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Title	**Frequency-Domain-Oriented Approaches for MBWA: Overview and Field Experiments**
Date Submitted	**2003-03-06**
Source(s)	Kevin Baum Motorola Labs 1301 E. Algonquin Rd., Rm 2928 Schaumburg, IL 60196 Email: Kevin.Baum@motorola.com
Re:	MBWA ECSG Call for Contributions
Abstract	This presentation provides an overview of frequency-domain-oriented approaches for mobile broadband air interfaces, and presents some related results from recent field experiments.
Purpose	For informational use only.
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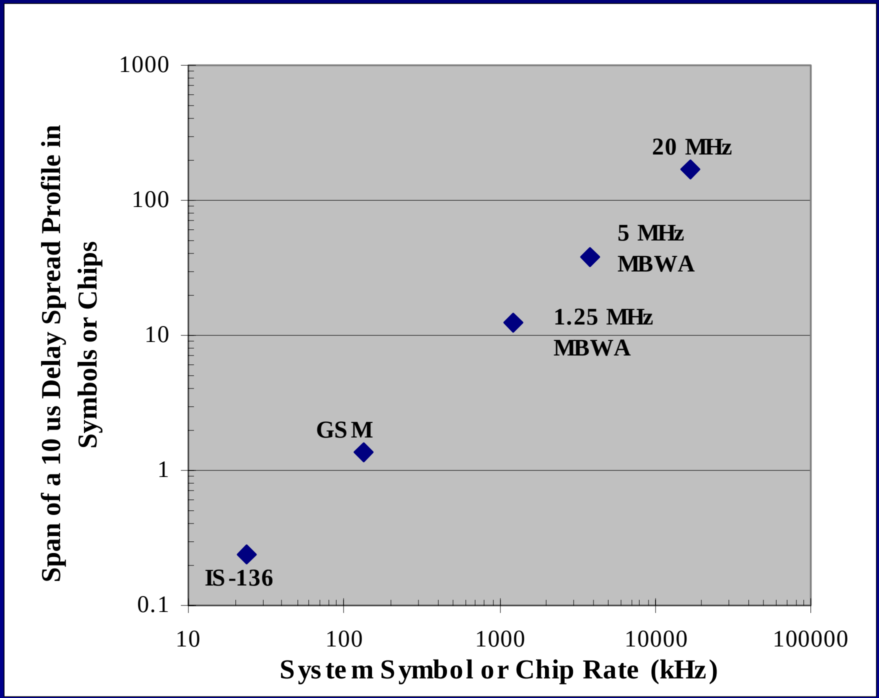
Frequency-Domain-Oriented Approaches for MBWA: Overview and Field Experiments

