

802.16.3 PHY Layer Initial Contribution

IEEE 802.16 Presentation Submission Template (Rev. 8)

Document Number:

802.16.3p-00/36

Date Submitted:

2000-11-7

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Venue:

IEEE 802.16 Session #10, Tampa, FL, Nov. 6-10, 2000.

Base Document:

IEEE 802.16.3c-00/36

Purpose:

Initial contribution: OFDM-based PHY proposal.

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802.16.3 PHY Layer Initial Contribution

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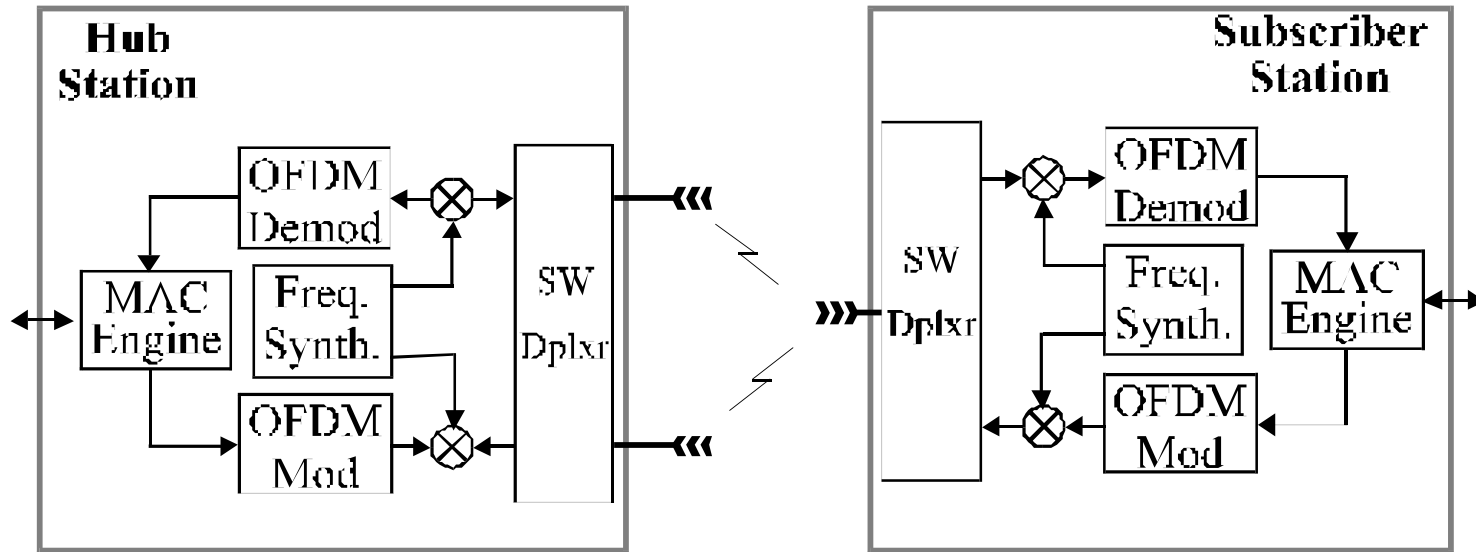
Scope

- n Identify key architectural features of proposed PHY**
 - o Detailed parameter values must await channel/traffic models**

- n Identify potential drawbacks of proposed PHY**
 - o Focus 802.16.3 attention to ensure proper consideration**

- n Identify claimed benefits of proposed PHY**
 - o Qualitative description of potential benefits**

System Overview



- n Scalable bi-directional OFDM
 - o Based on PHY layers of 802.11a and HiperLAN2
 - o MAC-agnostic, facilitating transition between available and wireless-optimal MACs
 - o **Optional** features: return link *iterative decoding*; 2-fold hub-*transmit-diversity*

- n OFDM modem is compatible with FDD, SFDD or TDD

Proposed PHY Layer

n Forward Link

- o Modulation: COFDM, based on 64FFT, with cyclic prefix, per HiperLAN2
- o FEC: K=7 terminated-state trellis code, with puncturing, per HiperLAN2
- o Scrambling + intra-frame interleaving
- o BPSK, QPSK, 16QAM and 64QAM
- o Burst: supports TDD, FDD, FDMA, TDMA
- o *Optional: 2-way transmit-diversity*

n Return Link

- o Modulation: COFDM, based on 64FFT, with cyclic prefix, per HiperLAN2
- o FEC: K=7 terminated-state trellis code, with puncturing, per HiperLAN2
- o Scrambling + intra-frame interleaving
- o BPSK, QPSK, 16QAM and 64QAM
- o Burst: supports TDD, FDD, FDMA, TDMA
- o *Optional: Iterative decoding*

