IEEE 802.16.3 PHY Layer Proposal

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Ron McCallister / John Liebetreu	Voice:	480-607-4831
Intersil Corporation	Fax:	480-607-4881
8515 East Anderson Drive	E-mail:	rmccalli@intersil.com
Scottsdale, AZ 85255		

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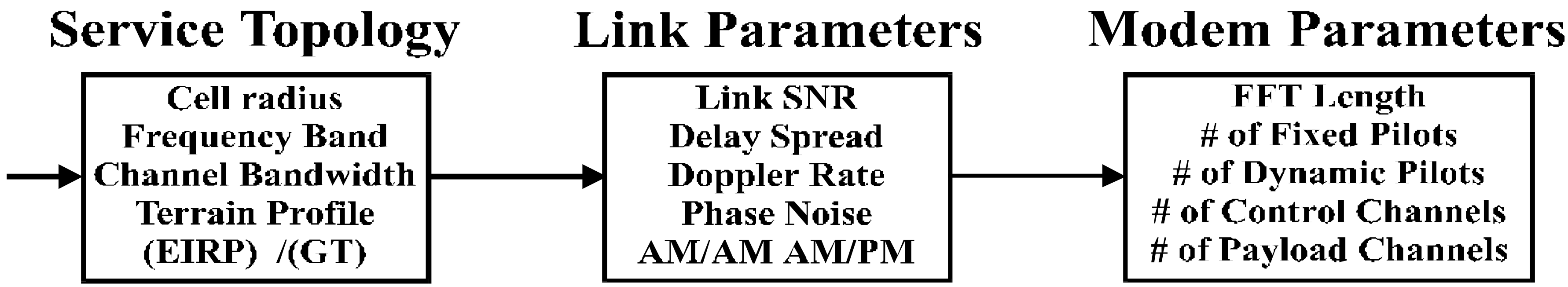
Purpose:

This proposal is submitted for consideration by Task Group 3 of the IEEE 802.16 Working Group on Broadband Wireless Access, as the 2-11 GHz Licensed Band PHY solution.

Key 802.16.3 PHY Challenges

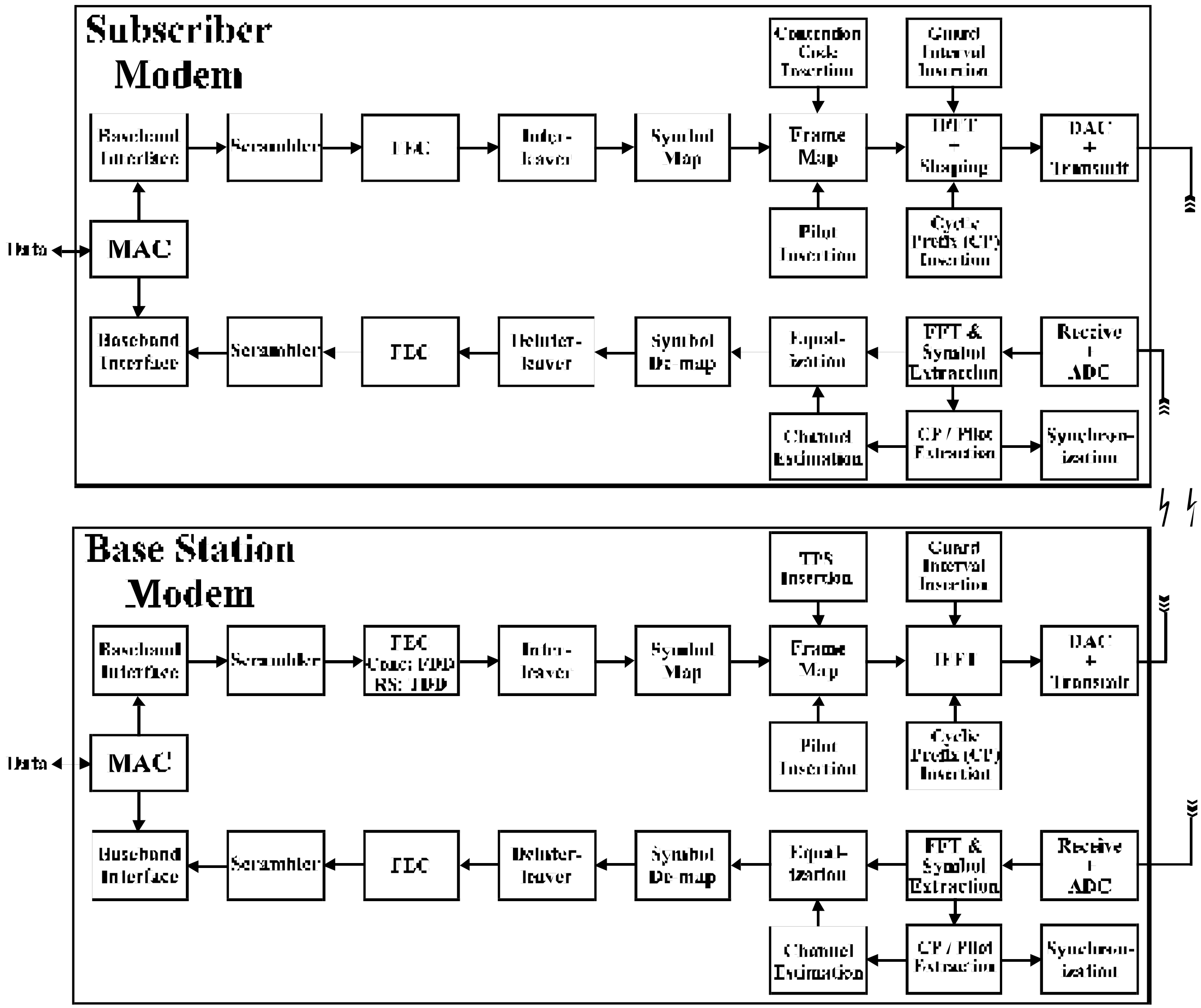
- **802.16.3 *link characteristics vary widely***
  - Propagation range and signal attenuation
  - Propagation channel distortion and dynamics
    - Delay spread (channel variation over frequency)
    - Doppler frequency (channel variation over time)
- **Our customers are *extremely capacity-sensitive***
  - Service-provider business is driven by return-on-investment
    - ROI is directly tied to capacity, to PHY bandwidth-efficiency
  - PHY must be flexible enough to evolve with MAC
  - PHY must ensure interoperability, yet reward innovation
- **Our PHY implementation must remain *simple***
  - Minimize cost, particularly of the subscriber equipment
  - Minimize deployment risk; ***this is not an R&D project***
- **Our PHY serves a *very large marketplace***
  - Chipmakers support a ***simple*** standards-compliant PHY solution

How do PHY challenges drive OFDM?