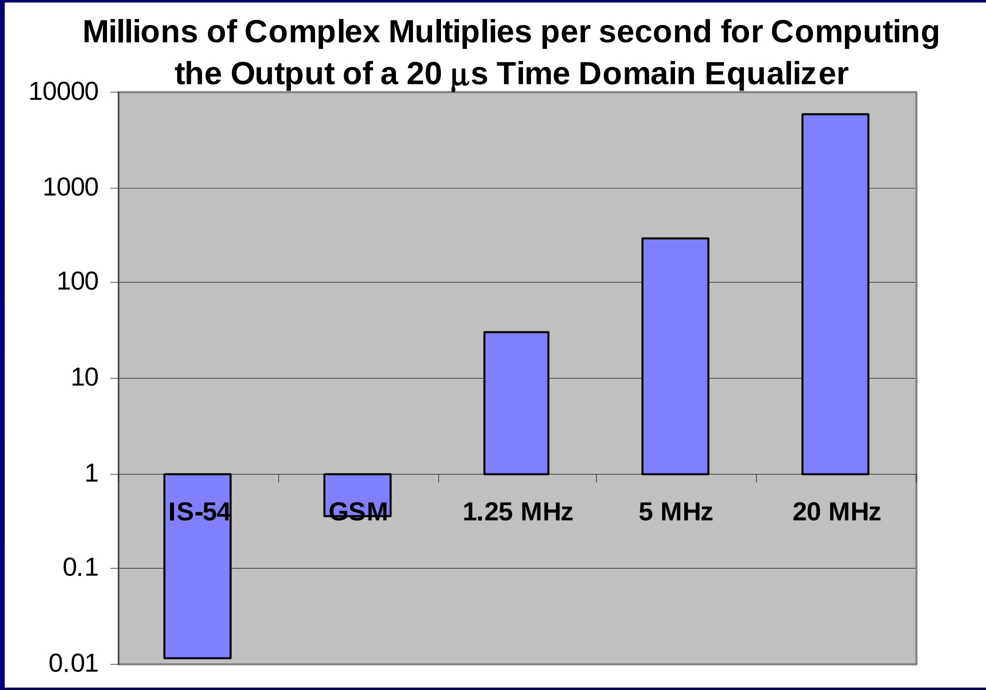
IEEE 802.20

March 10-14, 2003

Motivation

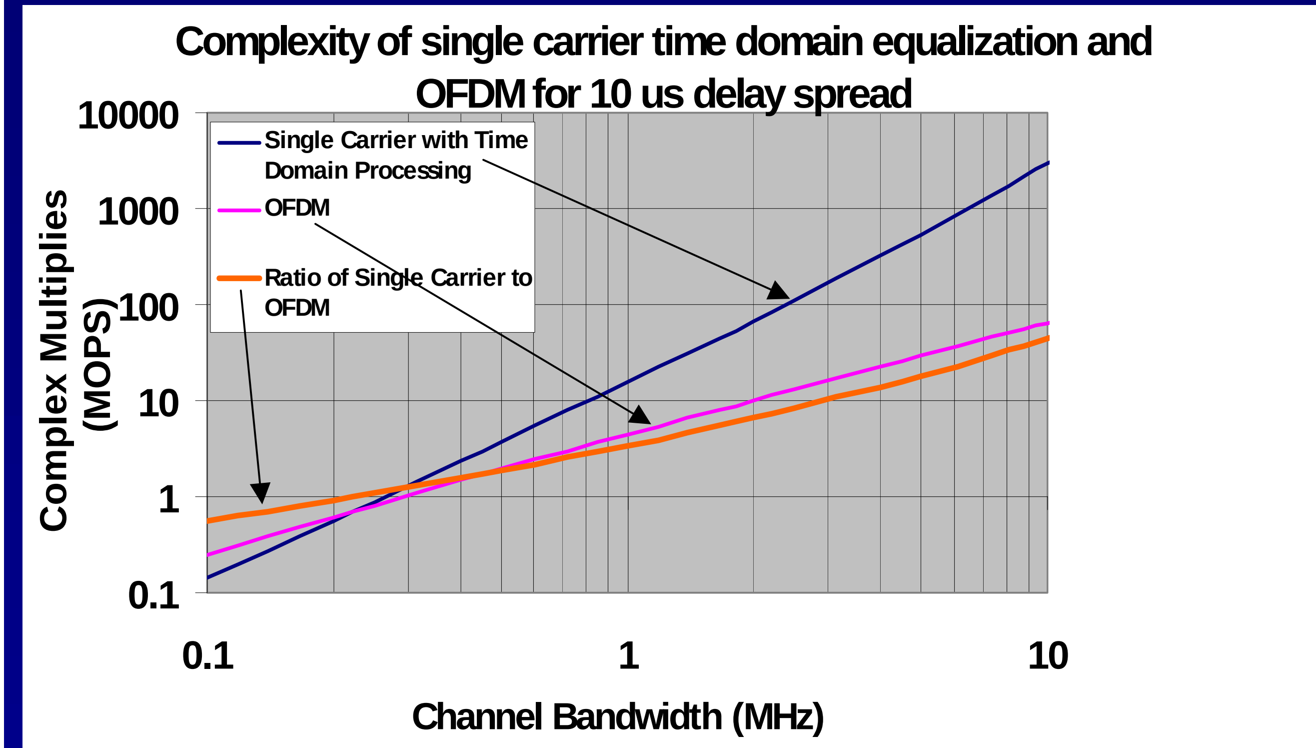
- The bandwidth of wireless systems continues to increase over time
- The impact of a constant delay-spread increases with bandwidth





- **Frequency domain approaches, based on efficient FFT processing, can be investigated to reduce the implementation complexity of broadband systems ($N\log_2 N$ complexity vs. N^2 or N^3)**

Complexity of Time Domain Equalization and OFDM "Equalization"



Assumptions

- Includes only equalizer output computation (at the symbol rate) and equalizer tap computation
- Equalizer taps computed from known channel impulse response every 1/(10Fd) sec
- Fd =200 Hz Doppler
- Time domain equalizer length = 2x channel length
- Complexity model of matrix inverse: $(L^3)/6$
- Complexity model of FFT: $(N/2)\log_2(N)$

- **The complexity advantage of frequency-domain approaches becomes compelling as the bandwidth increases**

Frequency-Domain-Oriented Approaches

Two main classes

Frequency domain oriented transmission and reception

- Transmission format specifically designed to support low complexity *frequency domain processing*
- Focus of this presentation

Frequency domain implementation of conventional linear filtering (receive-only)

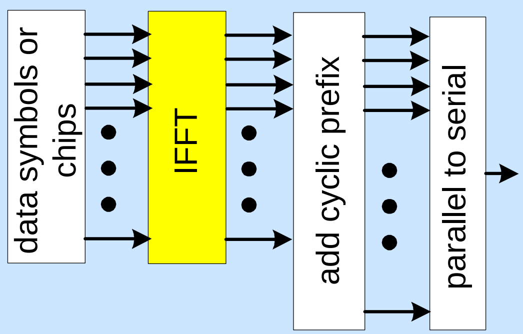
- Overlap-add, overlap-save filtering techniques
- Useful for "retrofit" applications
  - Does not change the transmit signal format
- Still has a high computational load for determining tap values
- Not discussed in this presentation

- ***High performance*** **with** ***low complexity*** **for broadband channels**
- **Well suited for** ***advanced multiple antenna*** **methods (MIMO, space-time coding, SDMA, adaptive antennas)**

Transmission

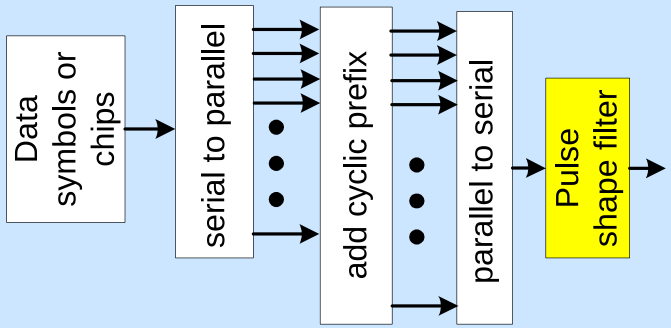
- **The main frequency domain oriented transmission methods:**
  - **Multicarrier (regular OFDM and spread OFDM/MC-CDMA)**
  - **Cyclic-prefix (CP) single carrier with frequency domain equalization**
  - **Others also exist**
  - **For brevity, this presentation will focus on OFDM and CP single carrier**

