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Physical Layer Proposal for the 802.16 Air Interface Specification

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Purpose:

This presentation is intended to provide an overview of the submission IEEE 802.161pc-00_13, "Physical Layer Proposal for the 802.16 Air Interface Specification"

Physical Layer Proposal for the 802.16 Air Interface Specification

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Overview

- Changes from previous proposal
- Reasons behind changes
- Review of current proposal
- Why FDD centric?
- Differences between the two proposals for supporting FDD
- Problems of having a “one size fits all” architecture
- Why are we here and how to move forward

Changes from previous proposal

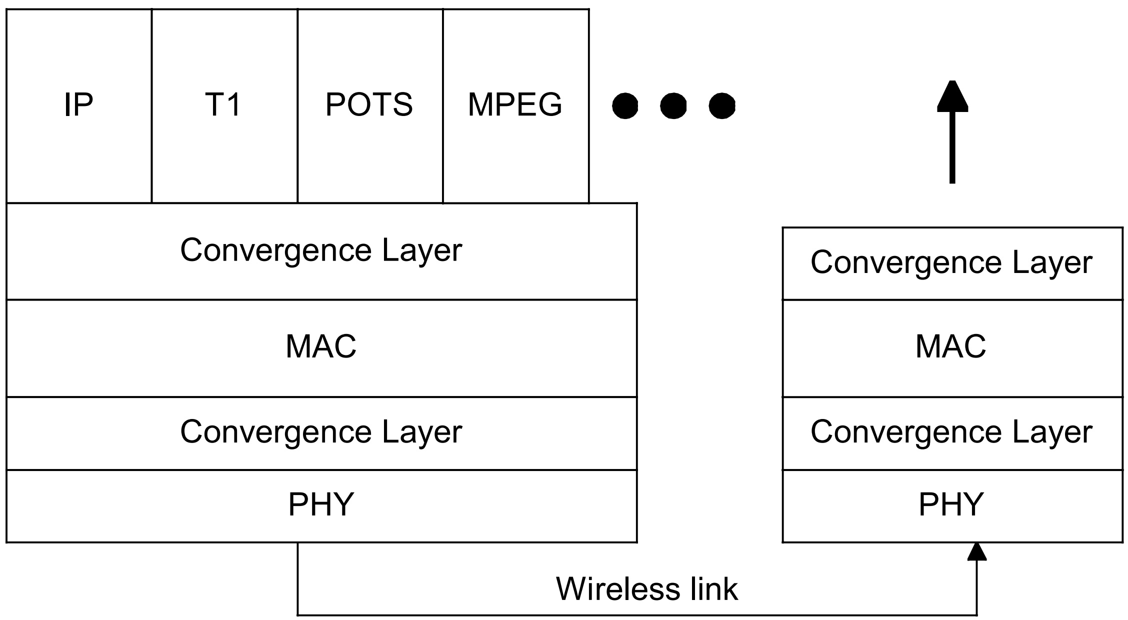
- Simplified proposal to focus on a single PHY layer architecture
  - Removed optional modes
  - Included PHY options only for the support of 8-PSK, 16-QAM, and 64-QAM which are straightforward extensions to the PHY layer
    - –Higher order modulations have cost impacts outside the MAC and PHY layers that need to be considered
- Included variable roll-off factors of 0.15, 0.25, and 0.35 in the upstream channel
  - –Allows for different power vs. spectral efficiency trade-offs

Reasons behind the changes

- Separate consideration of "options" from required PHY elements
- Simplified PHY layer has the following attributes:
  - Leverage the designs of other existing standards : ETSI EN 300 421, ETSI EN 301 210, ETSI EN 301 199, ITU-T J.83, Data-Over-Cable Service Interface Specifications (DOCSIS)
  - Allows for rapid deployment of standardized equipment
  - Reduces cost by allowing chip vendors to design products to meet multiple standards
  - Validates concept and robustness of design through operational equipment
  - Fosters international support for this standard
  - Scalable to support requirements today and in the future
- Define a simple and robust mode of operation
  - Reliability is very important for BWA to gain credibility in the public eye
- Flexibility is critical for allowing service providers the ability to target services, customer base, cost, region, available spectrum, etc.