- **Service topologies drive link parameters**
  - Every unique BWA application exhibits unique characteristics
  - Link topology variation implies variation in optimal link parameters
    - ***'Optimal' = 'maximizes link capacity'***
- **Link parameters drive optimal PHY parameters**
  - Specific link design parameters will maximize link capacity
    - How many FFT channels should be used?
    - How many redundant control channels maximize capacity?
    - How many pilot signals (fixed/dynamic) maximize capacity?
      - How often must dynamic pilot signals be re-transmitted?
    - How many FFT channels are available for payload (data)?
    - What modulation/coding combination maximizes capacity?

Generic OFDM PHY System Architecture



What does this PHY contribution offer?

- **We are not proposing a PHY system**
- **We are proposing three potential OFDM PHY features**
  - A simple and flexible means of optimizing OFDM capacity
  - An adaptive modulation/coding concept retaining concatenation
  - A simple and flexible means of achieving 2-way 2-fold diversity
- **OFDM capacity optimization is easy to achieve**
  - A simple, flexible means of maximizing OFDM link payload
  - A simple, flexible means of merging AMC with concatenated FEC
- **Rayleigh fading demands spatial diversity**
  - 30 dB flat fade will occur 0.1% of the time over Rayleigh channel
    - Achieving target 99.9% link availability will require diversity
  - Alamouti's transmit-diversity . . .
    - . . . is extremely simple to implement; single CPE antenna
    - . . . yields nearly all required link improvement
- **We will design a forward link to illustrate our points**

OFDM Design Methodology: Forward Link

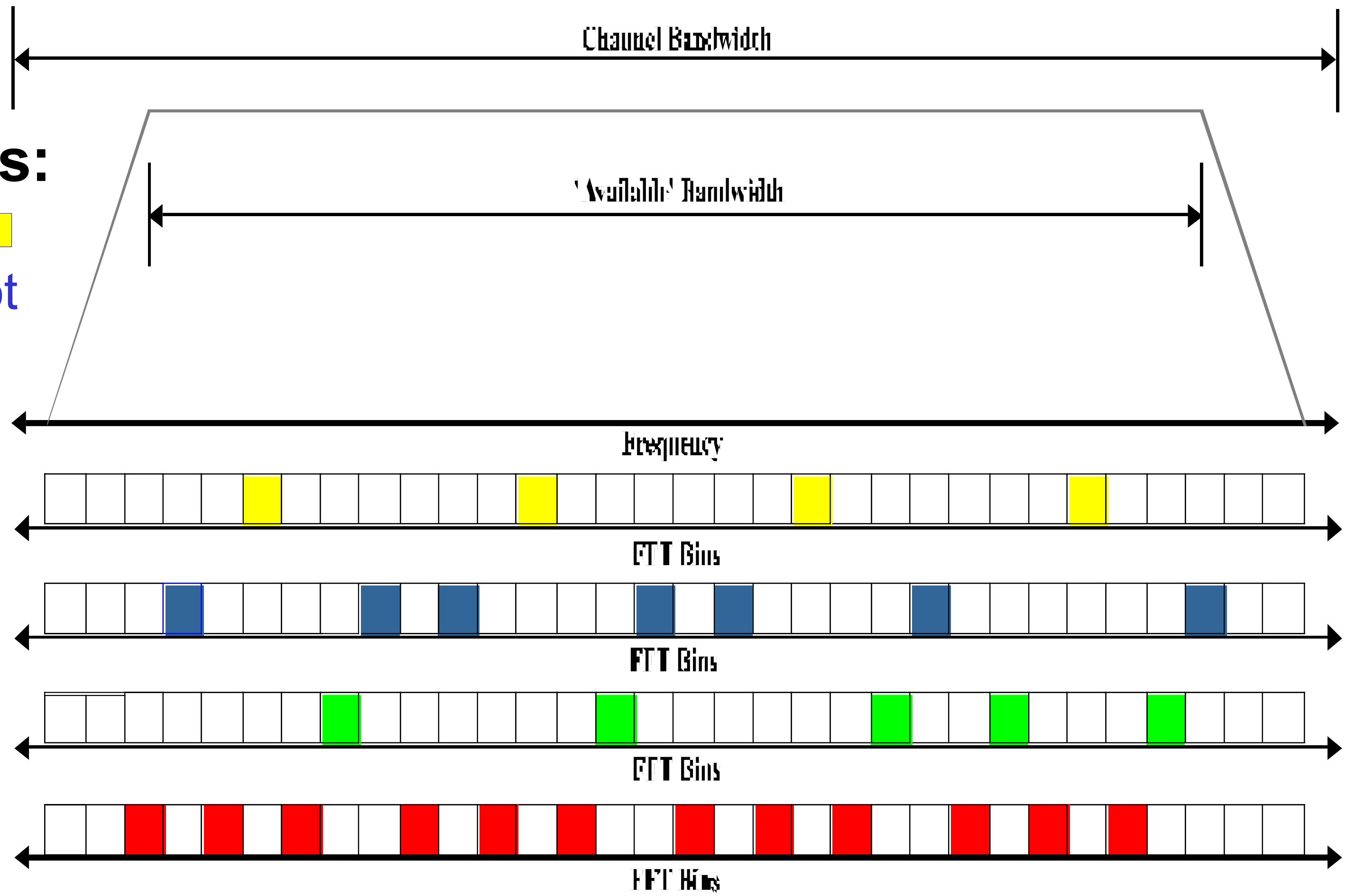
- **A subscriber needing BWA service must:**
  - Tune to the forward link band
  - Synchronize to the base station transmission frequency
  - Synchronize to the base station clock (PRS epoch)
  - Estimate the channel characteristics (mag/phase vs frequency)
  - Equalize the forward link signal and extract required control data
  - [Request needed service via return link]
  - Extract subscriber data as it appears embedded in forward link
- **The forward link conveys several key signal types:**
  - Frequency guard signals: which support spectral mask compliance
  - Fixed pilot signals: which facilitate frequency and timing sync
  - Dynamic pilot signals: which support accurate channel estimation
  - Control signals: which define new forward link configurations
  - Payload signals: which convey forward link (user) information
- **Our primary goal: *maximize achievable capacity***
  - **Maximize # *of payload channels*** and ***each channel's capacity***