Basic Tx structure for OFDM



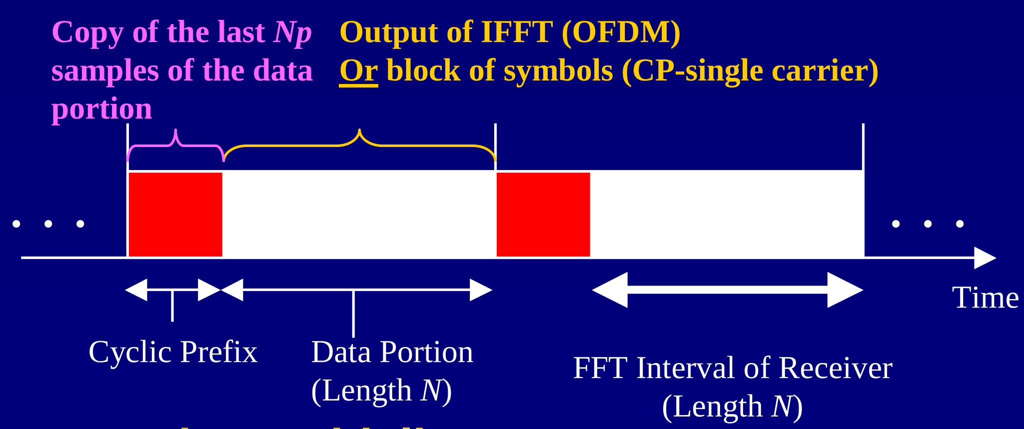
Data (and spreading code, if used) in frequency domain

Basic Tx structure for CP-single carrier



Data (and spreading code, if used) in time domain

Tx Time Format and Receiver

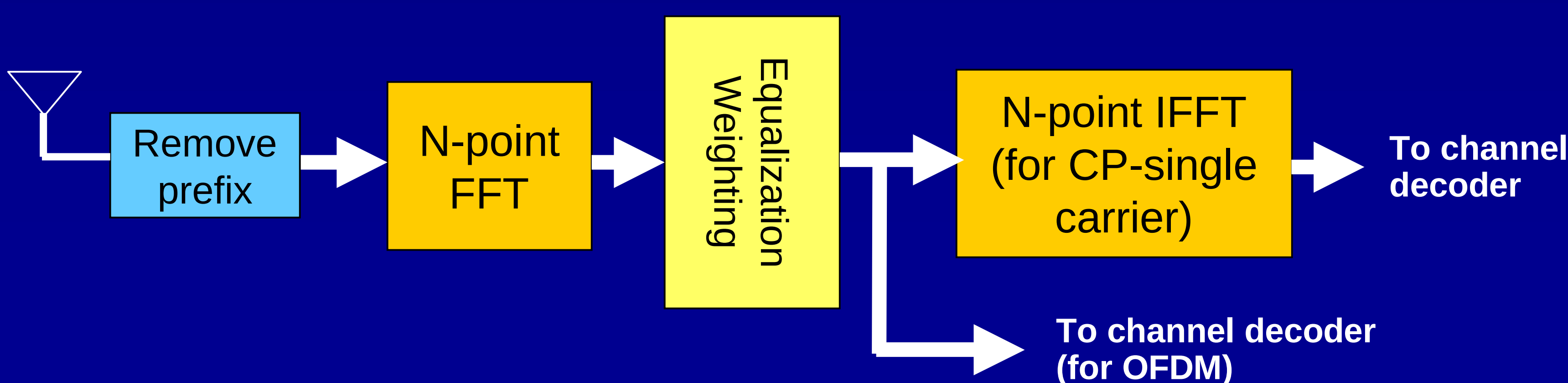


Cyclic prefix makes the linear convolution with the channel equivalent to a circular convolution (within the data portion)

FFT's are very efficient for processing circular signals! Frequency domain implementation of channel estimation, equalization, combining, …

- **Design Guidelines**
  - **Make CP longer than channel delay spread**
  - **Make data portion large enough that CP overhead is small**
  - **Make data portion short enough that channel does not change over the block**

Basic Receiver Structure

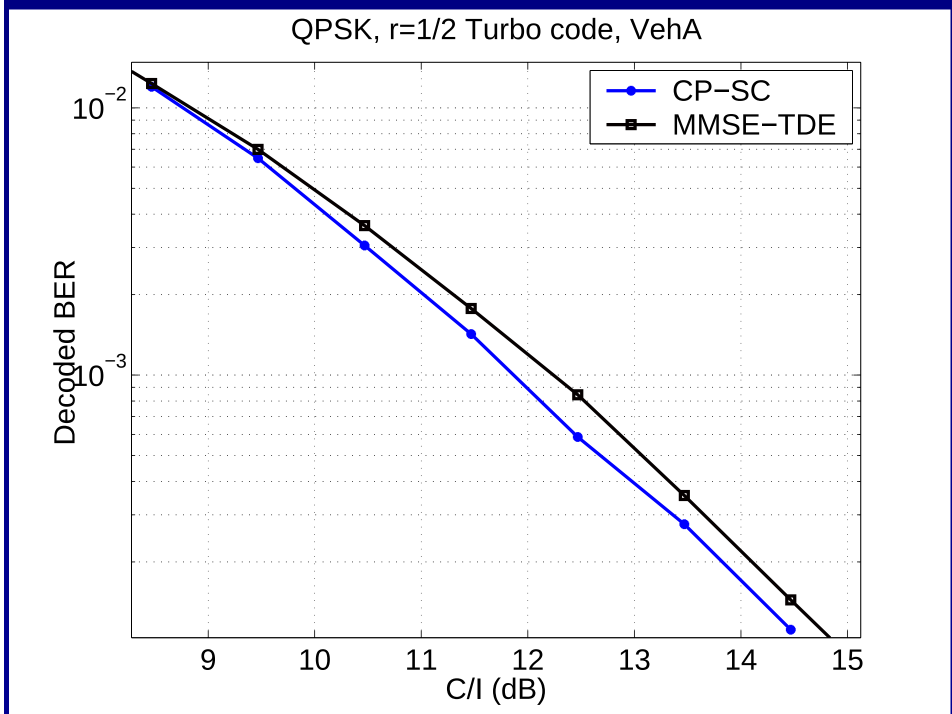


Simulation Example 1: Frequency Domain vs. Conventional Time Domain

- 5 MHz channel bandwidth, Vehicular A and GSM TU channels
  - Ideal channel knowledge, block fading
- Blue – Conventional single-carrier (without cyclic prefix) with time domain MMSE linear transversal equalizer (2x the channel length)
- Black – Cyclic-Prefix single-carrier with block size *N* = 384, frequency domain MMSE equalization

