802.16.3 PHY Layer Initial Contribution

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Purpose:

Initial contribution: OFDM-based PHY proposal.

802.16.3 PHY Layer Initial Contribution

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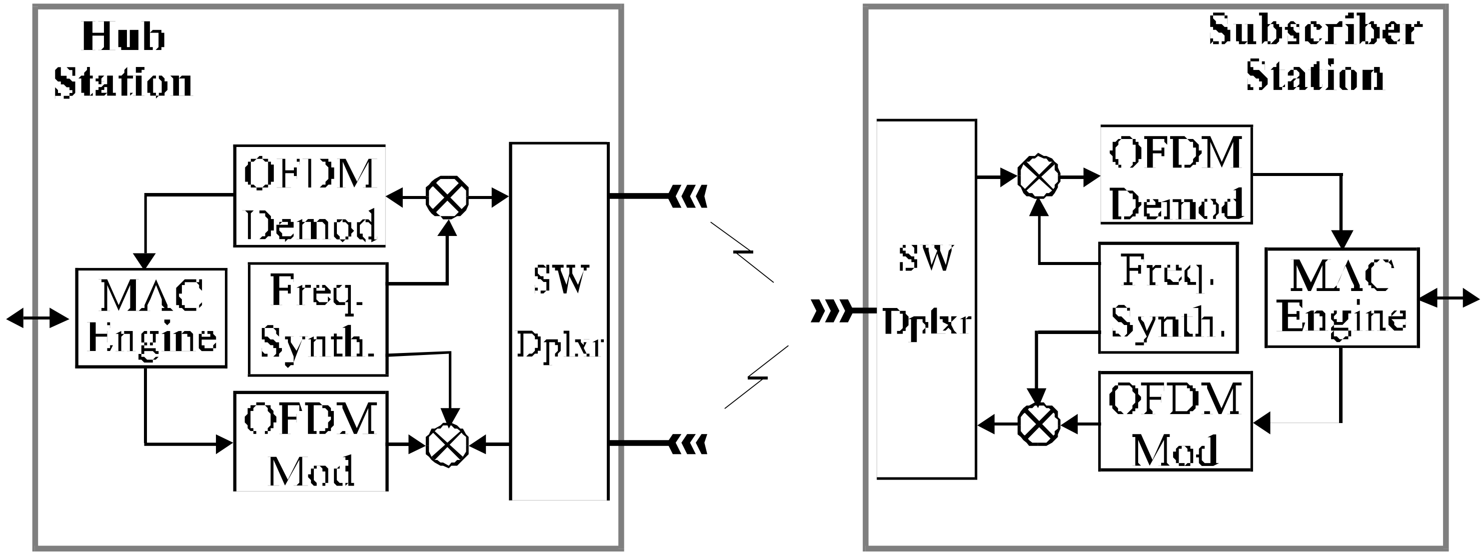
Scope

- Identify key architectural features of proposed PHY
  - Detailed parameter values must await channel/traffic models
- Identify potential drawbacks of proposed PHY
  - Focus 802.16.3 attention to ensure proper consideration
- Identify claimed benefits of proposed PHY
  - Qualitative description of potential benefits

System Overview



- Scalable bi-directional OFDM
  - Based on PHY layers of 802.11a and HiperLAN2
  - MAC-agnostic, facilitating transition between available and wireless-optimal MACs
  - ***Optional*** features: return link ***iterative decoding***; 2-fold hub-***transmit-diversity***
- OFDM modem is compatible with FDD, SFDD or TDD