Forward link design paradigm

- **Specify FFT length (NFFT) and channel bandwidth**
  - Filter shape, spectral masks $\Rightarrow$ # of freq. guard channels (NFG)
- **Specify frequency-selective fade characteristics**
  - Delay spread $\Rightarrow$ required pilot spacing (# of total pilot channels)
  - Initial synchronization time spec $\Rightarrow$ # of fixed pilot channels (NFP)
- **Specify the time-variability of the channel**
  - Doppler frequency $\Rightarrow$ re-visit rate (# of dynamic pilot channels, NDP)
- **Specify the required degree of control redundancy**
  - Impact of single CPE loss on network $\Rightarrow$ # of control channels (NC)
- **Assign every remaining channel to convey information**
  - NFFT – NFG – NFP – NDP – NC $\Rightarrow$ # of payload channels (NP)
- **Assign payload channels mod/coding based on SNR**
  - Margin vs link efficiency $\Rightarrow$ Modulation/coding selection (2 pipes)
- **Specify required re-format speed (defines frame length)**
  - Integer # of MPEG (RS) blocks per frame length $\Rightarrow$ zero-fill impact

FFT / Signal Assignments vs. Channel BW

- **5 signal types:**
  - Fixed Pilot
  - Dynamic Pilot
  - Control
  - Payload
  - Guard

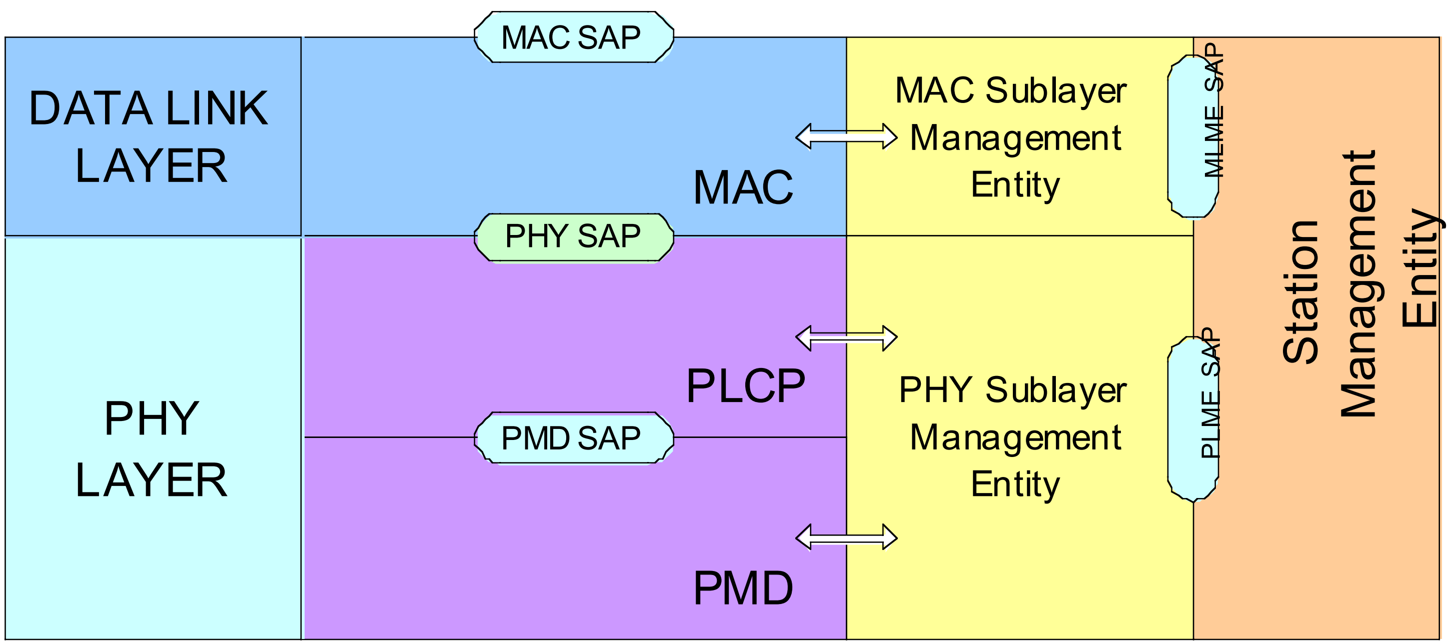


Where do they go, and who assigns them?

- **Ensure adequate fixed pilots for rapid synchronization**
  - *Spread FPs quasi-uniformly across band, and leave them in place*
- **Ensure adequate dynamic pilots for channel estimation**
  - *Spread DPs quasi-uniformly across band to enhance estimation*
  - *Ensure sufficient DPs for estimation within channel coherence time*
  - *Provide adequate averaging of DPs to assure reliable estimates*
  - *Minimize wasted channels, subject to above constraints*
- **Immunize control to frequency-selective fading**
  - *Spread redundant control signals quasi-uniformly across band*
  - *Randomize control signal locations on each OFDM symbol*
- **Immunize payload/control to frequency-selective fading**
  - *Spread payload signals quasi-uniformly across band*
  - *Randomize payload signal locations on each OFDM symbol*
- ***This sounds too difficult!***

