Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** **<http://grouper.ieee.org/groups/802/20>**
Title	Impact of Mobility on Phy Modulation Layer
Date Submitted	**2003-03-06**
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Re:	MBWA ECSG Call for Contributions, IEEE 802.02-03/05
Abstract	
Purpose	802.20 presentation on Dynamic Multipath impacts for consideration in development of Evaluation criteria, channel models and basic elements of MBWA Air Interface
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Release	
Patent Policy	

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Impact of Mobility on Phy Modulation Layer

Some of the larger issues …
Lessons learned …

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Introduction

- Motivations
  - Broadband wireless mobile communications will be challenging, but then we have experience (802.xx)
  - Phy Layer System Aspects We've learned …
    - **Overhead** can be very high – assuming system capacity greater than 50% of raw physical rate is sometimes overly optimistic (Protocols and Packet error rates are the likely culprits)
    - **Multipath** can be severe, now its dynamic! -- robustness is necessary for high quality service, minimizes retransmissions
    - **Multiple access** – A major consideration to keep overall capacity high, finer access granularity is desirable – data framing must be suitably designed
    - **KISS** – balance the number of modes vs system complexity vs performance – affects everything from the issuance of a streamlined standard to system deployment/interoperability
    - Etc
- PHY Modulation Technologies we have considered
  - OFDM/OFDMA
  - Single Carrier
  - CDMA
  - Both TDD/FDD methodologies have been applied to any of the base modulation technologies above
- Tradeoffs to achieve good multipath performance in a mobile environment are focused upon in this presentation

Outline

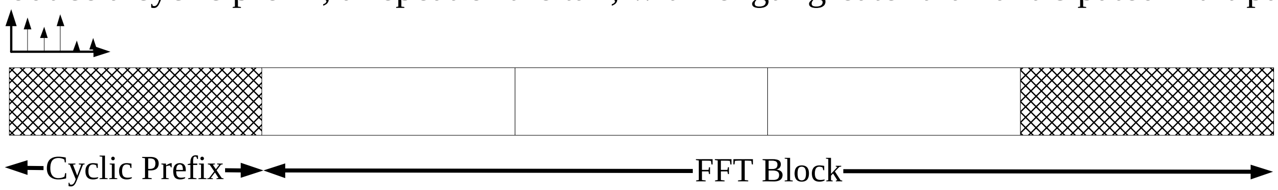
- Multipath Background
  - Channel model assumptions
  - OFDM mitigation approaches
  - Single Carrier mitigation approaches
- System implications …
  - Relative multipath performance
  - Doppler impact
  - Overhead
  - Synchronization
- Summary

Multipath Background

- Many channel modelling references on this subject
  - Two examples from 802.xx
    - Channel Models for Fixed Wireless Applications, 2001-07-05 802163c-01_29r2.pdf
    - Channel Modelling Suitable for MBWA, 2003-01-15 IEEE C802.20-03/09.pdf
  - Two examples from IEEE journals
    - Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85 GHz; IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 46, NO. 11, NOVEMBER 1998
    - An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments; IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 17, NO. 7, JULY 1999
- Conclusions from our 802.20 reference
  - K = 0 (Rayleigh fading) should be assumed for robust system design
  - Excess delay spread values vary from 0 - 20 μs
  - Doppler: hundreds of Hz, depending on mobile speed and carrier frequency
  - Diversity combining can be used to dramatically improve system coverage/reliability
- Generalities from 802.16 development
  - Several different models for varied propagation loss and multipath scenarios.
  - In particular, multipath ranging 0.4 - 20 μsec is discretely modelled by 3 taps
    - Empirical data for models may have been developed with lower ordered modulation systems in mind
  - Essentially static environment (less than few hertz)
  - K factor of zero & relative multipath tap powers up to –4db included
- Recommendation
  - System design should plan for the conclusions of the 802.20 reference
  - Plan for multipath model order ≥ 3, and plan for greater relative strengths for denser modulation alphabets

