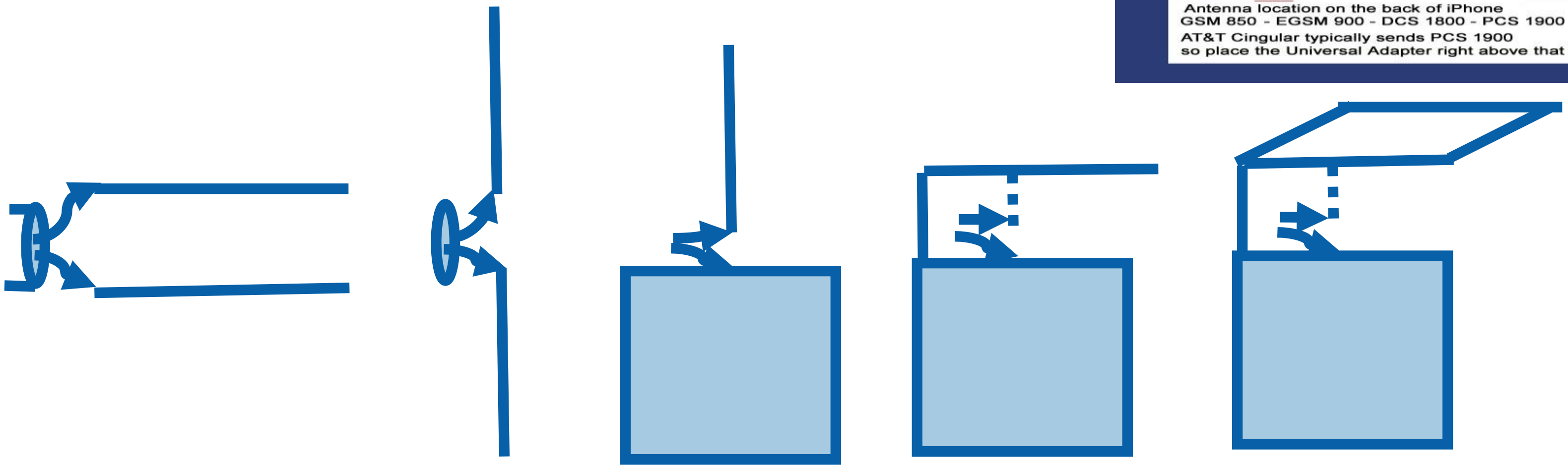
P. Mogensen et. al., "LTE Capacity compared to the Shannon Bound" IEEE Conf on Veh. Tech. April 2007

Communications Model



- TX Power Amplifiers (PA) are burdened by high peak to average ratios of OFDM signals – limited by power dissipation
- RX filters and cable insertion losses limit the noise figure of the system – not much improvement can be obtained – LNAs are close to ideal (w/o “cooling”)
- That leaves only the antennas & signal processing and their configuration and the channel to exploit

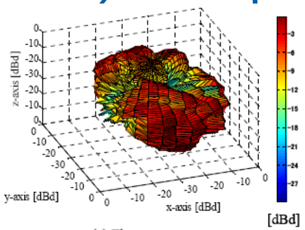
Antenna Backgrounder



• Capacitor Model, Dipole, Monopole, Inverted F, Broadband PiFA

• Near field (spherical waves) – Far Field (Plane Waves)

• power in, cable & matching losses, efficiency (ohmic losses), and pattern Gain (over isotropic) gives the power out in a given direc