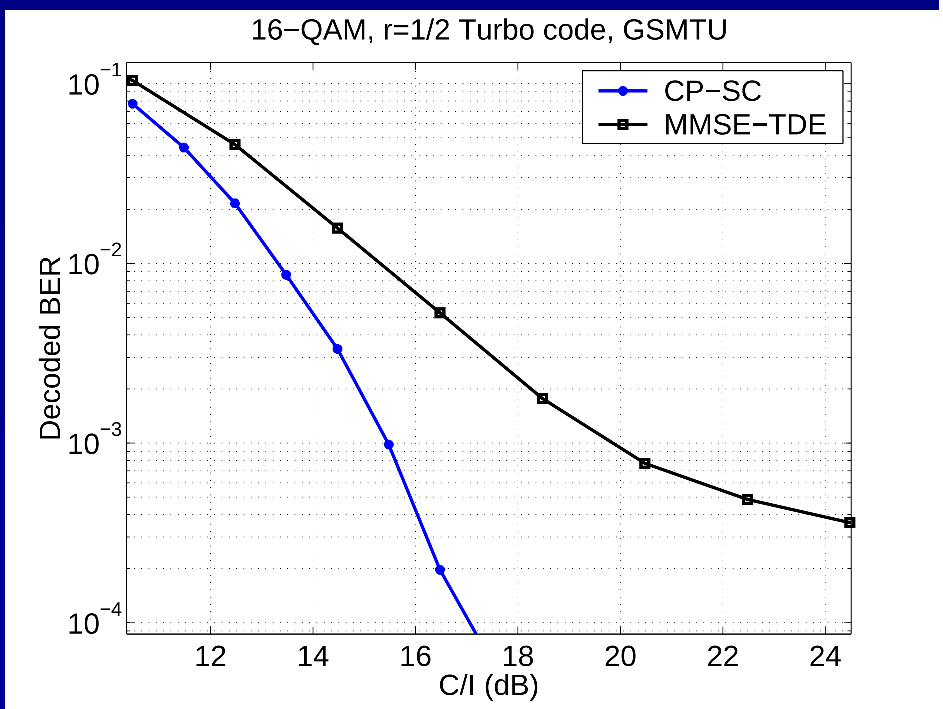
Low Delay Spread, Low-order Modulation

Vehicular A: 2.5 µs span, 370 ns RMS



Larger Delay Spread, Higher-order Modulation

GSM TU: 5 µs span, 1 µs RMS

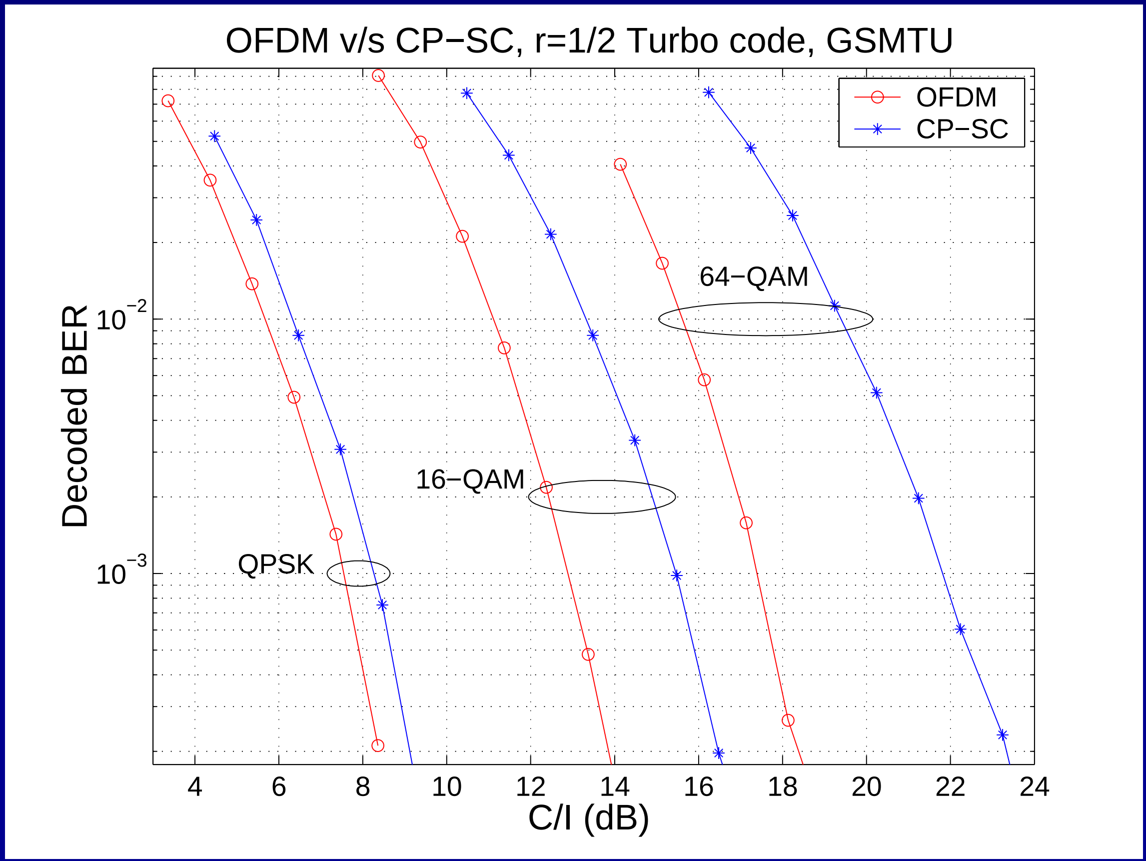


Example 2: Link Simulation of Different Frequency-Domain Approaches

- **Cyclic-prefix single carrier (CP-SC) and OFDM performance for R= ½ turbo coded QPSK, 16-QAM, 64-QAM modulation/coding schemes (MCS)**
  - **Assumptions:**
    - **5 MHz channel bandwidth, block-faded GSM TU channel (5 µs span, 1 µs RMS delay spread)**
    - **Frequency Domain MMSE equalizer, ideal channel knowledge**
    - **In practice, the MCS would be adaptively selected based on link quality (and additional MCS levels may be included)**