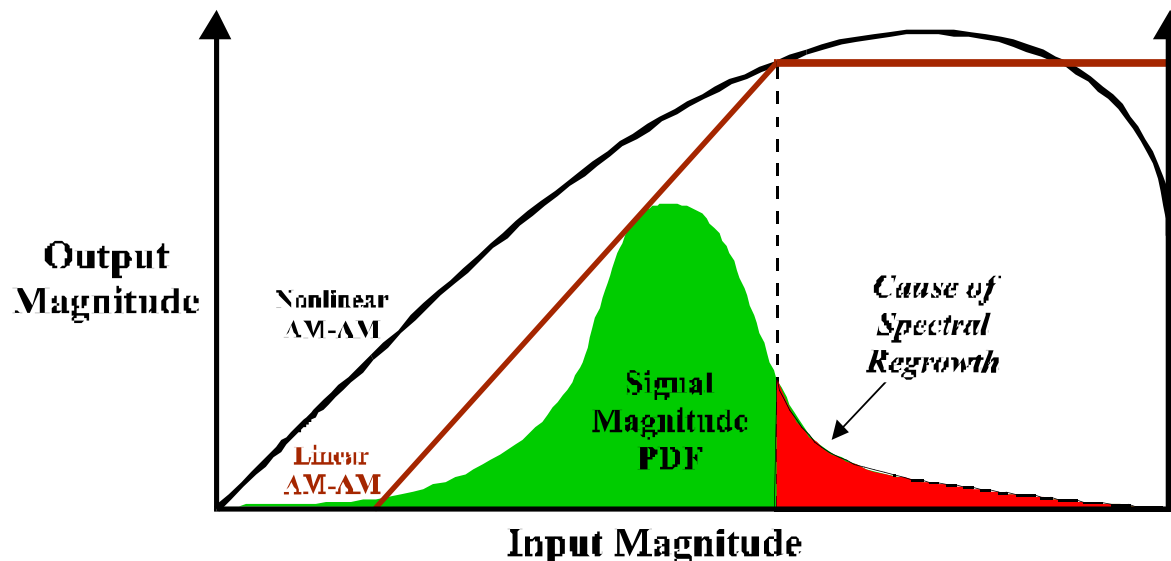
Issues: Peak-to-Average-Power (PAPR)

- n **How does OFDM PAPR compare to single-carrier PAPR?**
 - n Compare two signals, one single-carrier, the other OFDM
 - n Identical average power level (P_t)
 - n OFDM uses N sub-carriers, each of average power (P_t / N)
 - n Identical modulation order, coding, excess bandwidth (α)
 - o $r \equiv$ PAPR of single-carrier and of individual OFDM sub-carriers
 - o then , $P_{\text{peak, single-carrier}} \equiv r (P_t)$
 - o $P_{\text{peak, subcarrier}} \equiv r (P_t / N)$; $A_{\text{peak, subcarrier}} \equiv \div (r P_t / N)$
 - o and, $P_{\text{peak, OFDM}} \equiv [N \div (r P_t / N)]^2 = N (r P_t) = N P_{\text{peak, single-carrier}}$
- n **Conclusions:**
 - o $(\text{PAPR}_{\text{OFDM}} / \text{PAPR}_{\text{single-carrier}})$ varies linearly with N
 - o $(\text{PAPR}_{\text{OFDM}} / \text{PAPR}_{\text{single-carrier}})$ is independent of modulation order