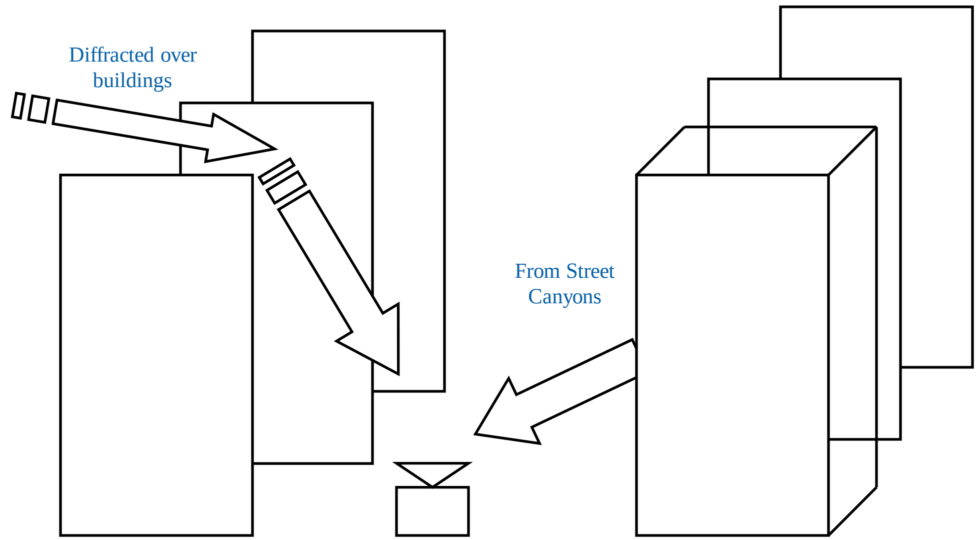
(a) Theta component

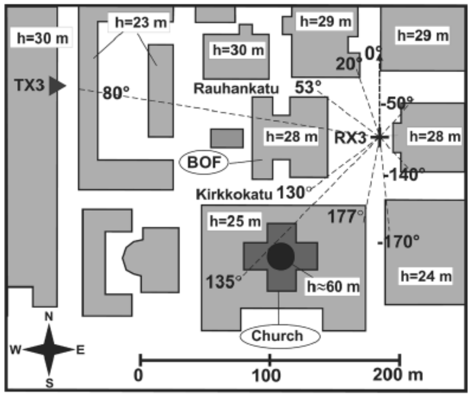
• Antenna Enclosure and Body, Head, hand-hold positio

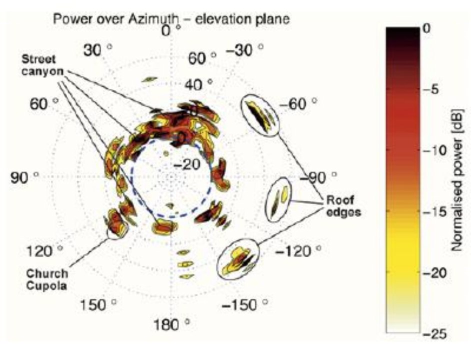
A. Yamamoto et. al., "Outdoor Urban Propagation Experiment of a Handset MIMO antenna with a Human Phantom located in a Browsing Stance" IEEE, 2007

Real World Transmission Paths for Macro-cells

- Signals come to the mobile station primarily from two mechanisms:
  - from street canyons and,
  - over the tops of buildings via diffraction (weaker) and reflection (stronger)
- Diffraction around corners and rooftops can result in key-hole effects
  - Produce more severe fading (double Rayleigh)
  - Reduces no. of independent MIMO channels





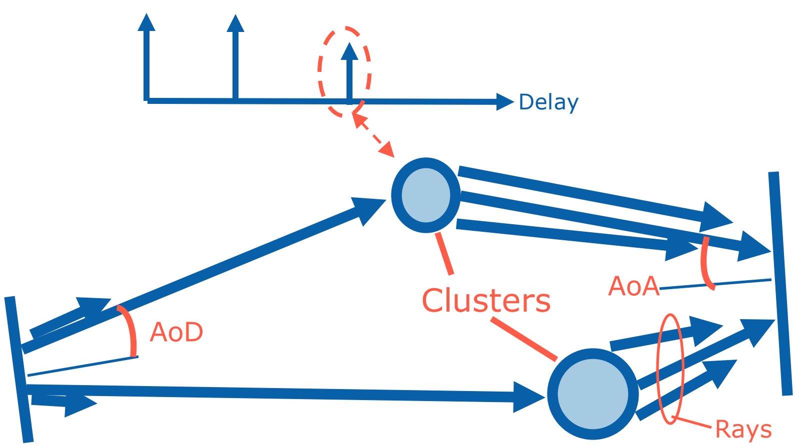


K. Kalliola et. al., "3-D Double-Directional Radio Channel Characterization for Urban Macrocellular Applications", IEEE Trans. On Anten. & Prop. Nov. 2003