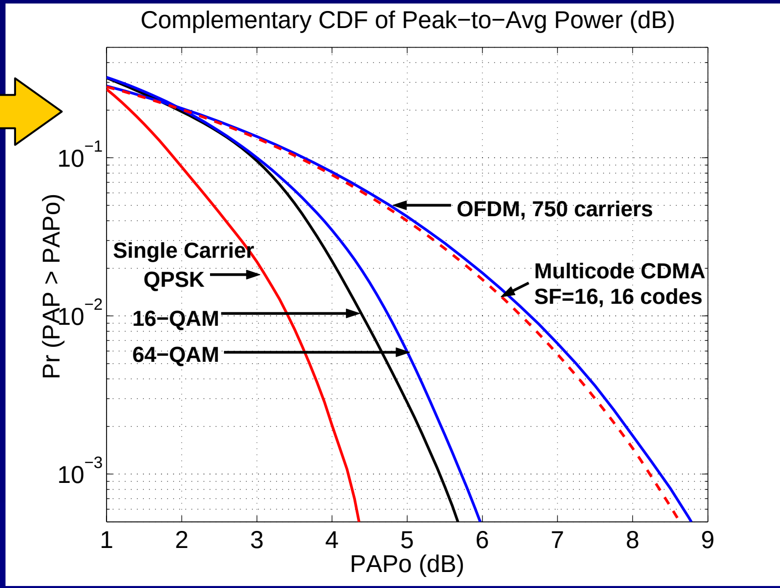
Red – OFDM

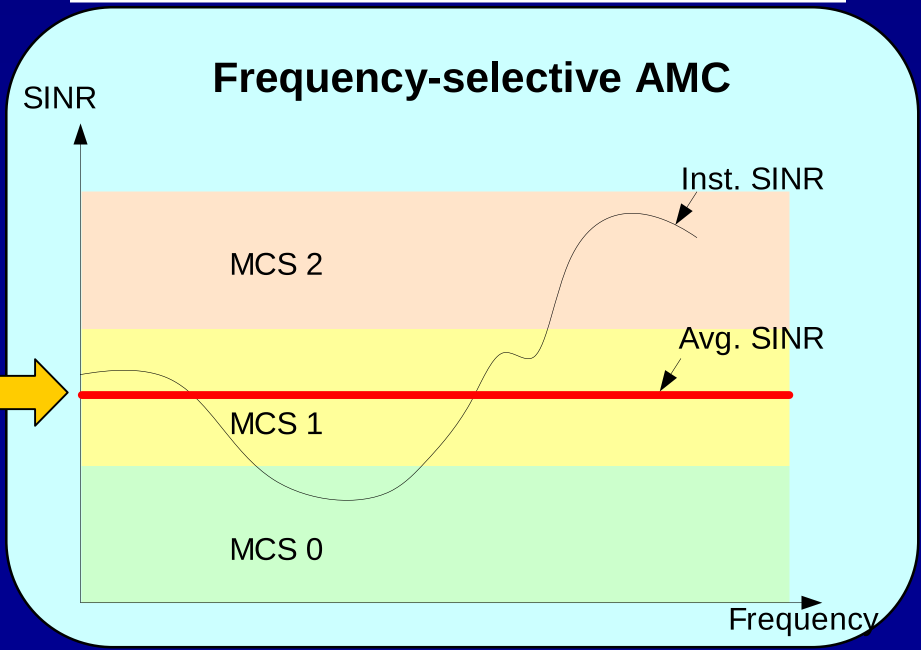
Blue – CP-single carrier with frequency domain equalization



Tradeoffs between OFDM and CP-SC

- **CP single carrier benefits**
  - **Low peak-to-average power ratio**
    - **A significant benefit for the uplink**
  - **Obtains frequency diversity regardless of coding rate**
    - **Leads to a performance benefit for QPSK with R > 2/3 coding**
- **OFDM benefits**
  - **Orthogonality between symbols in delay-spread channels**
    - **No noise enhancement**
    - **Better performance when MCS set is carefully chosen (e.g., use R = 3/8 16-QAM for 1.5 b/symbol rather than R = ¾ QPSK)**
  - **Full access to the "time-frequency grid"**
    - **Frequency selective transmission techniques can be considered**
      - **See analysis of frequency selective AMC and scheduling in Classon et al., ICC'03**





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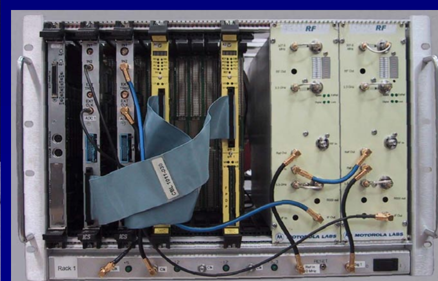
Field Experiments