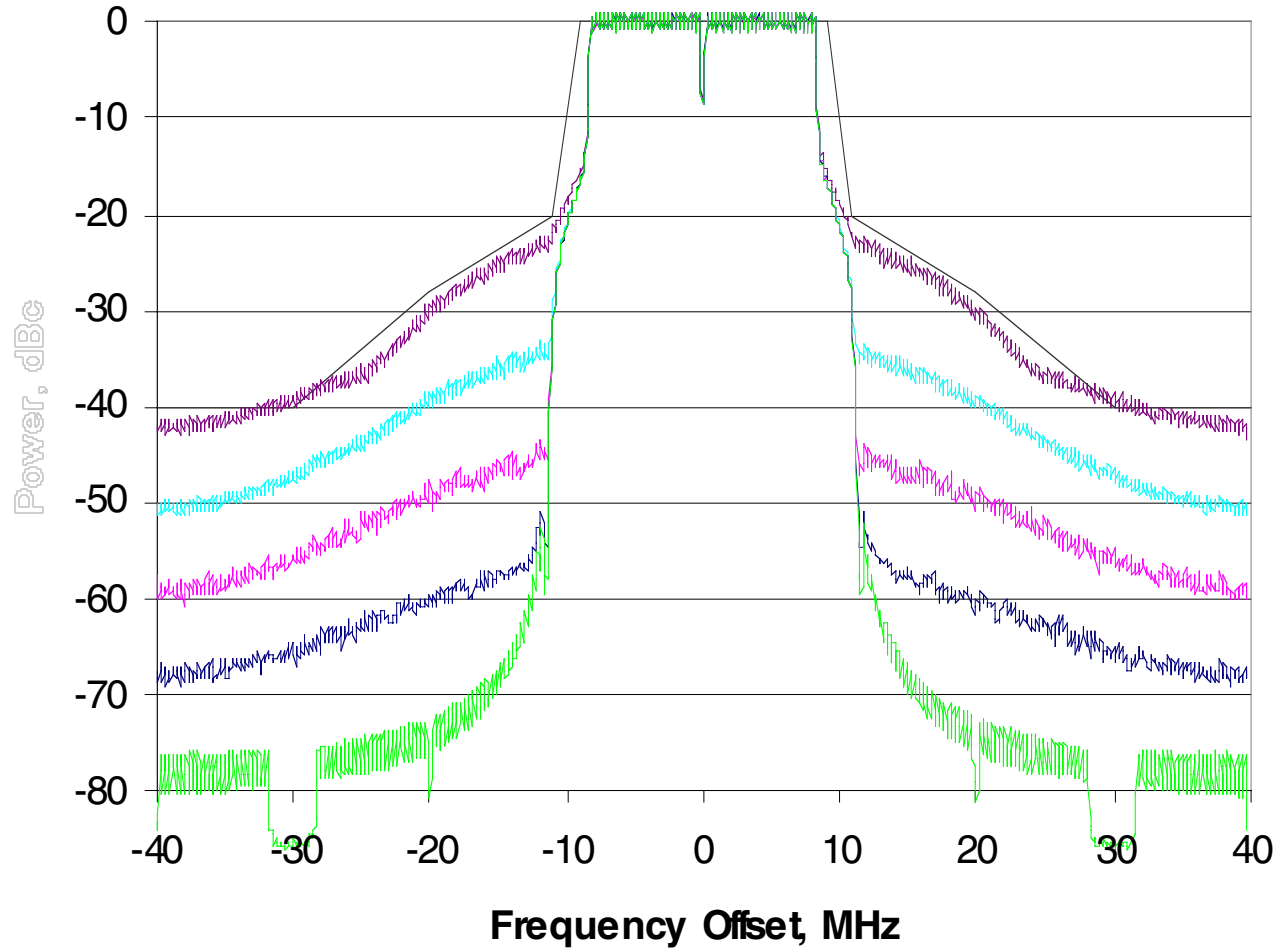
“Effective” PAPR: HPA Backoff

n ‘Peak’ vs ‘Effective Peak’ Issue

- o Actual ‘peak’ of OFDM increases linearly with # of channels
- o ‘Effective Peak’ is determined by HPA spectral regrowth
- o Modern HPAs well modeled as piecewise-linear amplifiers
 - n Digital linearization is available in modern modem ASICs
- o ‘Effective Peak’ ~ magnitude CDF value of 0.999 to 0.9999



HIPERLAN2 HPA Spectral Regrowth



Curves listed in order from top to bottom at 20 MHz:

- HIPERLAN2 Spectral Mask
- Clipping probability = 0.104530
- Clipping probability = 0.011266
- Clipping probability = 0.001141
- Clipping probability = 0.000128
- No clipping

OFDM with BPSK inner modulation.