- Channel Models developed to characterize directional aspects of propagation
- Important to accurately characterize in order to correctly predict MIMO and Diversity gains

Channel Model Backgrounder

- Classic: Impulse response model
  - But where do the signals actually come from???
- Measurement Data for Azimuth and Elevation
  - 3GPP (LTE) and 802.16m use WINNER II directional channel models
  - Based on extensive measurement campaign (indoor, rural, suburban, urban, and relay)
  - Generally AZ used only but EL should also be incorporated in modeling
- Double Directional Channel Model
  - – Clusters represent groups of similar delays and
  - – Angles of Departure and Angles of Arrival can differ due to Base-station (high above bldgs) vs. Mobile Station surrounding environments (reflectors farther and closer, respectively)



- AZ delay power spectrum
- ELEV delay power spectrum
- ELEV power spectrum

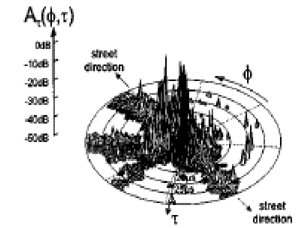


Fig. 23. Averaged ADPS, $A_\tau(\phi,\tau)$, of the incoming waves. We averaged over all scenarios in the environment class *Street_Corner*.

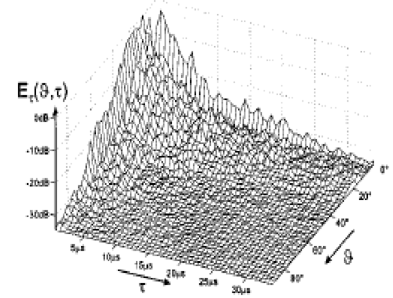


Fig. 24. Averaged EDPS $E_\tau(\vartheta,\tau)$ of the incoming waves. We averaged over all scenarios in street environments, including the environment classes *Street_Classic*, *Street_Far Echoes* and *Street_Corner*.

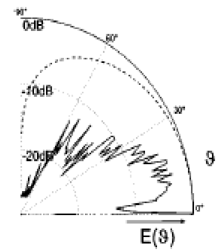


Fig. 25. Averaged EPS, $E(\vartheta)$, of the incoming waves (solid line). We averaged over all scenarios in street environments, including the environment classes *Street_Classic*, *Street_Far Echoes*, and *Street_Corner*. The dashed line represents the vertical antenna pattern of a $\lambda/4$ monopole mounted on a infinite conducting plane.

A. Kuchar et. al. "Directional Macro-Cell Channel Characterization from Urban Measurements" IEEE Trans Ant. & Prop. Feb. 2000.

Typical Urban Macro-cell Example Channel Model

Table 6-12 Scenario C2: NLOS Clustered delay line model.

Cluster #	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	Ray power [dB]
1	0	-6.4	11	61	-19.5
2	60	-3.4	-8	44	-16.4
3	75	-2.0	-6	-34	-15.0
4	145 150 155	-3.0 -5.2 -7.0	0	0	-13.0
5	150	-1.9	6	33	-14.9
6	190	-3.4	8	-44	-16.4
7	220 225 230	-3.4 -5.6 -7.4	-12	-67	-13.4
8	335	-4.6	-9	52	-17.7
9	370	-7.8	-12	-67	-20.8
10	430	-7.8	-12	-67	-20.8
11	510	-9.3	13	-73	-22.3
12	685	-12.0	15	-83	-25.0
13	725	-8.5	-12	-70	-21.5
14	735	-13.2	-15	87	-26.2
15	800	-11.2	-14	80	-24.2
16	960	-20.8	19	109	-33.8
17	1020	-14.5	-16	91	-27.5
18	1100	-11.7	15	-82	-24.7
19	1210	-17.2	18	99	-30.2
20	1845	-16.7	17	98	-29.7