Proposed PHY Layer

Forward Link

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

Return Link

- Modulation: COFDM, based on 64FFT, with cyclic prefix, per HiperLAN2
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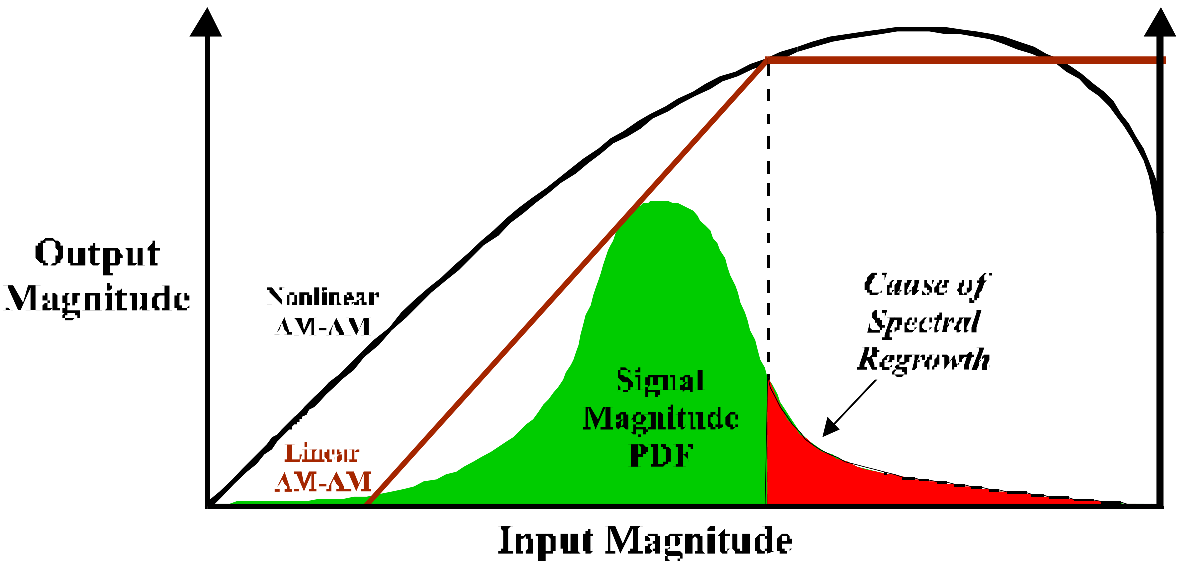
Issues: Peak-to-Average-Power (PAPR)

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

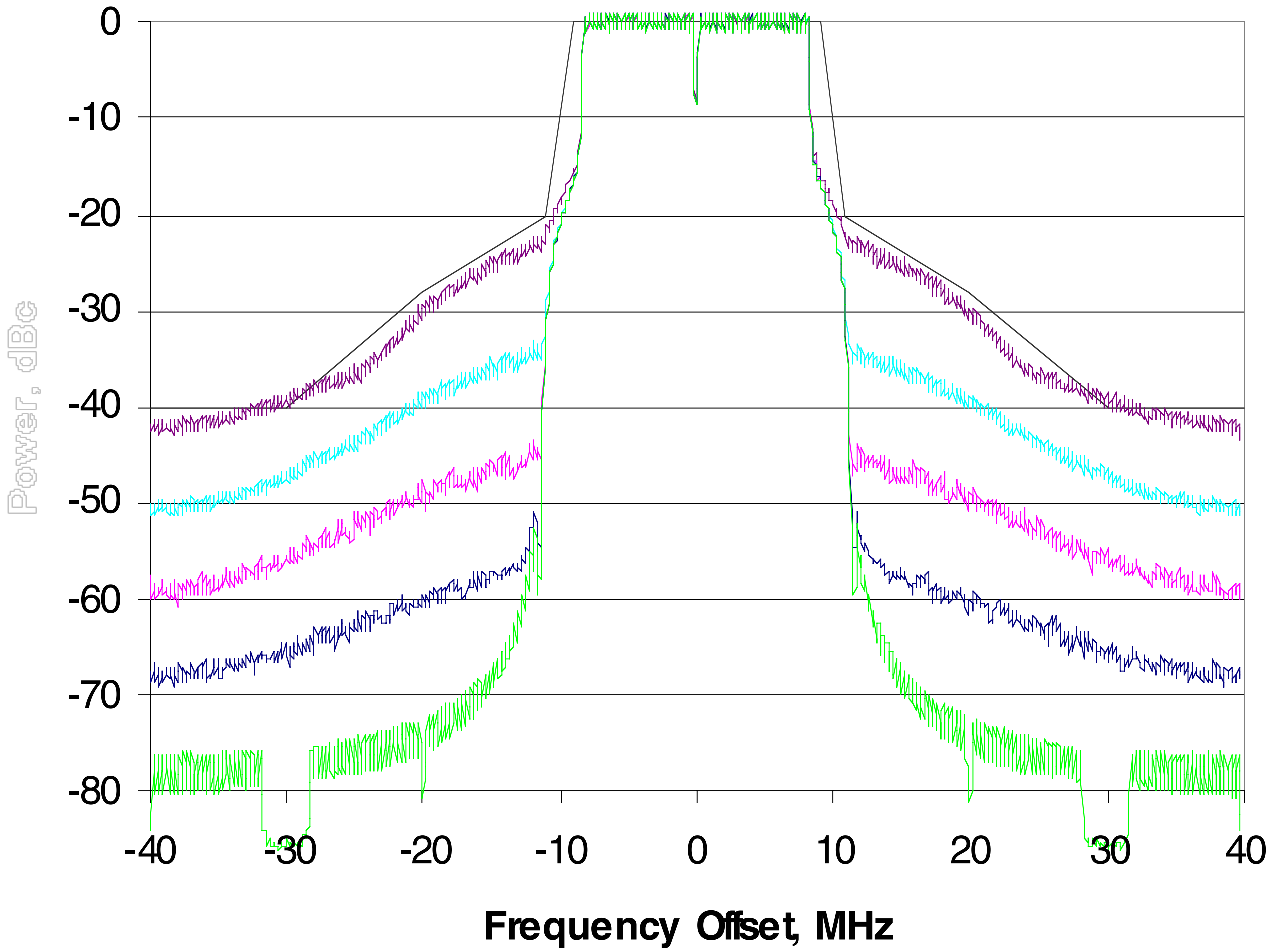
- **Conclusions:**
  - ($PAPR_{OFDM}$ / $PAPR_{single\text{-}carrier}$) varies linearly with N
  - ($PAPR_{OFDM}$ / $PAPR_{single\text{-}carrier}$) is independent of modulation order