80 MHz sample rate.

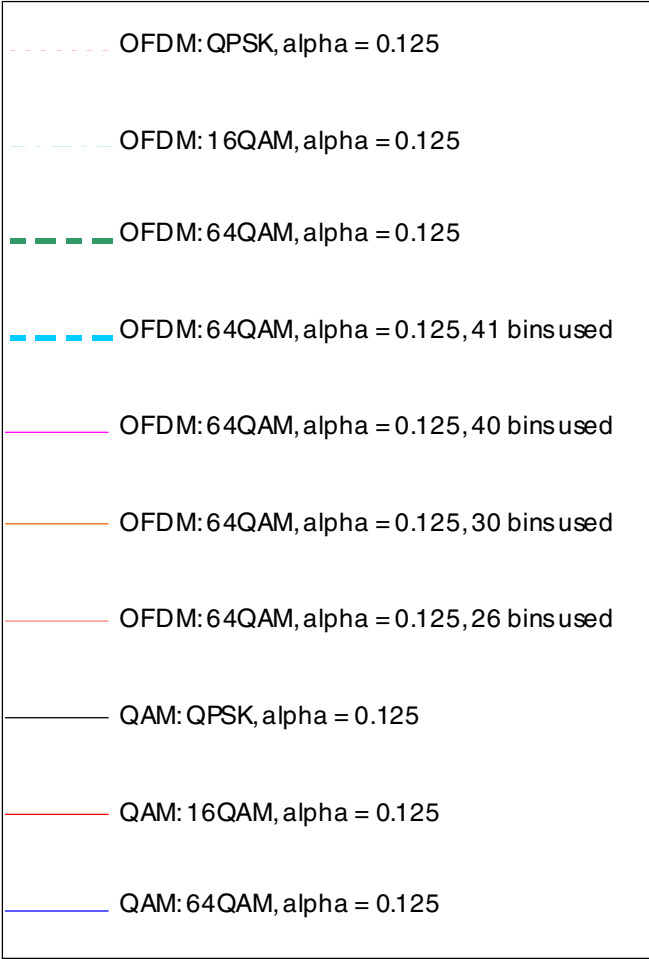
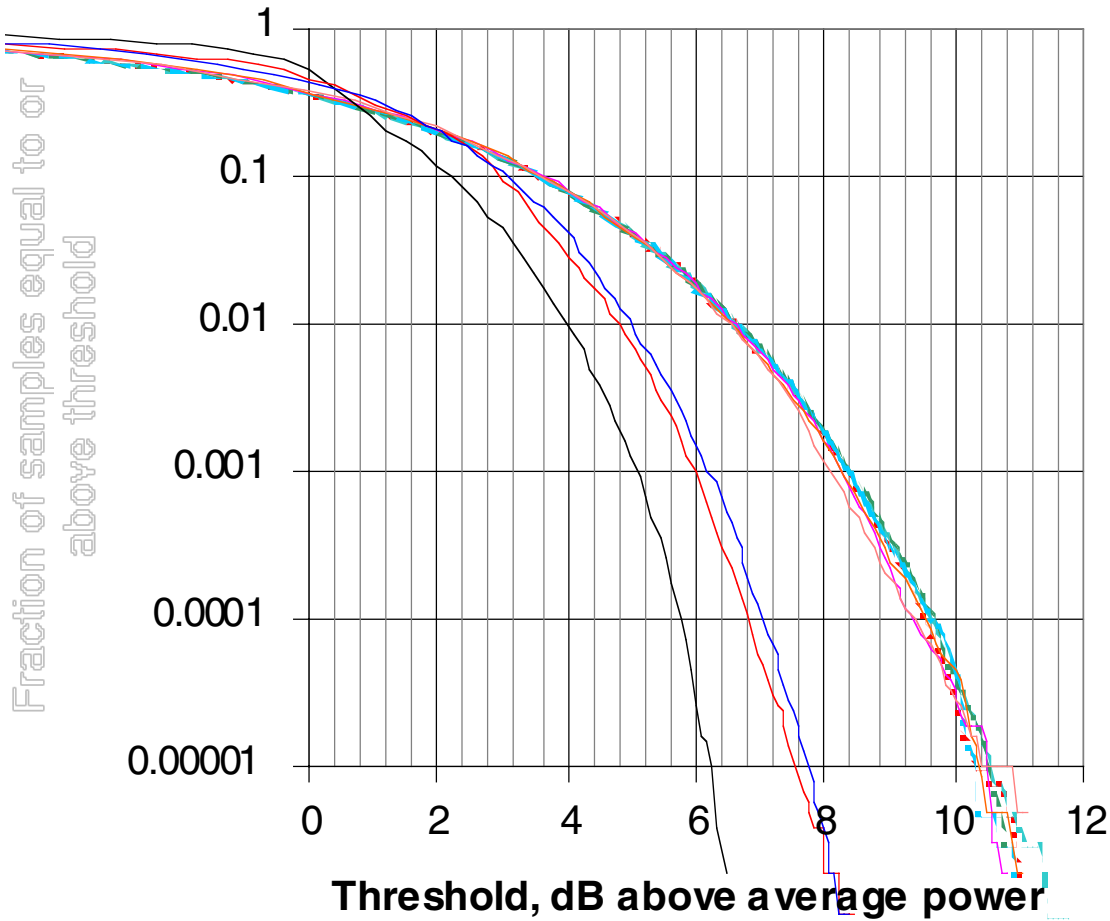
1024-point FFT with
4-term Blackman-Harris window,
156.25 kHz noise BW/bin, averaged
over 1 to 50 milliseconds.