Mobile Broadband Field Data Collection

Base Site Antennas

Test Truck

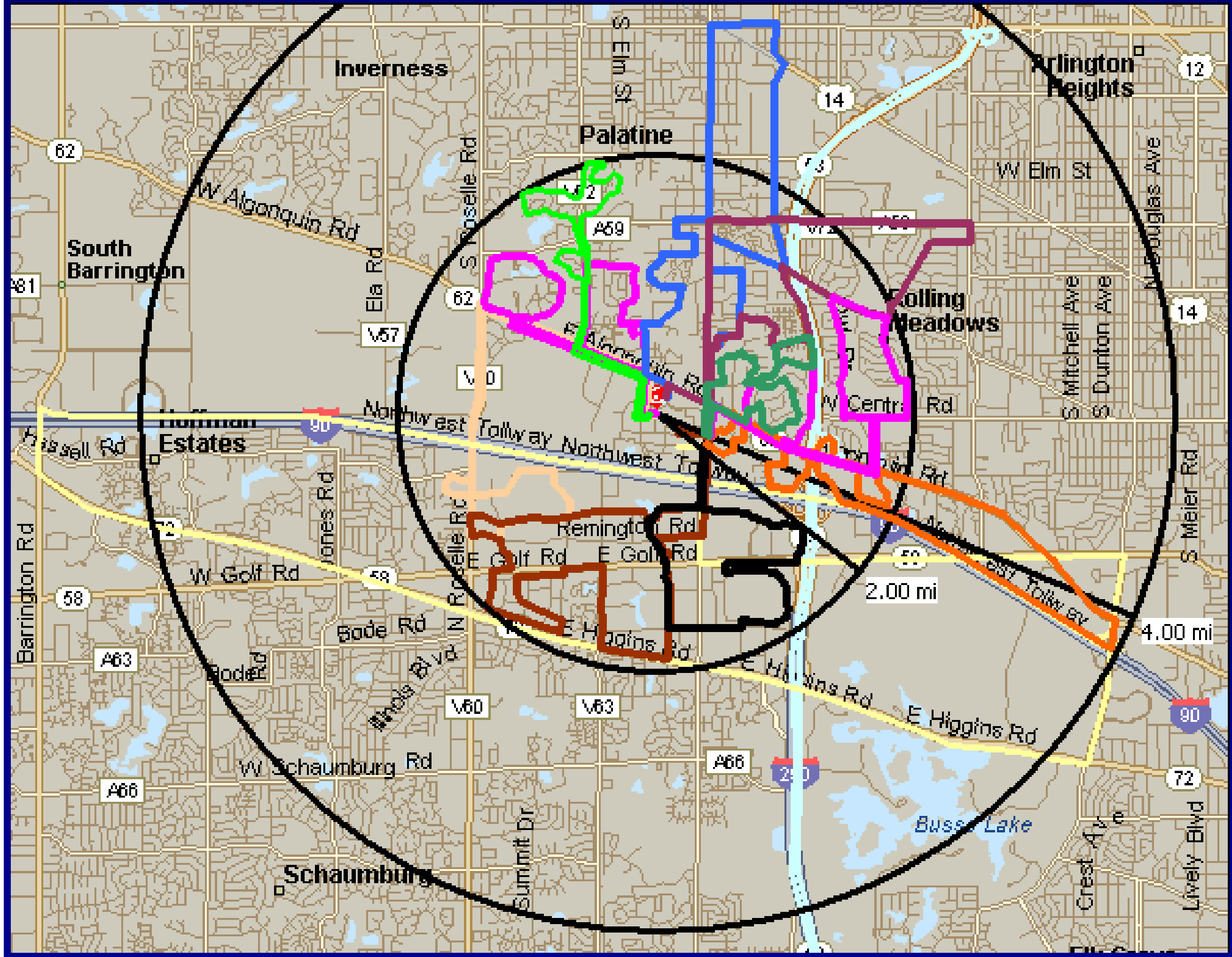
3.675 GHz carrier
20 MHz channel BW



6 sectors, 2 antennas/sector
Located on top of 6-story building

Two identical & independent Rx
5 dBi omni antennas, spaced ~9.3 λ
Synchronized to GPS and received signal
Time & Frequency domain data
720 snapshots of 9 MBytes per hour, 6.4GB/h