Cluster ASD = 2°
Cluster ASA = 15°
XPR = 7 dB

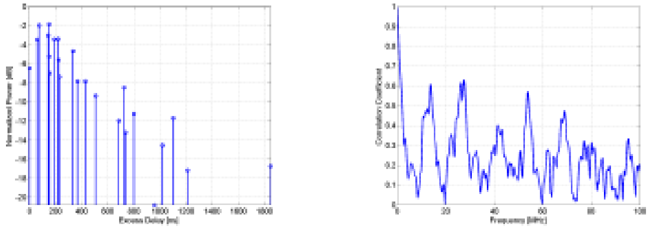


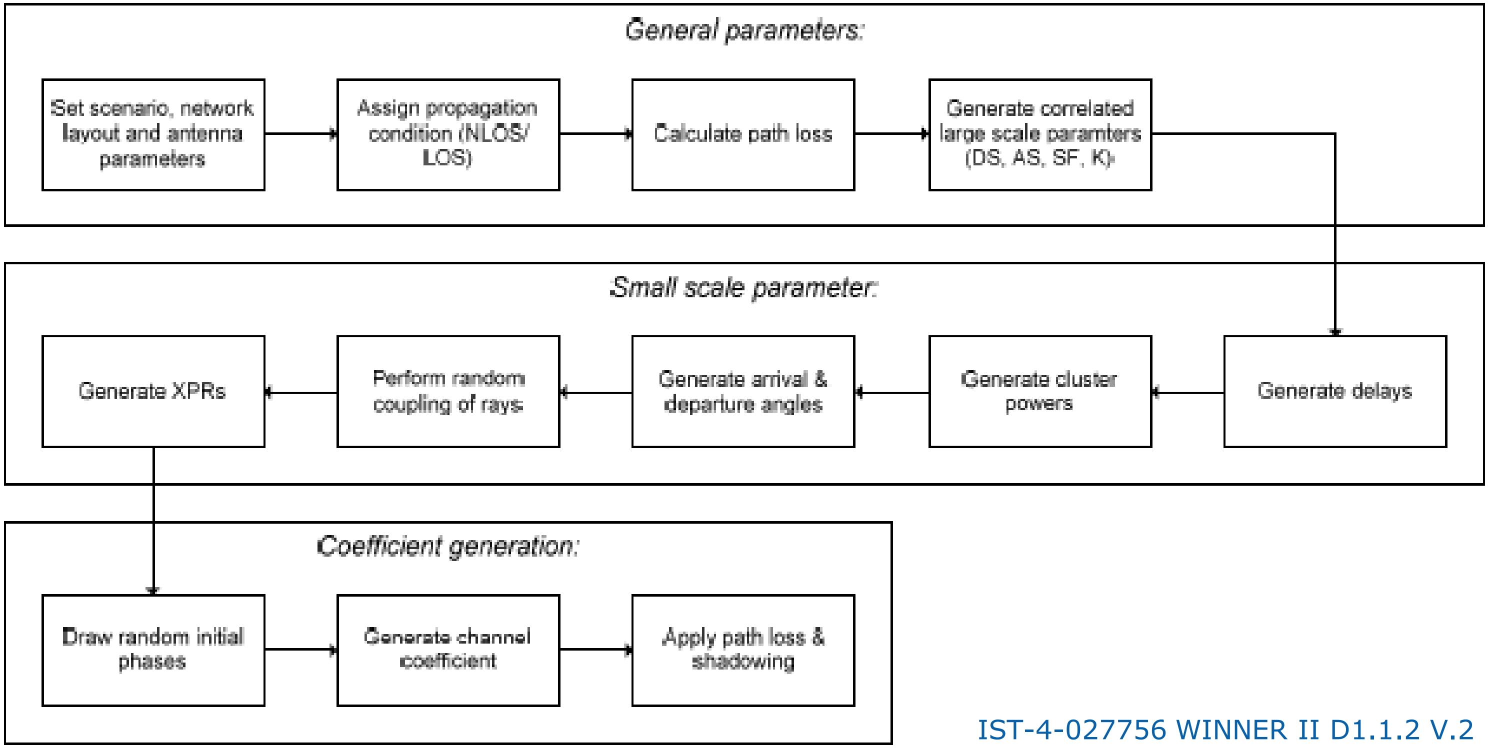
Figure 6-12: PDP and frequency correlation (FCF) of CDL model.