64T long FIR output filter.

Near-infinite quantization.

PAPR Issue: OFDM “penalty” is modest

n Effective PAPR is what matters



PAPR Reduction Options

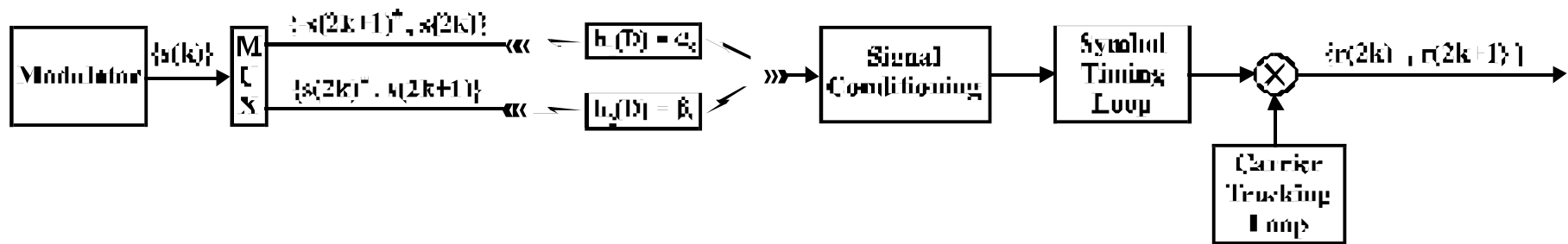
- n Numerous options mitigate HPA sensitivity to PAPR**
 - o Numerous OFDM waveform processing techniques**
 - o Advanced pre-HPA processing techniques (e.g. LINC)**

- n Assessment**
 - o PAPR issue is only a minor issue**

Hub-based 2-fold Transmit-Diversity

n Alamouti's [1] recent breakthrough

- o Full two-fold diversity achieved with negligible subscriber cost
- o T-D already embraced by 3G standards
- o Substantial link reliability gain in Rayleigh fading channels
- o T-D is a very low risk, low cost form of space-time processing



$$r(2k) = \alpha_0 s(2k) + \beta_0 s(2k+1) + n(2k)$$

$$r^*(2k+1) = -\alpha_0^* s(2k+1) + \beta_0^* s(2k) + n^*(2k+1)$$

$$R(2k) = H_A(D) S(2k) + N(2k)$$

$$H_A \cdots \begin{bmatrix} \alpha_0 & \beta_0 \\ \beta_0^* & -\alpha_0^* \end{bmatrix}$$