Reviewing OFDM Mitigation of Multipath

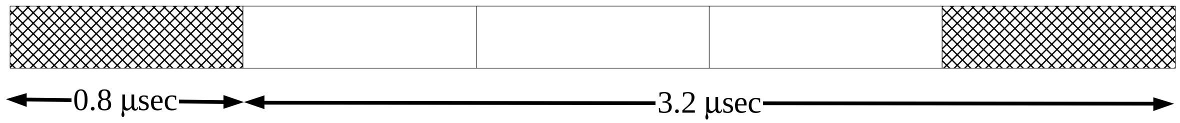
- Fundamental multipath mitigation concept
  - Introduce a cyclic prefix, a repeat of the tail, with length greater than anticipated multipath delay spreads



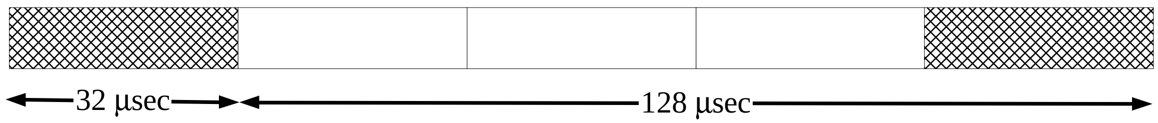
  - Thus, multipath (from prior OFDM symbols, e.g. FFT blocks) would ideally not be demodulated by FFT operation
- However the multipath is not eliminated …
  - The cyclic prefix primarily provides time orthogonalization of the FFT process (approximately if multipath exceeds the prefix)
  - Changes the nature multipath, but does not eliminate it (intra symbol delays are still present)
  - Spectral nulls, which can be significant, still remain. Simple straightforward subcarrier equalization by inversion can be implemented, but this can also introduce significant noise enhancement. Coding is employed to mitigate the latter effect.
- A dilemma exists …
  - Longer multipath can be mitigated by simple signal design (e.g. by choice of suitable cyclic prefix length) and regular performance anticipated, assuming sufficient coding or DSP cleverness to minimize the remaining intrasymbol multipath
  - However the fundamental signal design concept REQUIRES increasingly longer prefixes. Unfortunately, longer OFDM symbols result in order to maintain prefix to FFT length ratios of $\frac{1}{4}^{th}$ or less.
  - Even though good multipath performance may be retained, longer OFDM symbols result in data block transfers of longer length/latency which can impact system responsiveness.

From 802.11a to 802.16 – Too much of a good thing?

- OFDM symbol lengths
  - 802.11a: 20 Mhz system with 4 μsec symbol lengths



  - 802.16.3: 2 Mhz system with 160 μsec symbol lengths
    (see Table B.34, MMDS mode for 1.75 Mhz channel bandwidth; 802.16.3D7)



- Observations
  - "11"
    - Intended for indoor operation with peak multipath on order of 400 nsec
    - Shorter symbols accommodates indoor speeds by facilitating tracking of channel dynamics
  - "16"
    - Needed to accommodate much longer multipath possbilities, note 20 μsec is more than half the prefix length
    - The longer multipath symbols were not an issue regarding tracking, since only static channels are assumed
    - But
      - Long intrasymbol multipath still remains, resulting in numerous spectral nulls, many deep
      - Long symbols impact system attributes such as data granularity, overhead and multiple access
- The question for the MBWA system based upon an OFDM approach
  - Will our design support longer multipath?
  - Can we afford to simply increase OFDM symbol lengths as above, realizing the same penalties, and still operate in a dynamic multipath environment?

Reviewing Single Carrier Mitigation of Multipath

- Fundamental multipath mitigation concepts
  - Multipath destroys a single carrier modulation system employing pulse shaping, such as root raised cosine, resulting in non-orthogonal symbols (time orthogonality between sequential symbols at decision device is lost due to ISI)
  - Symbol by Symbol decision approaches employ equalization to regain time orthogonality
  - MLSE approaches can operate upon sequences of symbols, and may utilize channel estimation either to equalize for symbol decisions directly or indirectly via maximum likelihood sequence based decisions
- However, longer multipath scenarios demand more processing
  - Equalization becomes increasingly difficult
    - Longer training sequences, equalizers of greater length/complexity – convergence may not be easily achieved
    - Operation may be less stable – in DFE approaches, error feedback can be more pronounced
    - Equalizer noise increases
  - MLSE approaches can be more complex
    - Number of states in a trellis decoding operation grow rapidly with increasing channel memory
- A different dilemma exists …
  - Mitigation capability for increasing multipath delays does not rely on simple signal design (as with OFDM). Rather it is dependent on more sophisticated processing, typically making it increasingly harder to maintain performance as the multipath increases.
  - Thus, system performance may decrease directly by error performance