IST-4-027756 WINNER II D1.1.2 V.2

- Urban Macro-cell Channel Environment (3GPP and IEEE 802.16m)
  - 20 "Clusters" of delays with AoA and AoD associated with each "cluster"
  - Each Cluster contains 20 plane waves of random phase but identical amplitude for Rayleigh fading
  - AoD mean and spread (small at **2 deg.**) characterizes BS
  - AoA mean and spread (large at **15 deg.**) characterizes MS

Channel Simulation Procedure (Winner II)

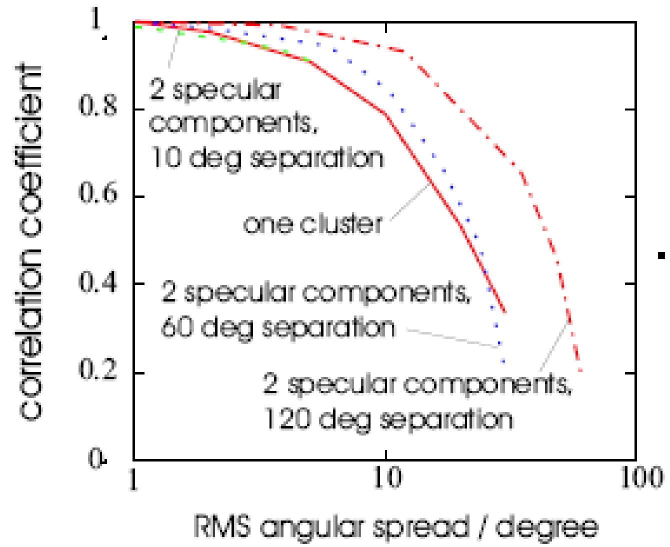
- Allows for full network simulation to assess true network capacity
- Highly accurate modeling factors in such key elements as antenna patterns



IST-4-027756 WINNER II D1.1.2 V.2

Directional Model Impact on Link

- •Impact on Communication Model – how does the channel affect the correlation between antennas?
  - – AoA spread per cluster improves capacity (more widespread scattering)
  - – More clusters makes for more independent channels for better capacity or better diversity – but they need to be widely dispersed
  - – Wider Antenna element separation can improve capacity for narrow AoA spread – needed for Base-station (typical only few degrees of AoD spread)
  - – High Base-station correlation can limit overall link capacity



A. Molisch, "Effect of far Scatterer Clusters in MIMO outdoor channel models" Andreas.Molish@ieee.org

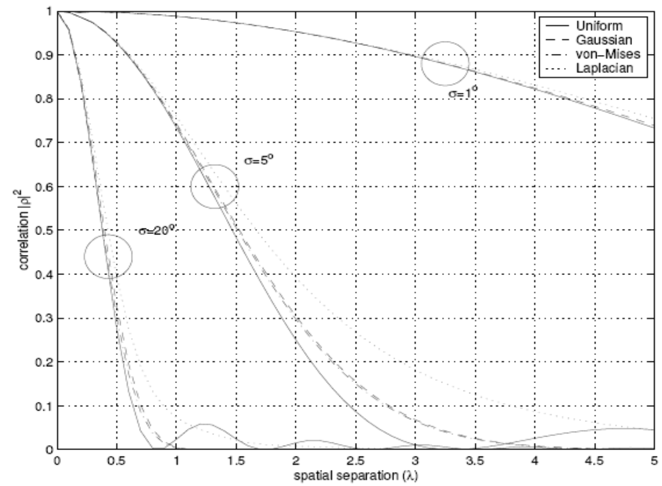


Figure 6: Spatial correlation between two antennas for mean AOA 90° (broadside) against spatial separation for Uniform, Gaussian, von-Mises, and Laplacian scattering distributions and angular spreads $\sigma = \{1°, 5°, 20°\}$.