"Effective" PAPR: HPA Backoff

- **'Peak' vs 'Effective Peak' Issue**
  - Actual 'peak' of OFDM increases linearly with # of channels
  - 'Effective Peak' is determined by HPA spectral regrowth
  - Modern HPAs well modeled as piecewise-linear amplifiers
    - Digital linearization is available in modern modem ASICs
  - '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:

- HIPERLAN/2 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.

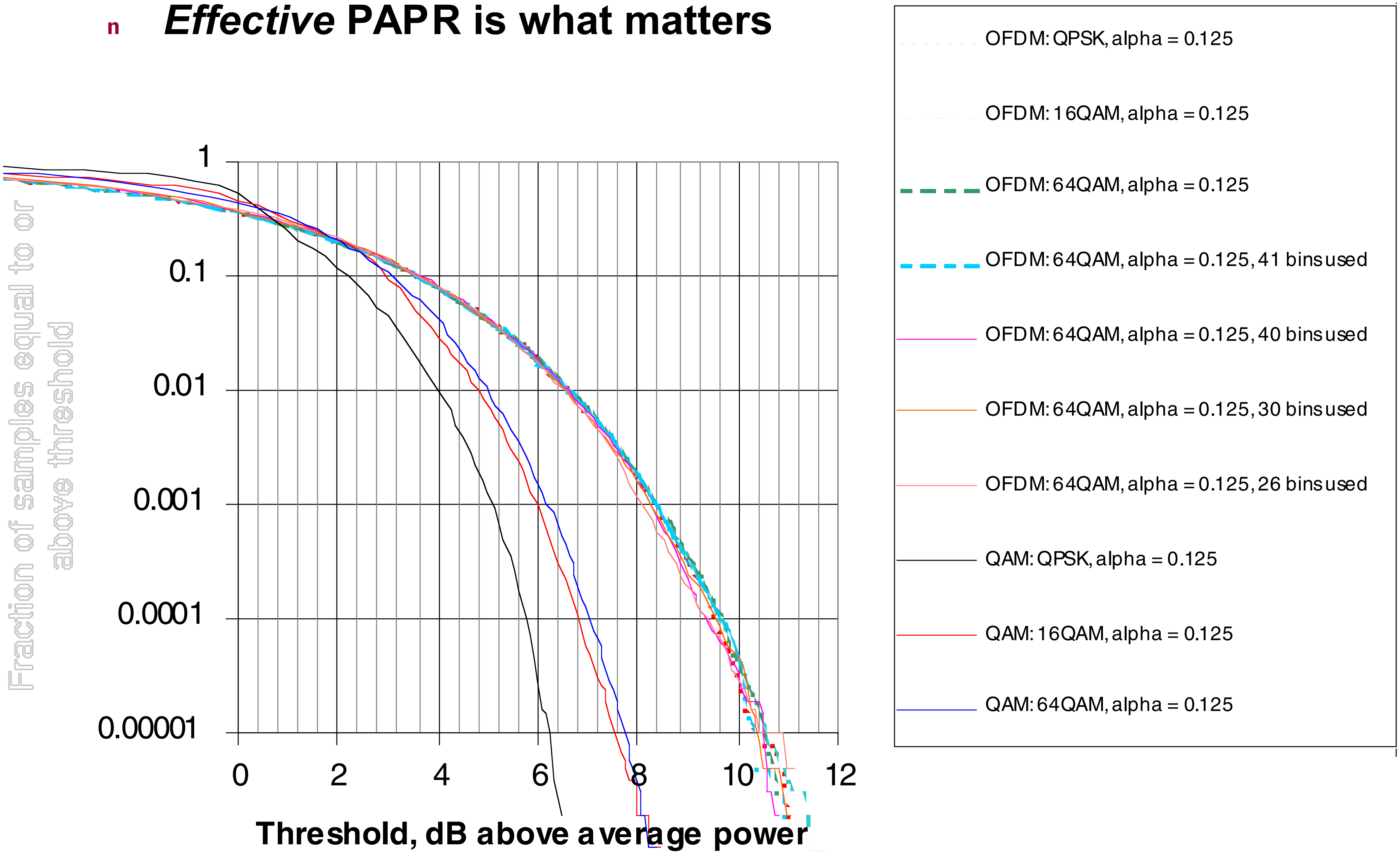
80 MHz sample rate.

