STANFORD ENGINEERING

Mobile Communications Technology 1990-2015

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Stanford University

25th Virginia Tech Symposium on Wireless Personal Communications
May 27, 2015

Congratulations to Wireless @ Virginia Tech !

Top Faculty

- We miss you Prof. Ted Rappaport

Superb Students

Dedicated Staff

Persistent Industry and Federal Support

25 Years of Excellence

Mobile Wireless 1991 - Phone

4.5 M Global Subs

Mobile Wireless 2015 – Platform

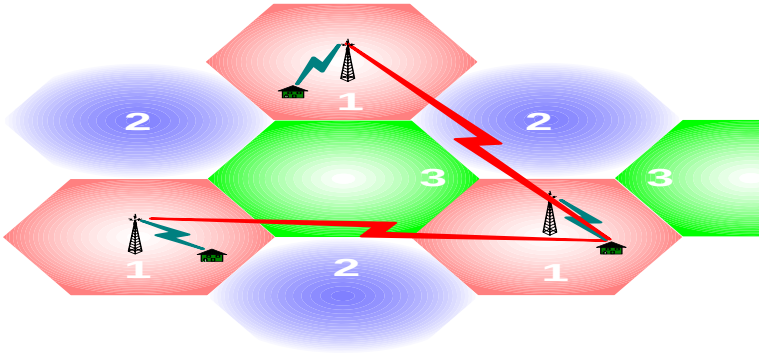
7 Billion Global Subs

Performance Drivers

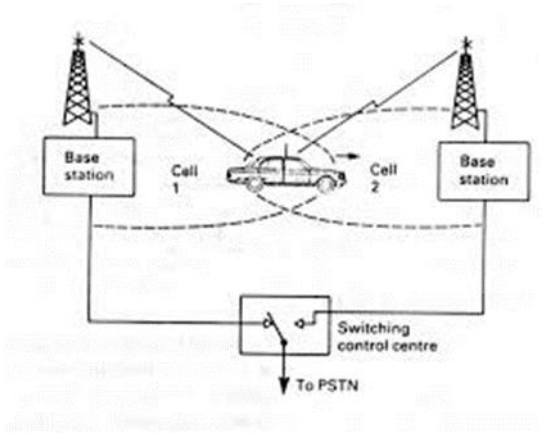
- Higher Capacity / Spectrum Efficiency
- Lower Latency
- Coverage Reliability and Uniformity
- Economics

Mobile Telephony – Pre Cellular

Scaling to 10,000s +



Cellular Reuse



Handover

DH Ring, WR Young, A Joel

Improving Spectrum Efficiency

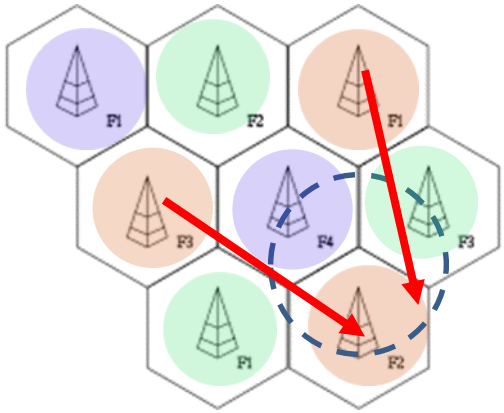
- Tighter reuse
- Transmit at capacity
- Mitigate interference
- Spatial dimension

Enablers

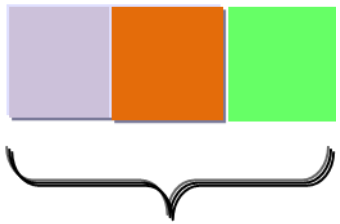
- Signal Diversity,
- Interference Mitigation
- Adaptive Mod./Coding
- MIMO Antennas