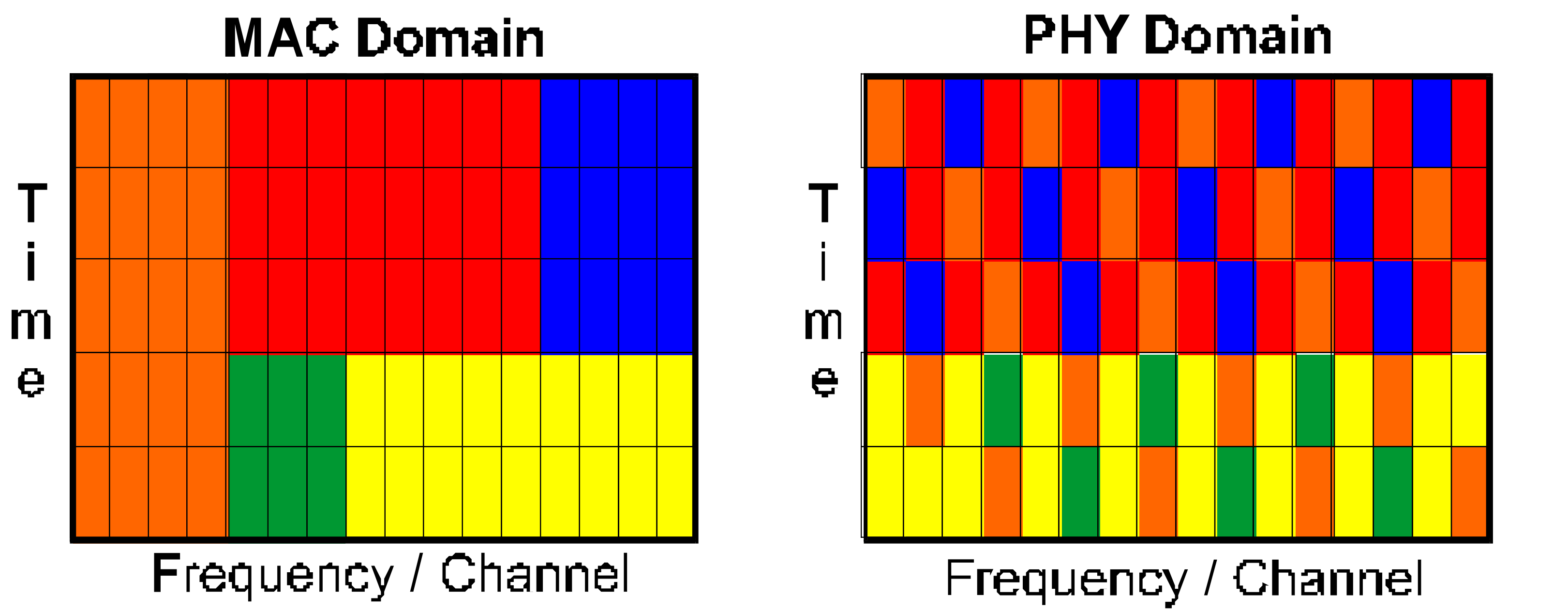
Reference Model of PHY and Interfaces

- **We must not place extra burden on 802.16.3 MAC**
  - *Getting our MAC will be the pacing item for our system, not PHY*
  - *Our 802.16.3 PHY must require only simple SAP primitives*



MAC / PHY interface concept

- **MAC Task:**
  - Assume maximization of payload channels has already occurred
  - Allocate available channels based on user rates/latency (QoS)
  - Direct forward link traffic thru 1 of 2 modulation/coding ‘pipes’:
    - Disadvantaged pipe: more robust modulation and coding
    - Mainstream pipe: higher bps/Hz for links with higher SNR/SIR
- **PHY Task:**
  - Distribute channels to minimize frequency-selective fading impact



Proposed Channel Assignment Algorithm

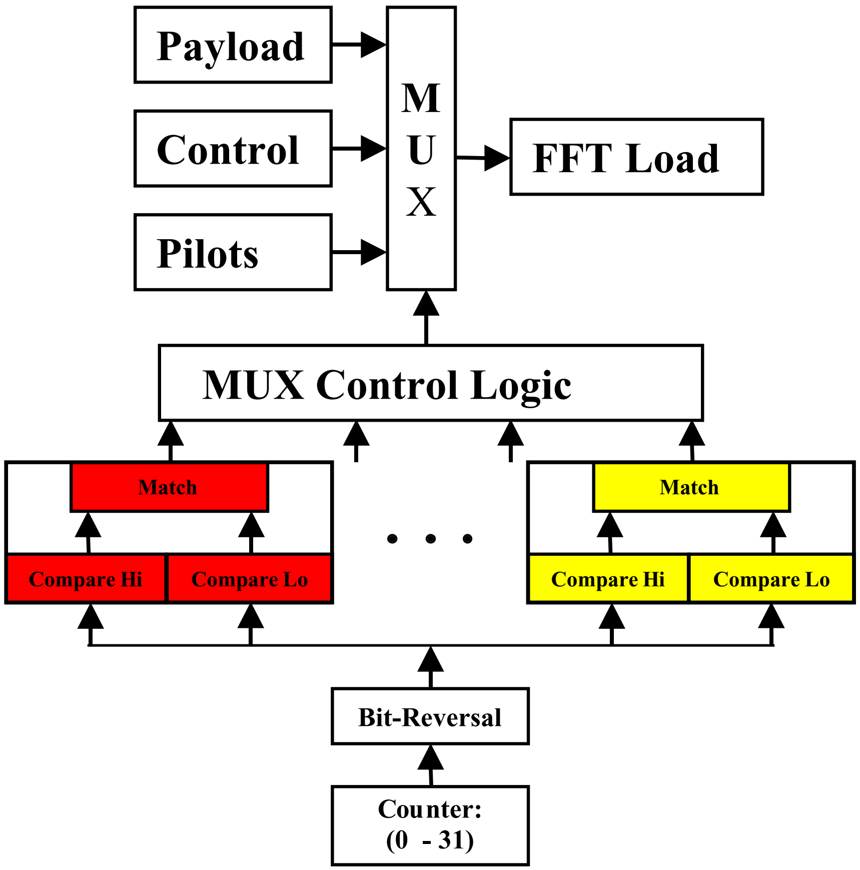
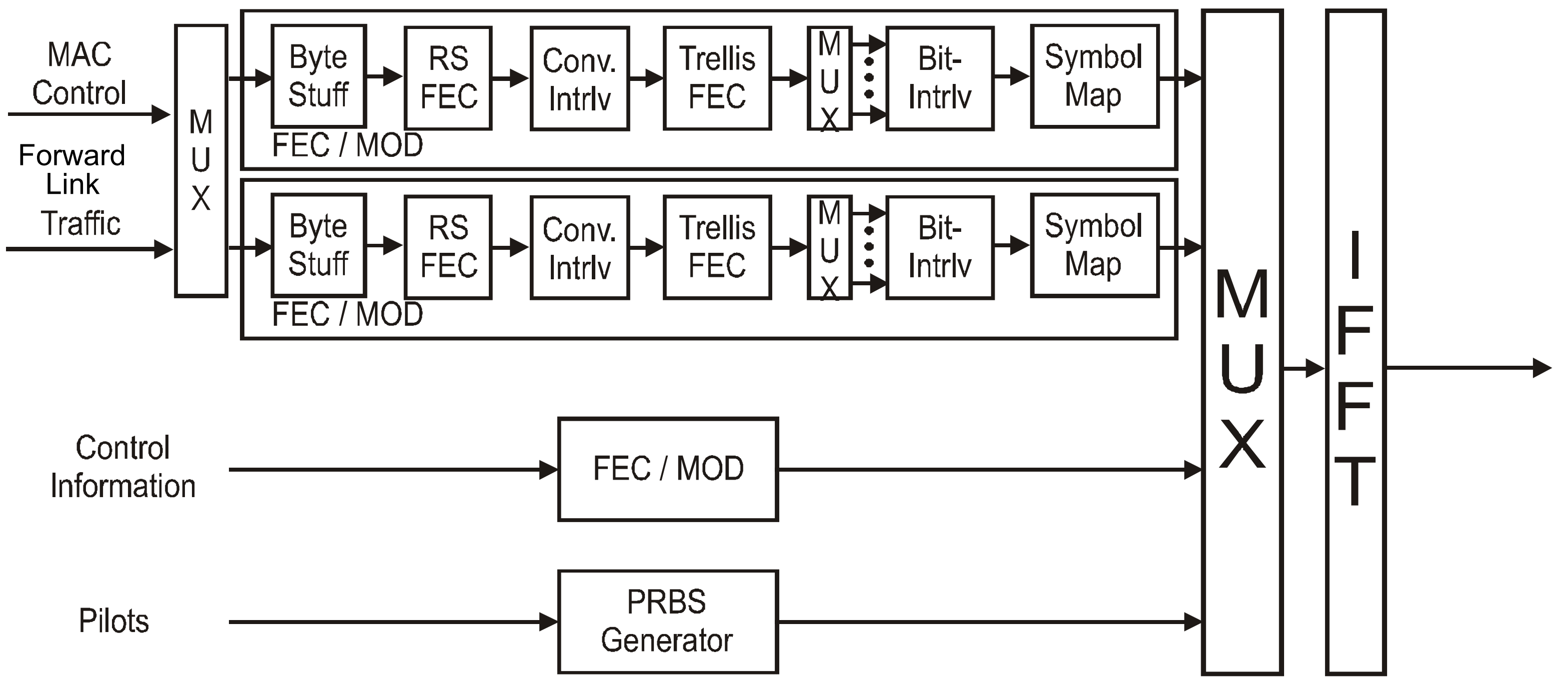


