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<td>Title</td>
<td>Frequency-Domain-Oriented Approaches for MBWA: Overview and Field Experiments</td>
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<td>Re:</td>
<td>MBWA ECSG Call for Contributions</td>
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<td>Abstract</td>
<td>This presentation provides an overview of frequency-domain-oriented approaches for mobile broadband air interfaces, and presents some related results from recent field experiments.</td>
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<td>Purpose</td>
<td>For informational use only.</td>
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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 ($M \log_2 N$ 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 $1/(10F_d)$ sec
- $F_d = 200$ 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
**TX Time Format and Receiver**

- **Copy of the last** \( N_p \) **samples of the data portion**
- **Output of IFFT (OFDM)**
- **Or block of symbols (CP-single carrier)**

**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

**Cyclic Prefix**

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, ...

- **Basic Receiver Structure**
  - Remove prefix
  - N-point FFT
  - Equalization
  - N-point IFFT (for CP-single carrier)
  - To channel decoder (for OFDM)
  - To channel decoder
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

- QPSK, $r=1/2$ Turbo code, VehA

### Larger Delay Spread, Higher-order Modulation

GSM TU: 5 μs span, 1 μs RMS

- 16-QAM, $r=1/2$ Turbo code, GSMTU
Example 2: Link Simulation of Different Frequency-Domain Approaches

- Cyclic-prefix single carrier (CP-SC) and OFDM performance for $R = \frac{1}{2}$ 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 $R = 3/4$ 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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**Graphs and Figures**

- Complementary CDF of Peak-to-Average Power (dB)
- Frequency-selective AMC
Field Experiments
Mobile Broadband Field Data Collection

Base Site Antennas

3.675 GHz carrier
20 MHz channel BW

Test Truck

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

- 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
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 1

RMS delay spread = 0.81 µs

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=$\frac{1}{2}$ 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