Bandwidth per Cell vs SIR

K= 3

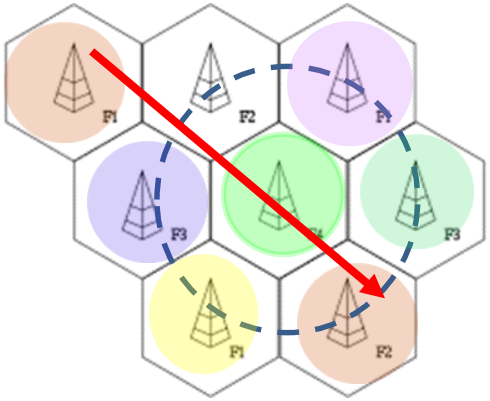


Higher Interference

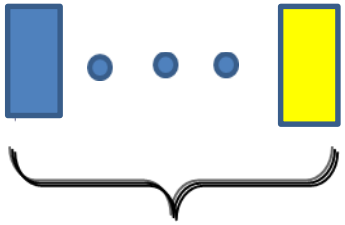


Total Bandwidth Available

K=7

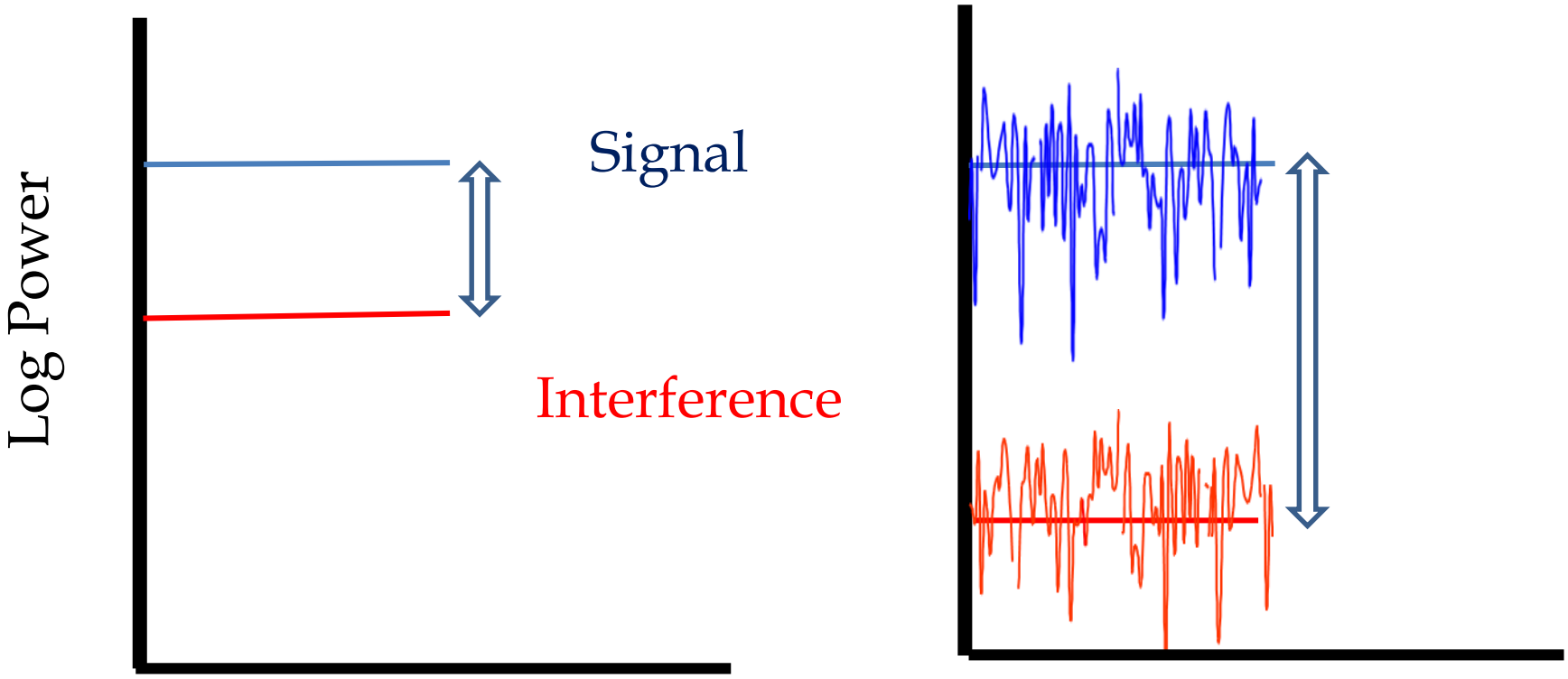


Lower Interference



Total Bandwidth Available

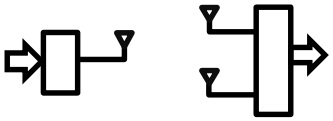
Required SIR w/o and w/ Variability

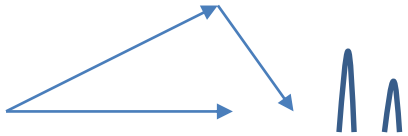


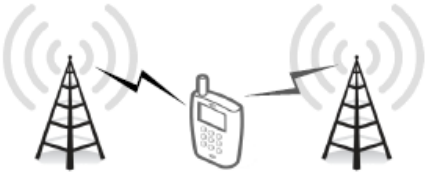
Fading / Variability -> Loose Reuse (Higher K)

Signal Diversity

- Microscopic
  - Antenna (space)
  - Time
  - Frequency (Path)
- Macroscopic

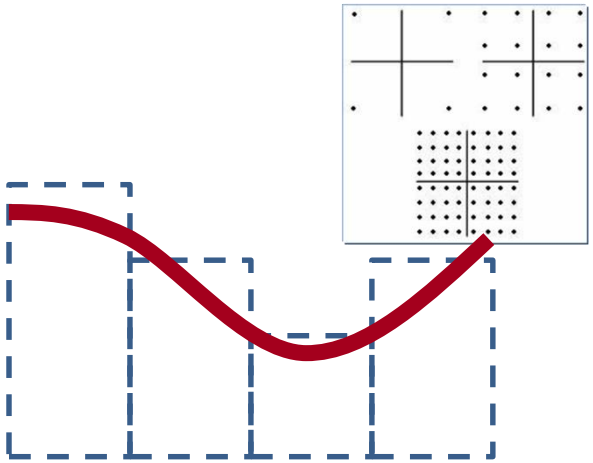