Table 1. Simple Channel Assignment Algorithm

Index In	Binary In	Binary Out	Index Out	‘Shortened’
0	00000	00000	0	
1	00001	10000	16	
2	00010	01000	8	
3	00011	11000	24	
4	00100	00100	4	
5	00101	10100	20	
6	00110	01100	12	
7	00111	11100	28	
8	01000	00010	2	
9	01001	10010	18	
10	01010	01010	10	
11	01011	11010	26	
12	01100	00110	6	
13	01101	10110	22	
14	01110	01110	14	
15	01111	11110	30	
16	10000	00001	1	
17	10001	10001	17	
18	10010	01001	9	
19	10011	11001	25	
20	10100	00101	5	
21	10101	10101	21	
22	10110	01101	13	
23	10111	11101	29	
24	11000	00011	3	
25	11001	10011	19	
26	11010	01011	11	
27	11011	11011	27	
28	11100	00111	7	
29	11101	10111	23	
30	11110	01111	15	
31	11111	11111	31	

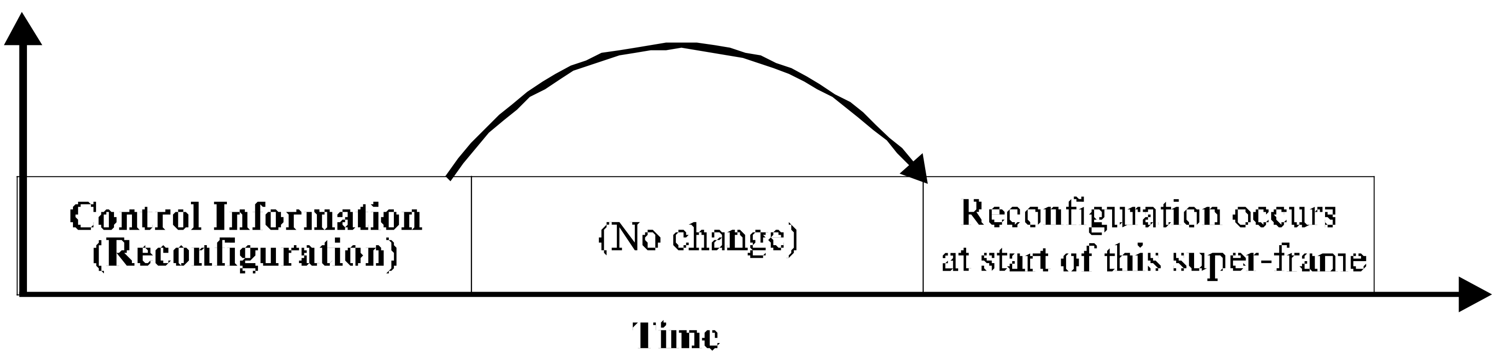
Adaptive Modulation and Coding (AMC)

- **Benefit vs complexity tradeoff suggests compromises**
  - Most AMC benefits are obtained using only two 'pipes'
    - 'Most-robust' pipe uses a low-order modulation and code rate
    - 'High-efficiency' pipe uses a high-order mod and code rate
  - Concatenated coding minimizes sensitivity to noise & interference
    - Byte-stuff operation assures integer # of RS blocks per frame
    - Avoids large coding gain loss incurred by 802.16.1 in FDD