T. Pollock et. al., "Introducing Space into MIMO Capacity Calculations" Australian National University, tony.pollock@anu.edu.au

Directional Channel’s Correlation impact on MIMO Capacity

- Ideal independently Rayleigh fading (from antenna to antenna) yields the best capacity
  - but it’s rare that signals come equal strength from “all” directions
  - If they do, then capacity increases with the number of TX = RX antennas
- Real world channels are directional
  - The directionality comes from different clusters with associated cluster spreads of signals
  - Increasing mean angle of arrival can reduce effective aperture and resolvability decreasing capacity
  - Loss of Correlation only affects the capacity of antenna systems with two or more elements

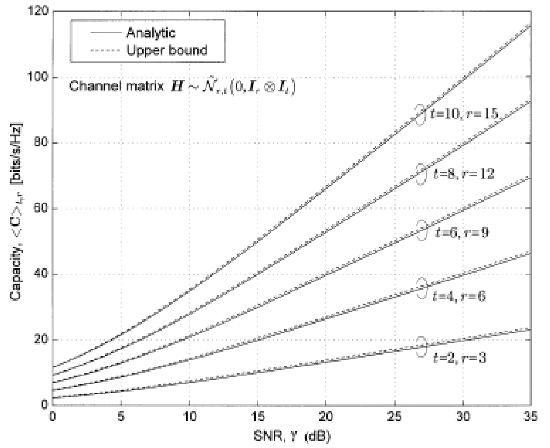


Fig. 1. Ergodic capacity of i.i.d. Rayleigh-fading MIMO channels with t transmit and r receive antennas.

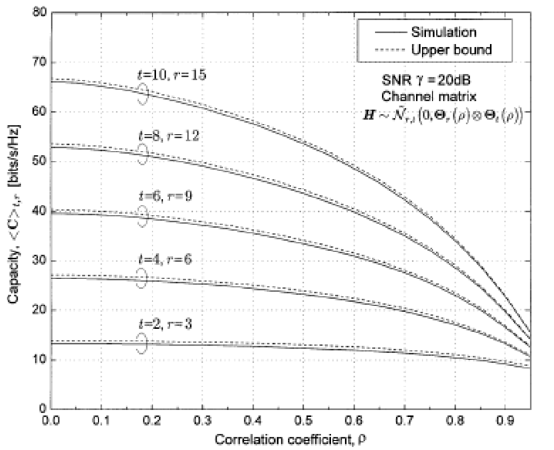
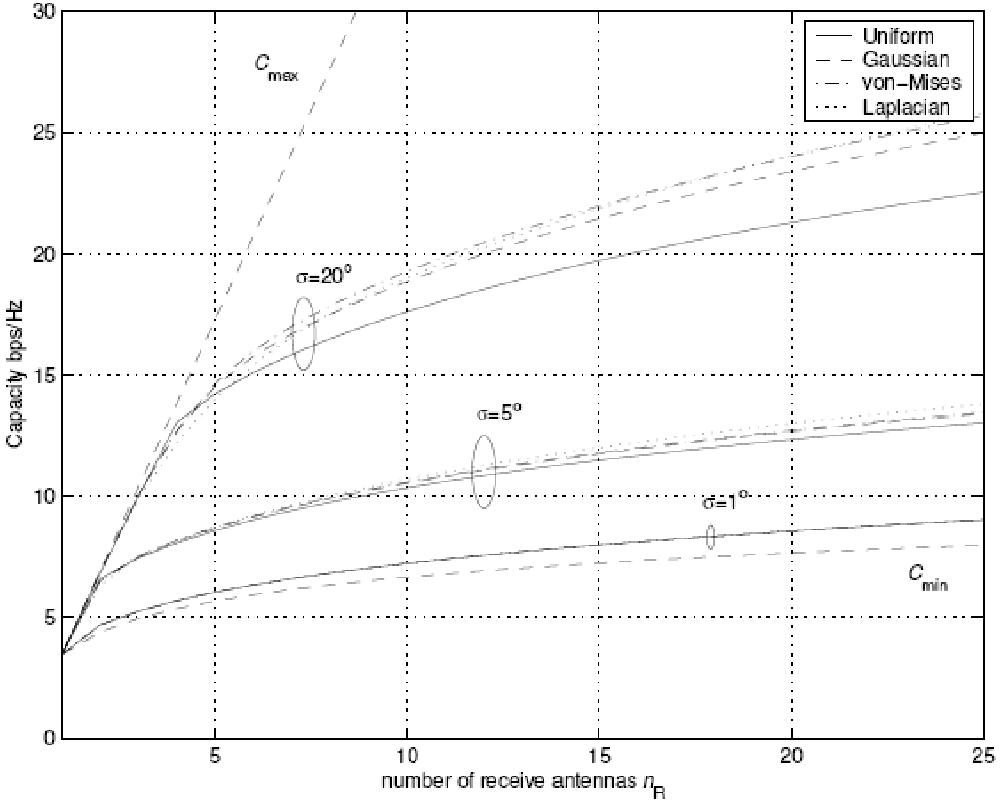