Field Data Collection Drive Routes

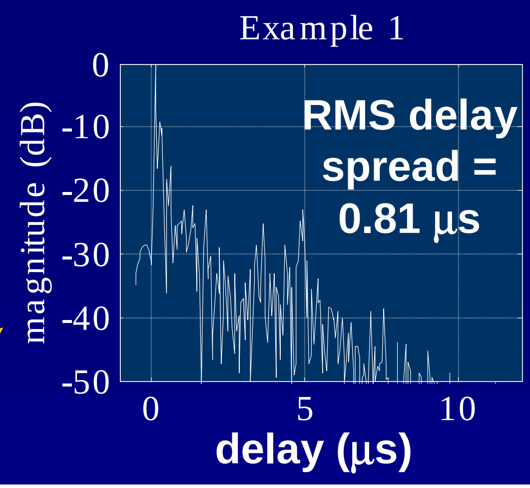


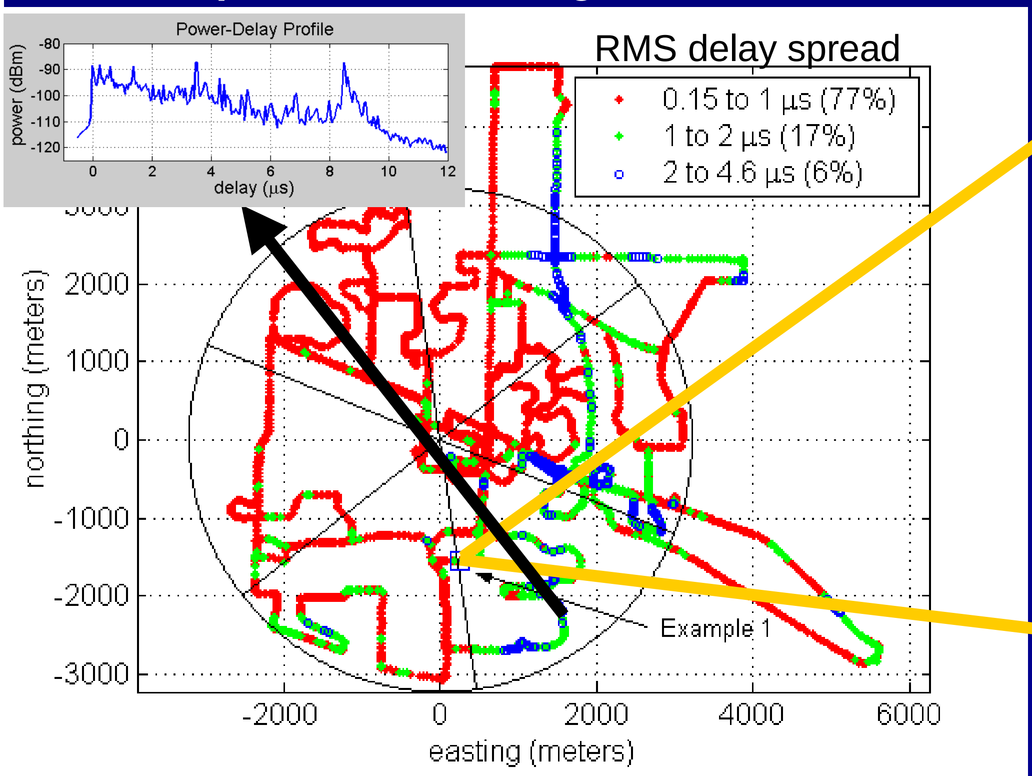
- Several different modulation formats and MCS levels are transmitted and captured
  - OFDM, SOFDM
  - CP single-carrier
  - CDMA
  - Plus various forms of Tx/Rx diversity and MIMO
- Ten drive routes
- Vehicle speed varies from 0 to 60 mph
- Most of the data captured within 2 miles from the base

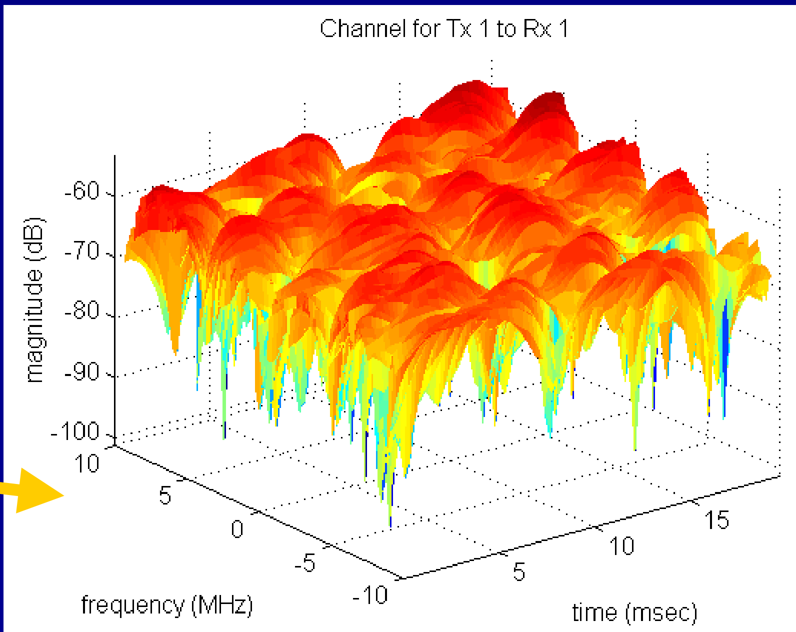
- Test area contains a mixture of single and multistory residential and commercial buildings with some undeveloped areas

Understanding the Mobile Broadband Channel

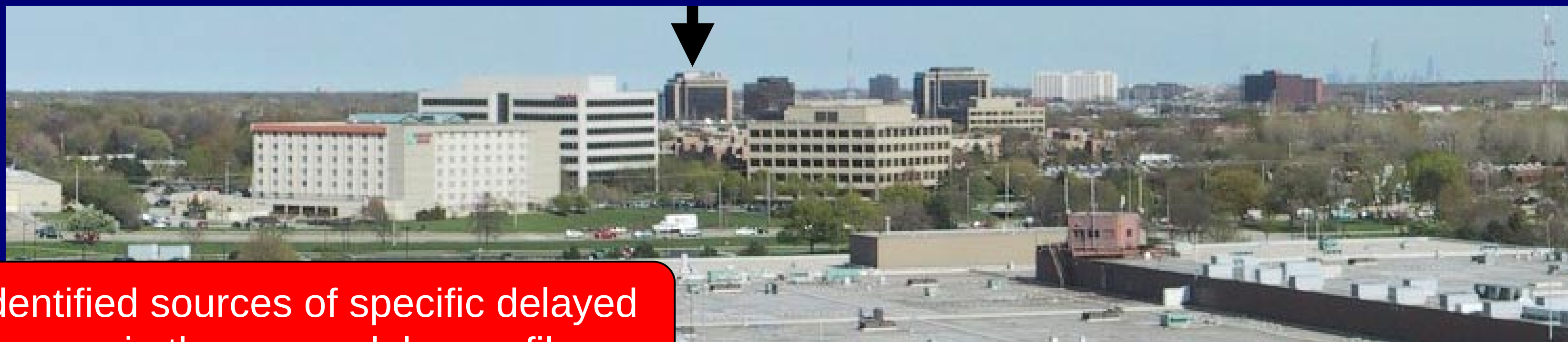
- **Variation across Time, Frequency & Space**
  - **Delay spread**
    - **Low delay spread still causes significant frequency selectivity on the broadband channel**
    - **Larger observed delay spreads occurred when a strong line-of-sight ray was absent**
  - **Path Loss**
  - **Spatial conditioning**