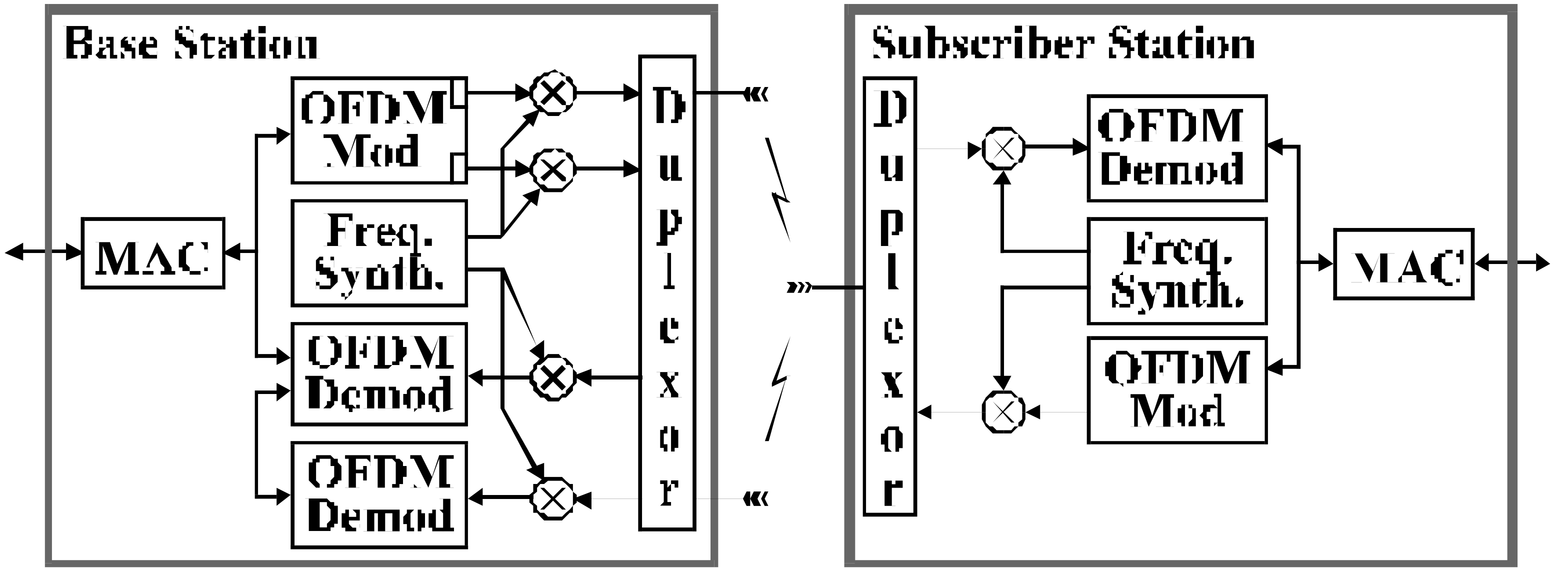


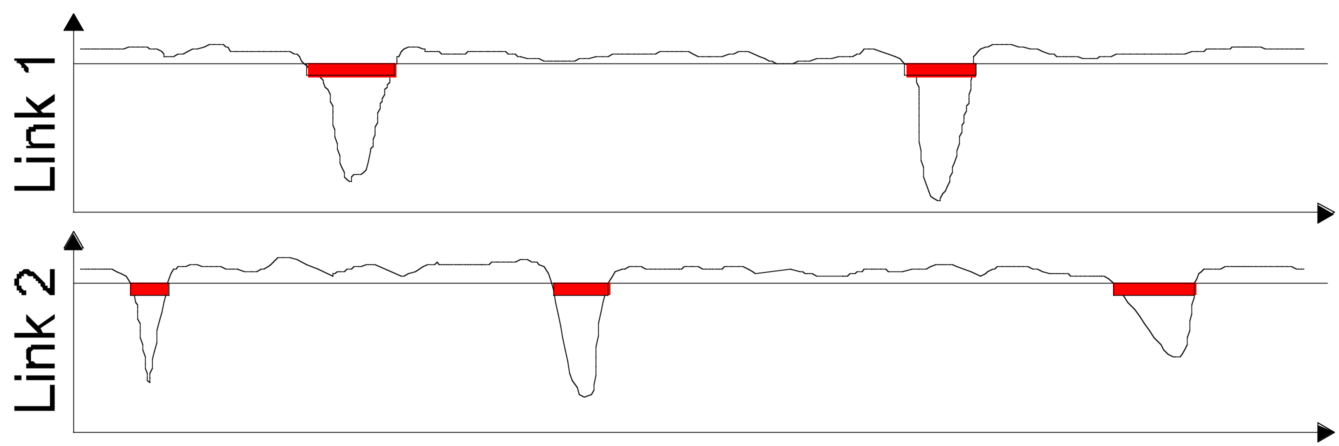
Control Channel Reconfiguration Timing

- **Control information defines OFDM configuration**
  - Seven N-tuples completely define remapping of frame symbols
    - {NFFT, NFG, NFP, NDP, NDPPS, NC, NPD}
      - NDPPS = # of DPs transmitted per OFDM symbol
      - NPD = # of payload channels assigned to ‘disadvantaged’ pipe
  - Proposed bit-reversal scheme greatly simplifies link optimization
  - Short frames enable valuable reconfiguration time
    - Changes don’t take effect until start of 2nd subsequent frame