$$R(2k) \cdots [r(2k), r^*(2k+1)]^T$$

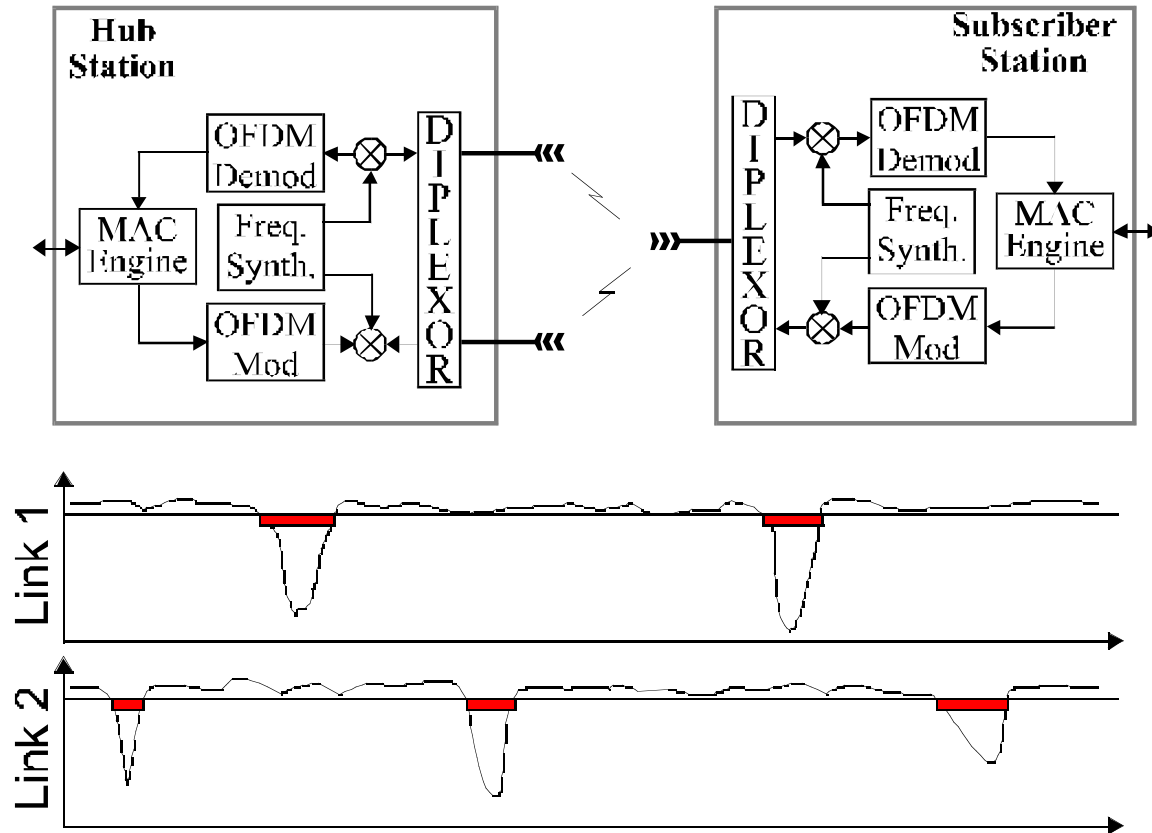
$$S(2k) \cdots [s(2k), s(2k+1)]^T$$

$$N(2k) \cdots [n(2k), n^*(2k+1)]^T$$

$$S(2k) = H_A^{-1}(D) R(2k) + H_A^{-1}(D) N(2k)$$

¹ S. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," IEEE J. Select. Areas Commun., vol. 16, pp. 1451-1458, October 1998.

Transmit-Diversity



- n **Transmit-diversity enhances link reliability**
 - o Two antennas at hub; single antenna at subscriber
 - o Bi-directional 2-fold diversity

Transmit-Diversity & Standards

- n Transmit-diversity: (Already adopted by all 3G open standards)
 - o WCDMA 3GPP FDD mode
 - o WCDMA 3GPP TDD mode
 - o CDMA2000
 - o EDGE
 - o Receiver processing for T-D is mandatory for all 3G mobiles.

Key Issues/Concerns

n Forward Error Correction

- o How much FEC vs ARQ?
- o Which FEC technique: RS, trellis or iterative decoding (ID)?
- o Cost might dictate different FEC for forward/return links.

n OFDM must be tailored to our specific channel model

- o Number of sub-channels
- o Guard Interval
- o Symbol Rate
- o FEC
- o Diversity
- o Compatibility with future MIMO extensions

n What specific problem are we solving?

- o What is the CDF of K-factors? What is the CDF of delay spread?

Summary: Proposed PHY Benefits

- n OFDM is highly robust**
 - o to channel distortion and in-band interference
 - o to partial-band co-channel interference

- n Based on existing standards → Rapid time-to-market**

- n Powerful and flexible FEC**
 - o Soft-decisions plus Euclidean metric; no IPR cost
 - o Iterative decoding on return link might enhance capacity

- n Transmit-diversity offers high bang-for-buck**
 - o Full 2-fold diversity with 1 subscriber antenna and 2 hub antennas
 - o Reliable links, even over severe Rayleigh fading channels
 - o “Low hanging fruit” of MIMO technology; not beamforming

- n Proposed PHY is responsive to the 802.16.3 FRD**
 - o Satisfies our stated evaluation criteria