Adaptive Modulation and Coding

- Modulation & Code rate adapted to SNR / channel capacity



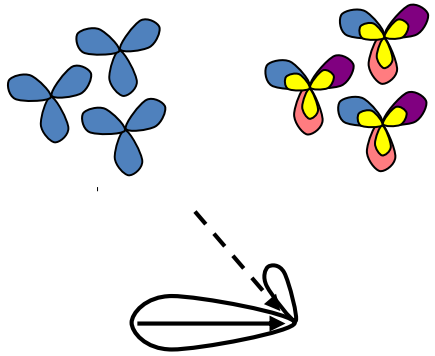
- Sources of capacity variability
  - Path loss and fading
  - Frequency selectivity
  - Time selectivity
  - Spatial selectivity (MIMO)

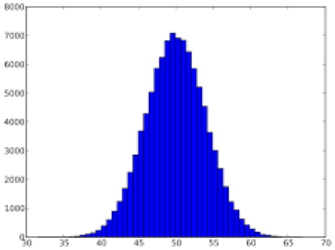
- Expose the different dimensions and transmit on each dimension at capacity

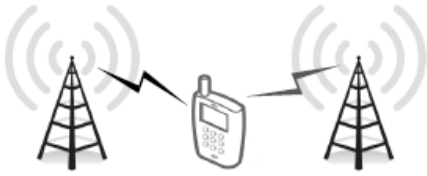
SIR dependent ?

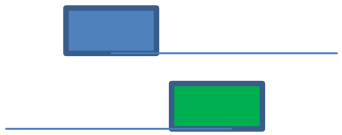
Interference Mitigation

- Control (by Reuse)
- Reduce mean level (cancel)
- Reduce variance (average)
- Avoid by scheduling