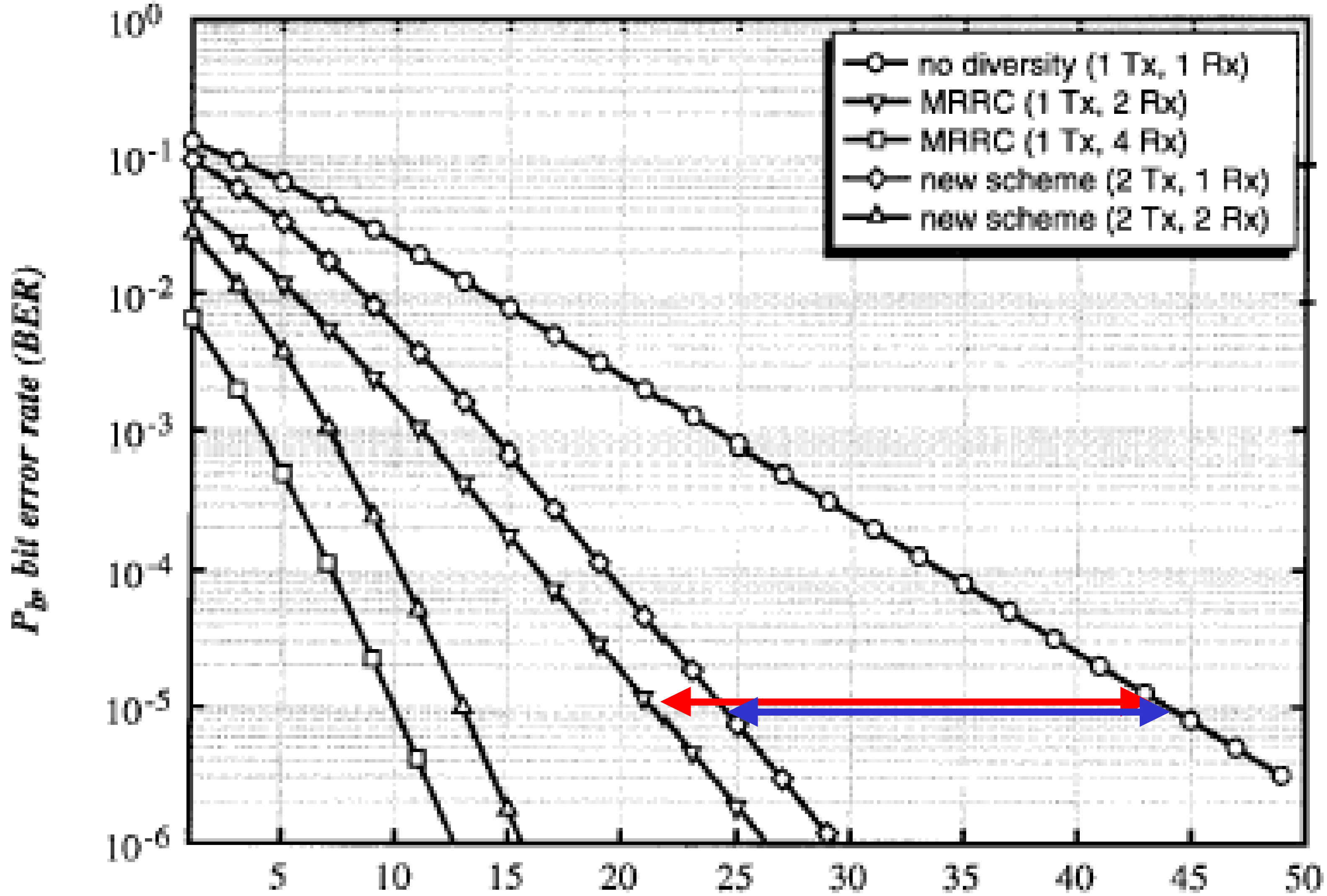


Alamouti's 2-way 2-fold Transmit-Diversity





Transmit Diversity BER Performance



Ref: M. Rude and C. Farlow, Physical Layer Elements of Next Generation Wireless Access: Technology vs. Value, WCA Technical Symposium, San Jose, CA, January 2001.

Spectral efficiency (1.5 MHz)

OFDM Bit Rate (Mbps) and Spectral Efficiency (bps/Hz)													
BW = 1.5 MHz		NFFT											
mod	rate	2048		1024		512		256		128		64	
		Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz
QPSK	1/2	1.3	0.8	1.2	0.8	1.2	0.8	1.1	0.8	1.0	0.7	0.8	0.6
	2/3	1.7	1.1	1.7	1.1	1.6	1.1	1.5	1.0	1.4	0.9	1.1	0.7
	3/4	1.9	1.3	1.9	1.2	1.8	1.2	1.7	1.1	1.6	1.0	1.3	0.8
	5/6	2.1	1.4	2.1	1.4	2.0	1.3	1.9	1.3	1.7	1.2	1.4	0.9
	7/8	2.2	1.5	2.2	1.4	2.1	1.4	2.0	1.3	1.8	1.2	1.5	1.0
	1	2.5	1.7	2.5	1.7	2.4	1.6	2.3	1.5	2.1	1.4	1.7	1.1
16QAM	1/2	2.5	1.7	2.5	1.7	2.4	1.6	2.3	1.5	2.1	1.4	1.7	1.1
	2/3	3.4	2.2	3.3	2.2	3.2	2.2	3.1	2.0	2.8	1.9	2.2	1.5
	3/4	3.8	2.5	3.7	2.5	3.6	2.4	3.4	2.3	3.1	2.1	2.5	1.7
	5/6	4.2	2.8	4.1	2.8	4.0	2.7	3.8	2.5	3.5	2.3	2.8	1.9
	7/8	4.4	2.9	4.3	2.9	4.2	2.8	4.0	2.7	3.7	2.4	3.0	2.0
	1	5.1	3.4	5.0	3.3	4.8	3.2	4.6	3.1	4.2	2.8	3.4	2.2
64QAM	1/2	3.8	2.5	3.7	2.5	3.6	2.4	3.4	2.3	3.1	2.1	2.5	1.7
	2/3	5.1	3.4	5.0	3.3	4.8	3.2	4.6	3.1	4.2	2.8	3.4	2.2
	3/4	5.7	3.8	5.6	3.7	5.4	3.6	5.2	3.4	4.7	3.1	3.8	2.5
	5/6	6.3	4.2	6.2	4.1	6.0	4.0	5.7	3.8	5.2	3.5	4.2	2.8
	7/8	6.6	4.4	6.5	4.3	6.4	4.2	6.0	4.0	5.5	3.7	4.4	3.0
	1	7.6	5.1	7.5	5.0	7.3	4.8	6.9	4.6	6.3	4.2	5.1	3.4

Spectral efficiency (3 MHz)

OFDM Bit Rate (Mbps) and Spectral Efficiency (bps/Hz)													
BW = 3 MHz		NFFT											
mod	rate	2048		1024		512		256		128		64	
		Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz
QPSK	1/2	2.5	0.8	2.4	0.8	2.3	0.8	2.1	0.7	1.9	0.6	1.4	0.5
	2/3	3.3	1.1	3.3	1.1	3.1	1.0	2.9	1.0	2.5	0.8	1.9	0.6
	3/4	3.8	1.3	3.7	1.2	3.5	1.2	3.2	1.1	2.8	0.9	2.1	0.7
	5/6	4.2	1.4	4.1	1.4	3.9	1.3	3.6	1.2	3.1	1.0	2.3	0.8
	7/8	4.4	1.5	4.3	1.4	4.1	1.4	3.8	1.3	3.3	1.1	2.4	0.8
	1	5.0	1.7	4.9	1.6	4.7	1.6	4.3	1.4	3.7	1.2	2.8	0.9
16QAM	1/2	5.0	1.7	4.9	1.6	4.7	1.6	4.3	1.4	3.7	1.2	2.8	0.9
	2/3	6.7	2.2	6.5	2.2	6.3	2.1	5.7	1.9	5.0	1.7	3.7	1.2
	3/4	7.5	2.5	7.3	2.4	7.0	2.3	6.4	2.1	5.6	1.9	4.2	1.4
	5/6	8.4	2.8	8.2	2.7	7.8	2.6	7.2	2.4	6.2	2.1	4.7	1.6
	7/8	8.8	2.9	8.6	2.9	8.2	2.7	7.5	2.5	6.5	2.2	4.9	1.6
	1	10.0	3.3	9.8	3.3	9.4	3.1	8.6	2.9	7.5	2.5	5.6	1.9
64QAM	1/2	7.5	2.5	7.3	2.4	7.0	2.3	6.4	2.1	5.6	1.9	4.2	1.4
	2/3	10.0	3.3	9.8	3.3	9.4	3.1	8.6	2.9	7.5	2.5	5.6	1.9
	3/4	11.3	3.8	11.0	3.7	10.5	3.5	9.7	3.2	8.4	2.8	6.3	2.1
	5/6	12.5	4.2	12.2	4.1	11.7	3.9	10.7	3.6	9.4	3.1	7.0	2.3
	7/8	13.2	4.4	12.8	4.3	12.3	4.1	11.3	3.8	9.8	3.3	7.3	2.4
	1	15.0	5.0	14.7	4.9	14.1	4.7	12.9	4.3	11.2	3.7	8.4	2.8

Spectral efficiency (3.5 MHz)