Fig. 3. Ergodic capacity as a function of correlation coefficient ρ for spatially correlated Rayleigh-fading MIMO channels with t transmit and r receive antennas. $\Phi_T = \Theta_t(\rho)$ and $\Phi_R = \Theta_r(\rho)$.

H. Shin and J.H. Lee “Capacity of Multiple-Antenna Fading Channels: Spatial Fading Correlation, Double Scattering, and Keyhole, IEEE Trans Inform. Theory, Oct. 2003

How close to Theory are Real-world channels?

- Broadside Linear Array with aperture of 4λ
- 20 deg. spread gives close to theory for up to 4 or so antennas
- 1 deg. spread gives diversity only performance



T. Pollock et. al., "Introducing Space into MIMO Capacity Calculations"
Australian National University, tony.pollock@anu.edu.au

Double Scattering and Keyhole Channels

- For some channels that
  - have long paths from TX to RX
  - Go thru repeaters, or
  - Diffract from the roof or around bulding corners
  - Go thru tunnels
- They have limits in capacity
  - The double scattering channel curves at right has 6 scatters (in the tunnel, for example) – the capacity curves show limited gains after 6 antennas
  - The key hole channel is even more constrained

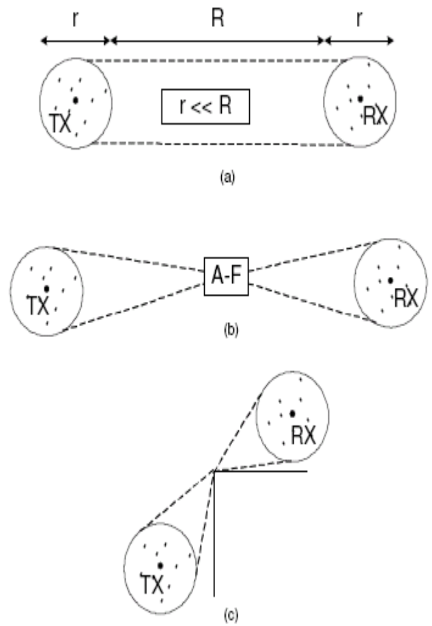


Fig. 1. Three propagation scenarios with double-Rayleigh fading. (a) keyhole created by two rings of scatterers separated by large distance [6]; (b) amplify-and-forward relay; (c) propagation via diffracting street corner [1].