System Implications

Calculating a few parameters due to dynamic multipath

What are the larger system considerations in the migration to a dynamic multipath environment?

- Key system attributes that <u>should not</u> be adversely affected by multipath mitigation approach
  - **Overhead**
    - Minimize ratio of time used for maintaining communication links to time actually used for transmitting user data
  - **Data granularity**
    - Minimize block lengths to minimize data loss in case of error and to maximize data access
  - **Mobile environment support**
    - High velocities (250 Km/hr) – maintaining synchronization, consistent performance
    - Handoffs – minimize dropouts
    - Independence of user location -- Consistent performance irrespective of user location (LOS, NLOS, distance, etc)
    - Independence of changing location -- Reliance on prior sync knowledge, or error handling should be minimized
  - **Power amplification**
    - Maintain consistently low percentage of total power allocated to modulation maintenance for range of multipath scenarios
  - **Performance**
    - Packet Error Rates (PER) – consistent minimum for a variety to modulation/channel scenarios
- Multipath Requirements
  - Short to long delays: <1 … 20 μsec
    - not known a priori due to mobile location and velocity (250 Km/hr)
  - More sensitive multipath mitigation capability
    - To support increased modulation alphabets for larger system capacity
  - Consistent modulation capability for varied multipath within "cell"
    - Flexible data granularity, e.g. not designed for one case either average or worst
    - PER maintained for all users, independent of location/speed/multipath

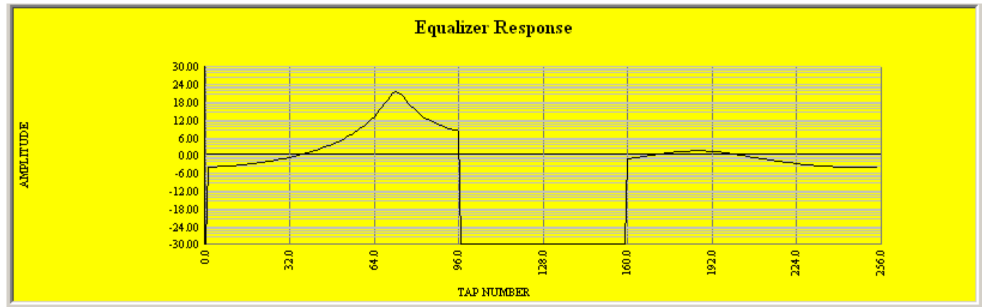
HOW DO THE FAMILIAR SOLUTIONS STACK UP?

- A few example calculations based upon solutions similar to either of 802.16.3 Fixed Broadband approaches …

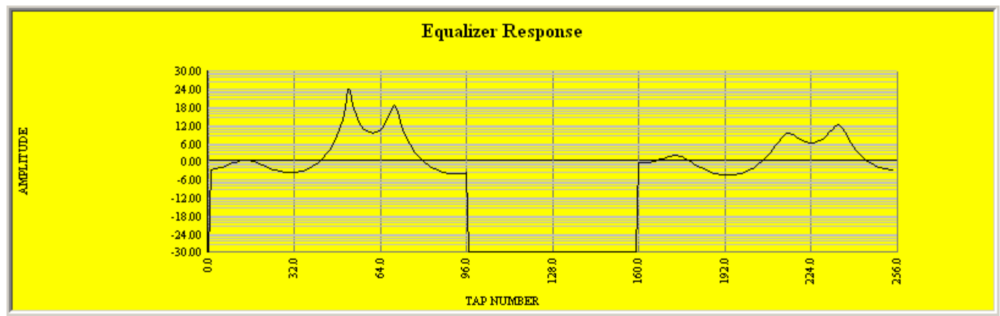
A look at the relative stress of the different SUI multipath channels on an OFDM mode with adequate protection