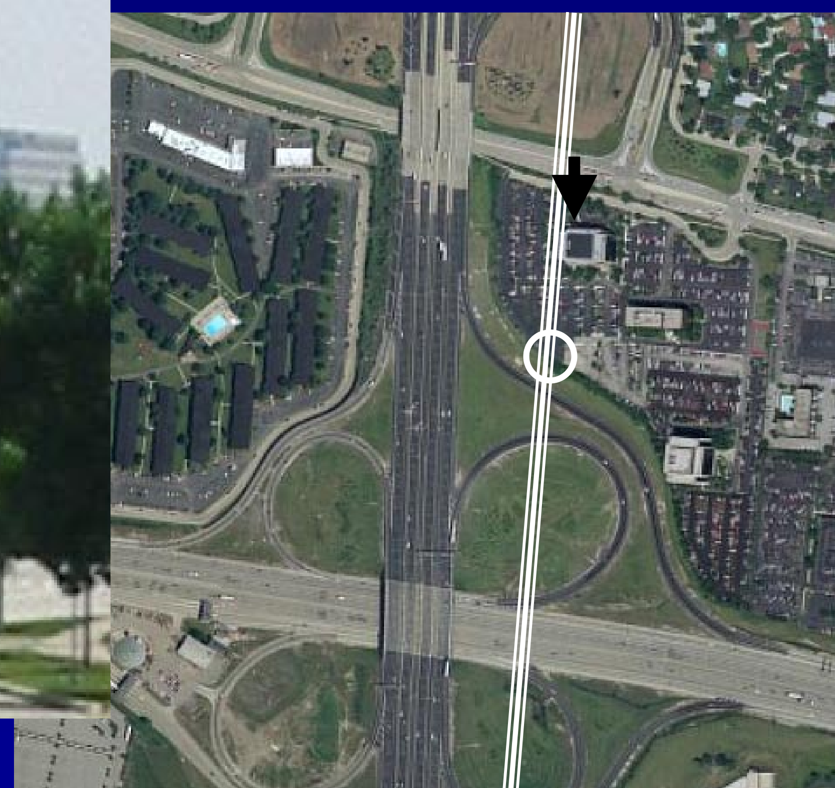




Example of Identified Scatterers

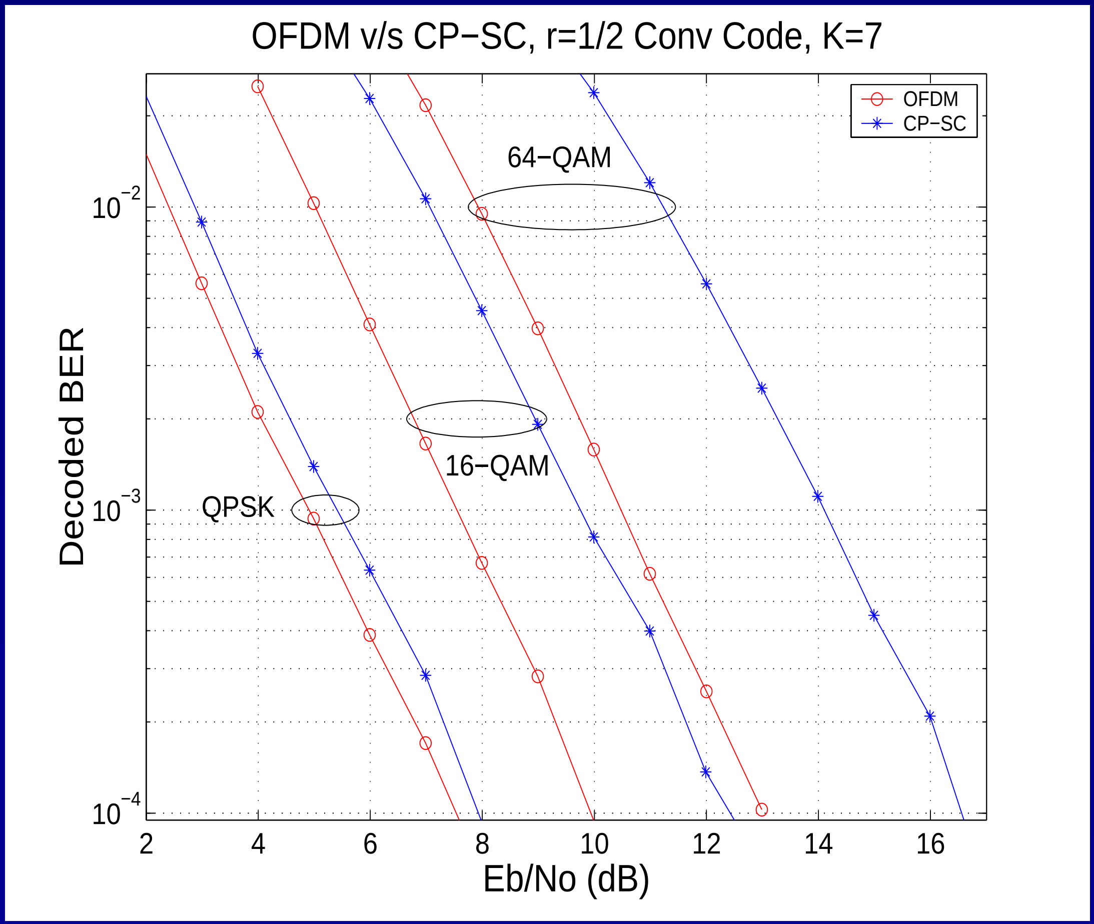


Identified sources of specific delayed rays in the power delay profile



Experimental System Modulation Study

- OFDM and CP single-carrier with MMSE equalization
  - 1 Tx and 1 Rx antenna
  - 20 MHz bandwidth, various drive routes at various speeds
  - Comparison of different constellation sizes (QPSK, 16-QAM, 64-QAM)



Decoded BER with Rate=½ convolutional coding

Red – OFDM

Blue – CP single-carrier

Trends appear consistent with earlier simulation results

Summary

- Frequency-domain-oriented approaches appear promising for future mobile broadband wireless systems
  - As the channel bandwidth increases, their benefits become more compelling
    - This presentation focused mainly on the larger bandwidths (i.e., 5 to 20 MHz)
    - Further investigation for the "narrow" channel case (1.25 MHz) would be useful