Agenda

• Introduction
  – Usage models
  – Ecosystem Changes

• Communications Model/Environment

• Channel Model – Backgrounder

• Directional Channel Model Example

• Performance and Design Guidelines

• Summary and Conclusions
Usage Models

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) – avoid wasting power/time

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

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

• 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)

Typical Urban Macro-cell Example Channel Model

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

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- 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

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

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

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

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

How close to Theory are Real-world channels?

- Broadside Linear Array with aperture of $4\lambda$
- 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 building 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

![Double Scattering Diagram](image)


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:

• More on Power Amplifiers:
  – Poulin, D., “How to meet the design challenges of WiMax Power Amplifiers,” Wireless Net Design Line, 10 June 2008

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