- OFDM system mode
  - 2 Mhz sampling, 256 point
  - 160 µsec total symbol length, 32 µsec guard

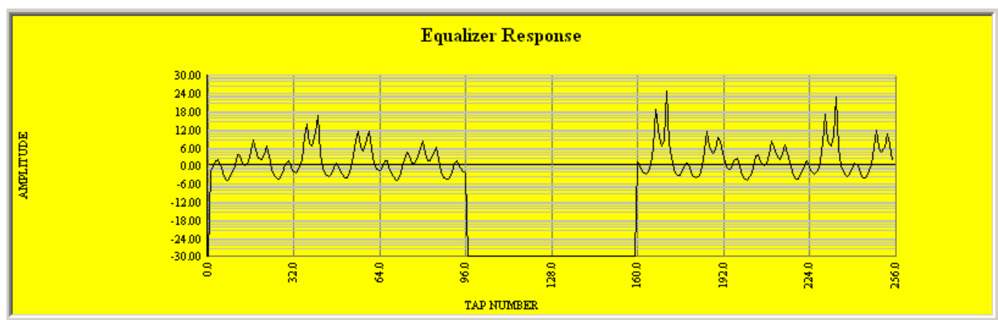
– SUI 2 multipath: A high K factor with low delay spread (0.4 and 1.1 µsec with –12 and –15 db strengths respectively for omni antenna)
  – Smooth, the instantaneous profile shown is more demanding than average



– SUI 4 multipath: A low K factor with moderate delay spread (1.5 and 4 µsec with –4 and –8 db strengths respectively for omni antenna)
  – Less smooth, probabilistically more demanding channels appear



– SUI 6 multipath: A low K factor with high delay spread (14 and 20 µsec with –10 and –14 db strengths respectively for omni antenna)
  – Now irregular, many nulls/peaks occur with significant depths; coding protection essential



Increased Doppler is likely to degrade OFDM's multipath protection and also demand a greater channel bandwidth

- Doppler computation
  - Doppler shift is equal to velocity divided by wavelength
  - Outdoor mobile @ 250 Km/hour => 810 hertz doppler shift, assuming 3.5 Ghz
- Revising an example 802.16 OFDM system for this doppler
  - Assume a 2 Mhz Fs, 256 point FFT system. It has a 160 µsec symbol duration and provides multipath delay protection of 20 µsec
    - An intercarrier spacing of 7.8 khz results – irrelevant for the static system design
    - However, it is less than 10 times the doppler of the mobile system
  - Revising the OFDM symbol parameters to track the increased doppler
    - A carrier tracking update rate of 3xOFDM symbol rate, or approximately 2 Khz, would be less than three times the computed doppler. Not recommended. $updaterate_{ofdm} := \frac{1}{3 \cdot T_s}$ $updaterate_{ofdm} = 2.08333 \times 10^3$ ***hertz***
    - Reducing to approximately 40 usec symbol length, provides about a 10x update rate for carrier sync relative to the doppler, which could be considered more appropriate

$$updaterate_{ofdm} := \frac{1}{3 \cdot \left(40 \cdot 10^{-6}\right)} \qquad updaterate_{ofdm} = 8.333 \times 10^3 \quad \textit{hertz}$$

  - **Side impact on Multipath protection is reduction by 1/4th**
    - Instead of 32 µsec, 8 µsec guard is available for multipath mitigation (for same ¼ guard/FFT length ratio)
  - **Side impact Channel Bandwidth is an increase by 4**
    - A factor of four reduction in FFT length from 128 to 32 µsec, results in a four fold increase in bandwidth from 2 to 8 Mhz.

$$N_{FFT} := 256 \qquad \frac{N_{FFT}}{128 \cdot 10^{-6}} = 2 \times 10^6 \quad ===> \quad \frac{N_{FFT}}{32 \cdot 10^{-6}} = 8 \times 10^6 \quad \textit{hertz}$$