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

- *Effective* PAPR is what matters

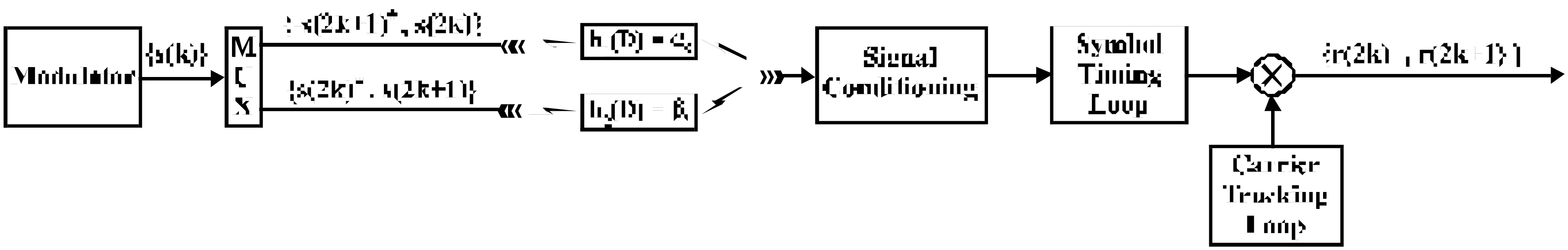


PAPR Reduction Options

- **Numerous options mitigate HPA sensitivity to PAPR**
  - Numerous OFDM waveform processing techniques
  - Advanced pre-HPA processing techniques (e.g. LINC)
- **Assessment**
  - PAPR issue is only a minor issue

Hub-based 2-fold Transmit-Diversity

- **Alamouti's** [1] **recent breakthrough**
  - Full two-fold diversity achieved with negligible subscriber cost
  - T-D already embraced by 3G standards
  - Substantial link reliability gain in Rayleigh fading channels
  - T-D is a very low risk, low cost form of space-time processing



$$r(2k) = \alpha_0\, s(2k) + \beta_0\, s(2k+1) + n(2k)$$
$$r^*(2k+1) = -\alpha^*_0\, s(2k+1) + \beta^*_0\, s(2k) + n^*(2k+1)$$