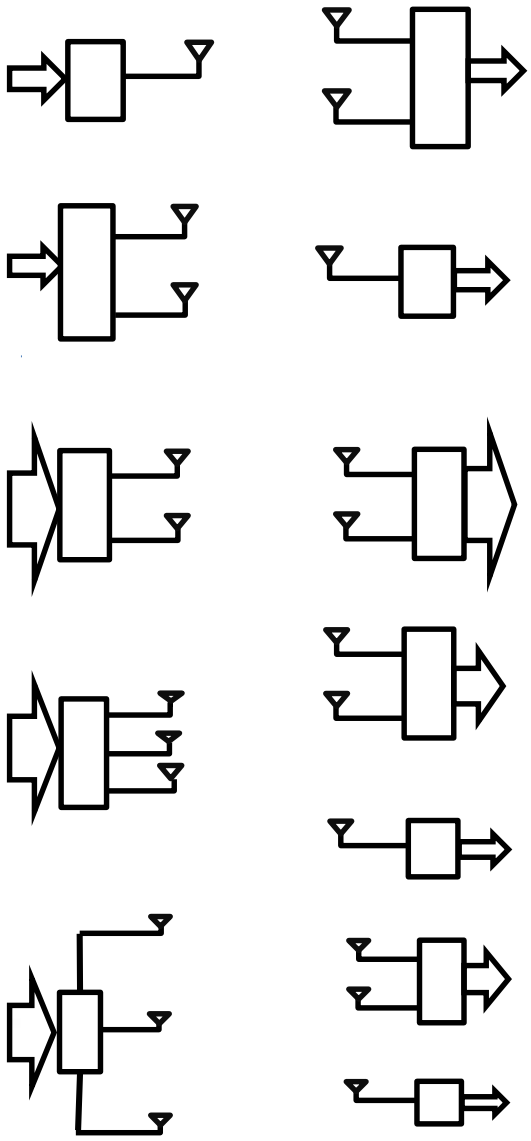






Antennas

- Receive diversity
- Transmit diversity
- Spatial Multiplexing (MIMO)
- MU-MIMO
- D-MIMO



Multiple Access / Modulation

- FDMA / FM, TDMA / GMSK , CDMA / DS-SS and OFDMA / OFDM

- Little direct impact on spectrum efficiency, but made it easier to exploit the real enablers
  - Signal Diversity,
  - Interference Mitigation
  - Adaptive Mod./Coding
  - MIMO Antennas

1G (AMPS) – Mid 80s

- **Analog**
- Loose reuse (K = 21)
- **FDMA / FM**
- 30 KHz channels

- ATT, Ericsson, NTT

- Tighter reuse
- Transmit at capacity
- Mitigate interference
- Spatial dimension

J Engel M Cooper R Frenkiel

2G (GSM) – Early 90s

- **Digital**
- Medium Reuse (K=9)
- **TDMA / GMSK**
- 200 KHz channel
- + Voice Coding
- + Channel Coding
- + Loose power control
- + Intf. Averaging by FH

- ETSI, Ericsson, Alcatel, Matra

- Tighter reuse
- Transmit at capacity
- Mitigate interference
- Spatial dimension

T Haug, A Maloberti, J Ausdestad

3G – WCDMA

- Tight reuse (1)
- **CDMA / DS-SS**
- 5 MHz Channel
- + Tight power control
- + Interference Diversity (DS-SS)
- + Turbo / LDPC coding
- + Path and antenna diversity
- + Macro diversity (soft handoff)
- + Var. Spreading
- Qualcomm, NTT, 3GPP

- Tighter reuse
- Transmit at capacity
- Mitigate interference
- Spatial dimension

A Viterbi, I Jacobs, F Adachi

4G – Early 10s

- **Packet switched**
- **OFDMA / OFDM**
- 5,10,20 + MHz Channels
- + Signal Diversity (Antenna, Freq.)
- + MIMO
- + Tx Beamforming
- + Fractional Reuse
- + Adaptive Modulation / Coding
- + PHY ARQ
- + Multi-User Diversity
- + Interférence Cancellation
- Iospan, Intel (WiMAX), 3GPP

- Tighter reuse
- Transmit at capacity
- Mitigate interference
- Spatial dimension

A Paulraj, S Alamouti, 3GPP

Mobile Technology Today

- 95% global cell phones penetration
- 28% broadband (4G)
- Phones: Android, IOS, ..
- Infrastructure: Ericsson, Huawei, Nokia
- Semiconductors: Qualcomm, Mediatek, Intel
- Peak speeds - touching 140 Mbps

Summary

- Landmark societal impact
- Massive global enterprise – basic ideas, research, standards, engineering development, manufacture, deployment and network operations
- W@VT has been a important influencer and contributor