Planning for a dynamic channel environment experiencing long multipath more frequently could adversely affect overhead

- General architectural assumptions for a “16” and “20” system
  - Uplinks/downlinks
  - TDD and/or FDD access
  - Uplink is bursty, whereas downlink is TDM framed structure, permitting regularity in design assumptions.
- OFDM
  - 802.16’s overhead is largely due to Frame sync (periodic preambles) and Guard Periods on each Symbol
  - Downlink for 256 point FFT mode 20% < overhead < 62 %
    - Maximum occurs when downlink consists of preamble, single burst PDUs of min 6 OFDM symbols and ¼ guards

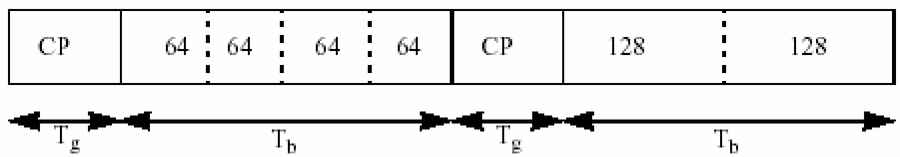


Figure 128al—DL and initial ranging preamble structure

    - Minimum occurs when guard is the only overhead counted
  - Uplink – depends on mode, requests or data transfer
    - In data mode, each uplink burst has a short preamble of length equal to one OFDM symbol, including the ¼ guard, the overhead is 120%; As the number of OFDM symbols increase, the overhead tapers down to about 21%
    - In Bandwidth requests, a long preamble (the downlink’s periodic preamble, which is 1.8 x OFDM symbol) is used with a single OFDM symbol. Thus 200% overhead results
- Single carrier
  - Phy layer overhead depends primarily on training lengths (for equalizers …) which grows for longer multipath
- For either case, longer dynamic multipath exacerbates the overhead
  - Regularity in the downlink can be used to minimize training but to a less extent in the dynamic mobile environment.
  - For the uplink, independent training may be more demanding due to user channel dynamics

Can the overhead be reduced? Yes, if less need for preambles can be devised

- Why are such long preambles embedded in the framing structures?
  - Allows channel estimation <==> equalizer training for planned for worst case channel scenarios (allows other receiver training as well)
  - Allows frame synchronization
- Necessary for frame synchronization?? … No, its overkill
  - Using typical analysis (as per Scholtz, IEEE Communications Transactions 1980)
  - Length 31 sync word, for example, provides very good sync characteristics
  - Even at high BER operating point very easy synchronization can be achieved with length 31 sync word
    - Uncoded BER of 0.05, a 2 out of 3 sync verification test has a probability of successful sync of at least 98.7%.
    - Uncoded BER of 0.01, a 2 out of 3 sync verification test has a probability of successful sync of at least 99.99%.
    - False alarm probabilities are negligible ($< 10^{-9}$)
- Thus, as expected driven by need for channel estimation
  - Easy to understand for OFDM
    - simply the preamble blocks must allow estimation of subcarrier channel equalization, and are thus on order of same size blocks
    - And a means for averaging must be applied, such as utilizing more than one
  - Single carrier
    - Determining the training word length is not as obvious, but is similar in length as the OFDM preamble lengths (not significantly shorter, nor longer)
    - In the "16" single carrier mode, training length/frequency is selectable to allow system & design freedom
  - What is not emphasized in the "16" system is the scheduling of preambles
    - Selectable insertion frequency
    - Certainly this will be an important issue for the "20" system

Summary

- Some of the key issues pertaining to dynamic multipath were presented
  - The goal was to stimulate our planning, raise questions
  - In particular, focus attention on multipath mitigation while at the same time maintaining system performance
  - Certainly others issues could have been addressed

- Recommendations
  - Invite contributions that address these system issues
    - Support for longer multipath delay spreads
    - Enhanced multipath sensitivity for larger symbol alphabets
    - Shorter Training/Initialization/preamble approaches to reduce overhead
    - …