OFDM Bit Rate (Mbps) and Spectral Efficiency (bps/Hz)													
BW = 3.5 MHz		NFFT											
mod	rate	2048		1024		512		256		128		64	
		Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz
QPSK	1/2	2.92	0.83	2.84	0.81	2.71	0.77	2.47	0.70	2.12	0.60	1.55	0.44
	2/3	3.89	1.11	3.79	1.08	3.61	1.03	3.29	0.94	2.82	0.81	2.07	0.59
	3/4	4.38	1.25	4.26	1.22	4.07	1.16	3.70	1.06	3.18	0.91	2.33	0.66
	5/6	4.86	1.39	4.73	1.35	4.52	1.29	4.11	1.17	3.53	1.01	2.59	0.74
	7/8	5.10	1.46	4.97	1.42	4.74	1.36	4.31	1.23	3.70	1.06	2.71	0.78
	1	5.83	1.67	5.68	1.62	5.42	1.55	4.93	1.41	4.23	1.21	3.10	0.89
16QAM	1/2	5.83	1.67	5.68	1.62	5.42	1.55	4.93	1.41	4.23	1.21	3.10	0.89
	2/3	7.78	2.22	7.57	2.16	7.23	2.06	6.57	1.88	5.65	1.61	4.14	1.18
	3/4	8.75	2.50	8.52	2.43	8.13	2.32	7.40	2.11	6.35	1.81	4.65	1.33
	5/6	9.72	2.78	9.47	2.70	9.03	2.58	8.22	2.35	7.06	2.02	5.17	1.48
	7/8	10.21	2.92	9.94	2.84	9.49	2.71	8.63	2.47	7.41	2.12	5.43	1.55
	1	11.67	3.33	11.36	3.25	10.84	3.10	9.86	2.82	8.47	2.42	6.21	1.77
64QAM	1/2	8.75	2.50	8.52	2.43	8.13	2.32	7.40	2.11	6.35	1.81	4.65	1.33
	2/3	11.67	3.33	11.36	3.25	10.84	3.10	9.86	2.82	8.47	2.42	6.21	1.77
	3/4	13.13	3.75	12.78	3.65	12.20	3.48	11.09	3.17	9.53	2.72	6.98	1.99
	5/6	14.58	4.17	14.20	4.06	13.55	3.87	12.33	3.52	10.59	3.02	7.76	2.22
	7/8	15.31	4.38	14.91	4.26	14.23	4.07	12.94	3.70	11.11	3.18	8.14	2.33
	1	17.50	5.00	17.04	4.87	16.26	4.65	14.79	4.23	12.70	3.63	9.31	2.66

Spectral efficiency (25 MHz)

OFDM Bit Rate (Mbps) and Spectral Efficiency (bps/Hz)													
BW = 25 MHz		NFFT											
mod	rate	2048		1024		512		256		128		64	
		Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz	Mbps	bps/Hz
QPSK	1/2	18.60	0.74	16.41	0.66	13.26	0.53	9.47	0.38	5.95	0.24	2.99	0.12
	2/3	24.81	0.99	21.89	0.88	17.68	0.71	12.63	0.51	7.93	0.32	3.99	0.16
	3/4	27.91	1.12	24.62	0.98	19.89	0.80	14.21	0.57	8.92	0.36	4.49	0.18
	5/6	31.01	1.24	27.36	1.09	22.10	0.88	15.79	0.63	9.91	0.40	4.99	0.20
	7/8	32.56	1.30	28.72	1.15	23.20	0.93	16.57	0.66	10.41	0.42	5.24	0.21
	1	37.21	1.49	32.83	1.31	26.52	1.06	18.94	0.76	11.89	0.48	5.99	0.24
16QAM	1/2	37.21	1.49	32.83	1.31	26.52	1.06	18.94	0.76	11.89	0.48	5.99	0.24
	2/3	49.61	1.98	43.77	1.75	35.36	1.41	25.26	1.01	15.86	0.63	7.98	0.32
	3/4	55.81	2.23	49.24	1.97	39.78	1.59	28.41	1.14	17.84	0.71	8.98	0.36
	5/6	62.02	2.48	54.71	2.19	44.20	1.77	31.57	1.26	19.82	0.79	9.98	0.40
	7/8	65.12	2.60	57.45	2.30	46.41	1.86	33.15	1.33	20.81	0.83	10.48	0.42
	1	74.42	2.98	65.66	2.63	53.04	2.12	37.88	1.52	23.79	0.95	11.97	0.48
64QAM	1/2	55.81	2.23	49.24	1.97	39.78	1.59	28.41	1.14	17.84	0.71	8.98	0.36
	2/3	74.42	2.98	65.66	2.63	53.04	2.12	37.88	1.52	23.79	0.95	11.97	0.48
	3/4	83.72	3.35	73.86	2.95	59.67	2.39	42.62	1.70	26.76	1.07	13.47	0.54
	5/6	93.02	3.72	82.07	3.28	66.30	2.65	47.36	1.89	29.73	1.19	14.97	0.60
	7/8	97.68	3.91	86.17	3.45	69.61	2.78	49.72	1.99	31.22	1.25	15.71	0.63
	1	111.63	4.47	98.48	3.94	79.56	3.18	56.83	2.27	35.68	1.43	17.96	0.72

System Inputs

Delay Spread (us)=	10
Doppler (Hz) =	2
Coherence Time (ms) =	89.52
Update rate (Hz) =	22.34
Desired SNR Improvement in Channel Estimate (dB)	15
Required number of pilot averages	32

Required number of pilots / update + symbols / update yields number of pilots / symbol

	NFFT					
	2048	**1024**	**512**	**256**	**128**	**64**
Nc	*1728*	*864*	*432*	*216*	*108*	*54*
Npc	*4*	*4*	*4*	*4*	*4*	*4*
Nctrl	*32*	*20*	*12*	*8*	*4*	*4*

Efficiency

- 512 point FFT, 3.5 MHz bandwidth

Frequency guard band impact	80 carriers
Fixed pilots	4
Dynamic Pilots	9
Control	12
Data-bearing carriers	407
Useful symbol period (SF = 7/8)	128 μs
Guard time	10 μs
OFDM symbol period	138 μs
OFDM symbol rate	7,246 sps
Outer code rate	187/204
Inner code rate	_
Modulation (4 bits/sym)	16QAM

Summary

- **We are not proposing a PHY system**
- **We are proposing three OFDM PHY features**
  - A simple and flexible means of optimizing OFDM capacity
  - An adaptive modulation/coding concept retaining concatenation
  - A simple and flexible means of achieving 2-way 2-fold diversity
- **We urge that you carefully consider our proposal**