J. Salo et. al. "Impact of Double-Rayleigh Fading on System Performance," 2006 1st International Symposium on Wireless Pervasive Computing

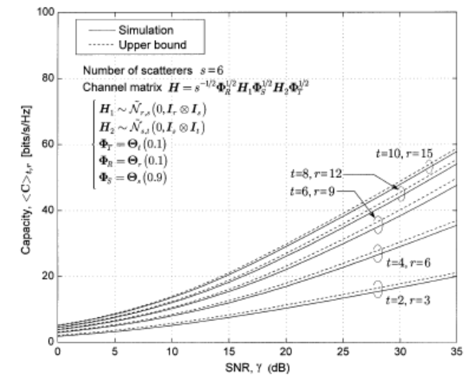


Fig. 5. Ergodic capacity of double scattering MIMO channels with t transmit and r receive antennas. $s = 6$, $\Phi_T = \Theta_t(0.1)$, $\Phi_R = \Theta_r(0.1)$, and $\Phi_S = \Theta_s(0.9)$.

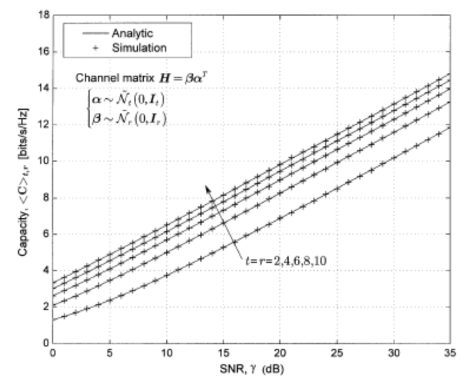


Fig. 6. Ergodic capacity of keyhole MIMO channels with t transmit and r receive antennas.

H. Shin and J.H. Lee "Capacity of Multiple-Antenna Fading Channels: Spatial Fading Correlation, Double Scattering, and Keyhole, IEEE Trans Inform. Theory, Oct. 2003

Performance Summary

- Base-station antenna spacing should be large since the angular spread is relatively small
- Mobile-station antenna spacing is necessarily small but angular spreads are relatively large
- Much of the time, MIMO capacity can be close to theory
- But sometimes it will be constrained by real world channels such as tunnels, diffraction, etc.

Exploiting the Channel: Performance and Design Guidelines

- What can Module Designers do?
  - Exploit clusters that offer the “best capacity”
  - A proper balance must be maintained between interference rejection, diversity, and spatial multiplexing
- What can the operator do?
  - Provide better performance metrics for module designers and also to the users
  - Provide matched antenna configurations at the base-stations
- What can the user do to improve TX and RX?
  - Avoid blocking the antennas – hold the handset correctly
  - Welcome more cell towers/repeaters in the local neighborhood! (don’t worry about property values!)

Overall Summary

- With Voice saturating, the growth areas will be in data
- Spectrum is limited, infrastructure costs are high and Shannon Limits have nearly been reached
- Systems have not exploited all the channel characteristics – most systems designed for non-directional or impulse response channel models
- Directional Channel Models (DCMs) are based on extensive real world channel measurements
- DCMs were developed for MIMO performance predictions – use them in network simulations
- DCMs provide much insight into how a more efficient uplink (and downlink) can be engineered

For More Information

- More on MIMO Capacity:
  - "Information Theory" ELEN244 Santa Clara University (Dr. Xiaoshu Qian)
- More on Antennas:
  - **Antennas from Theory to Practice,** Yi Huang and Kevin Boyle, 2008 Wiley
- More on Directional Channels:
  - The COST 259 Directional Channel Model-Part II: Macrocells, "H. Asplund, et al., IEEE Transactions on Wireless Communications, Vol. 5., No. 12, Dec. 2006
- More on Power Amplifiers:
  - Poulin, D., "How to meet the design challenges of WiMax Power Amplifiers," Wireless Net Design Line, 10 June 2008
- Xiaoshu Qian – Xiaoshuqian@yahoo.com
- Ernest Tsui – ett55@ieee.org