$$\mathbf{R}(2k) \triangleq [r(2k), r^*(2k+1)]^T$$

$$\mathbf{S}(2k) \triangleq [s(2k), s(2k+1)]^T$$

$$\mathbf{N}(2k) \triangleq [n(2k), n^*(2k+1)]^T$$

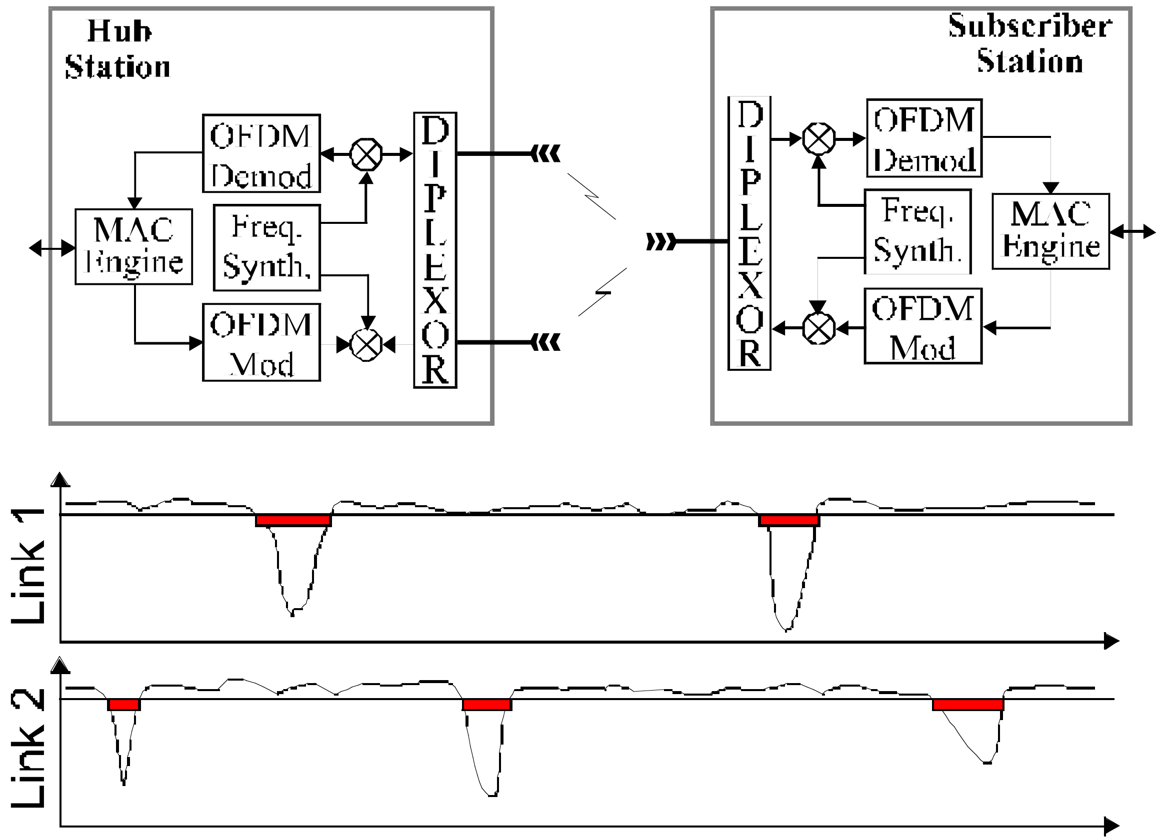
$$\mathbf{R(2k)} = H_A\mathbf{(D)}\ \mathbf{S(2k)} + \mathbf{N(2k)}$$

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

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

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

Transmit-Diversity



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

Transmit-Diversity & Standards

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

Key Issues/Concerns

- **Forward Error Correction**
  - How much FEC vs ARQ?
  - Which FEC technique: RS, trellis or iterative decoding (ID)?
  - Cost might dictate different FEC for forward/return links.
- **OFDM must be tailored to our specific channel model**
  - Number of sub-channels
  - Guard Interval
  - Symbol Rate
  - FEC
  - Diversity
  - Compatibility with future MIMO extensions
- **What specific problem are we solving?**
  - What is the CDF of K-factors? What is the CDF of delay spread?

Summary: Proposed PHY Benefits

- **OFDM is highly robust**
  - to channel distortion and in-band interference
  - to partial-band co-channel interference
- **Based on existing standards → Rapid time-to-market**
- **Powerful and flexible FEC**
  - Soft-decisions plus Euclidean metric; no IPR cost
  - Iterative decoding on return link might enhance capacity
- **Transmit-diversity offers high bang-for-buck**
  - Full 2-fold diversity with 1 subscriber antenna and 2 hub antennas
  - Reliable links, even over severe Rayleigh fading channels
  - “Low hanging fruit” of MIMO technology; not beamforming
- **Proposed PHY is responsive to the 802.16.3 FRD**
  - Satisfies our stated evaluation criteria