Review of current proposal

Reference Configuration



Review of current proposal (cont.)

Multiple Access and Duplexing Technique

- Multiple Access and Multiplexing
  - TDM Downstream (DS)
  - TDMA Upstream (US)
    - Bandwidth on Demand allocation of time slots
- Duplexing Technique
  - PHY layer designed to optimally support FDD
    - Many allocations world wide have already defined US and DS channels
    - Ortho-mode transducers (OMT) can be used to reduce radio unit cost and allow operation in narrow channels
    - Proven technique in multi-cellular deployments
  - Further justification for FDD given later as well as thoughts on how to move forward given some polarized views

Review of current proposal (cont.)

Baud rates and channel bandwidths

- Flexibility is key for efficient use of the spectrum
  - large amount of spectrum in 10-60 GHz range
  - different regulatory requirements exist in different countries regarding spectral masks
  - allow vendors to trade-off radio cost/PA linearity requirements with symbol rates
  - allow vendors to optimize symbol rates for services provided
- Granularity of baud rates and/or channel sizes is TBD
- Recommendations for interoperability testing is TBD
- These requirements need an architecture that is easily transportable to different symbol rates

Review of current proposal (cont.)

DS Transmission Convergence Sublayer

- Based on MPEG packet structure including a 4-byte header + a 1-byte pointer byte as needed
  - Allows for efficient multiplexing of MPEG video streaming with MAC payload
    - Added flexibility results in only ~2-3% reduction in Downstream Bandwidth
- Convergence sublayer segments the incoming data from the MAC into fixed 188 byte payloads to be Reed-Solomon encoded
- Convergence sublayer is independent of MAC layer packet structure

Review of current proposal (cont.)

Format of MPEG packet

Header 4-bytes	P	183-184 byte Payload

Field	Length (bits)	Description
sync_byte	8	0x47 or 0xB8; MPEG Packet sync byte
transport_error_indicator	1	Indicates an error has occurred in the reception of the packet. This bit is reset to zero by the sender, and set to one whenever an error occurs in the transmission of the packet.
payload_unit_start_indicator (PUSI)	1	A value of one indicates the presence of a pointer_field as the first byte of the payload (fifth byte of the packet).
transport_priority (frame_start_indicator)	1	This bit is set to 1 to indicate the beginning of a downstream frame, when framing is used.
PID	13	802.16 well-known packet ID (TBD)
transport_scrambling_control	2	Reserved, set to '00'
adaptation_field_control	2	'01'; use of the adaptation_field is NOT ALLOWED on the 802.16 PID
continuity_counter	4	cyclic counter within this PID

Review of current proposal (cont.)

Operation of the pointer byte

- The pointer_field contains the number of bytes in the packet that immediately follow the pointer_field that the subscriber station decoder must skip past before looking for the beginning of an 802.16 MAC frame.
- A pointer field MUST be present if it is possible to begin an 802.16 MAC frame in the packet, and MUST point to either:
  - –the beginning of the first MAC frame to start in the packet
  - –to any stuff_byte preceding the MAC frame

Header (PUSI=1)	P =M	Tail of MAC frame #1 (M bytes)	stuff_byte (0 or more)	Start of MAC Frame 2

P=1 byte pointer field

Review of current proposal (cont.)

Downstream framing

- Downstream channel could be partitioned into a series of frames, where each frame contains an integer number of MPEG packets.
- Variable length frame times can be supported by having programmable symbol rates using any of the DS coding options that will be discussed.
- Frame_start_indicator in the header byte can be used to frame the DS packets.
- This framing bit can be ignored if framing is not used or controlled completely by the MAC.

Review of current proposal (cont.)

US convergence sublayer and framing

- Directly transports MAC packets in the upstream channel
  - No convergence sublayer encapsulation used
- Upstream time slot and framing concept
  - Upstream channel is divided into a contiguous series of time slots which define the granularity of bursts
  - Time slot sizes and uses are to be defined by the MAC layer
  - A "virtual framing" structure can be accommodated
    - Used to simplify bandwidth allocations for guaranteed QoS applications
    - Variable length frame times can be supported through programmable symbol rates

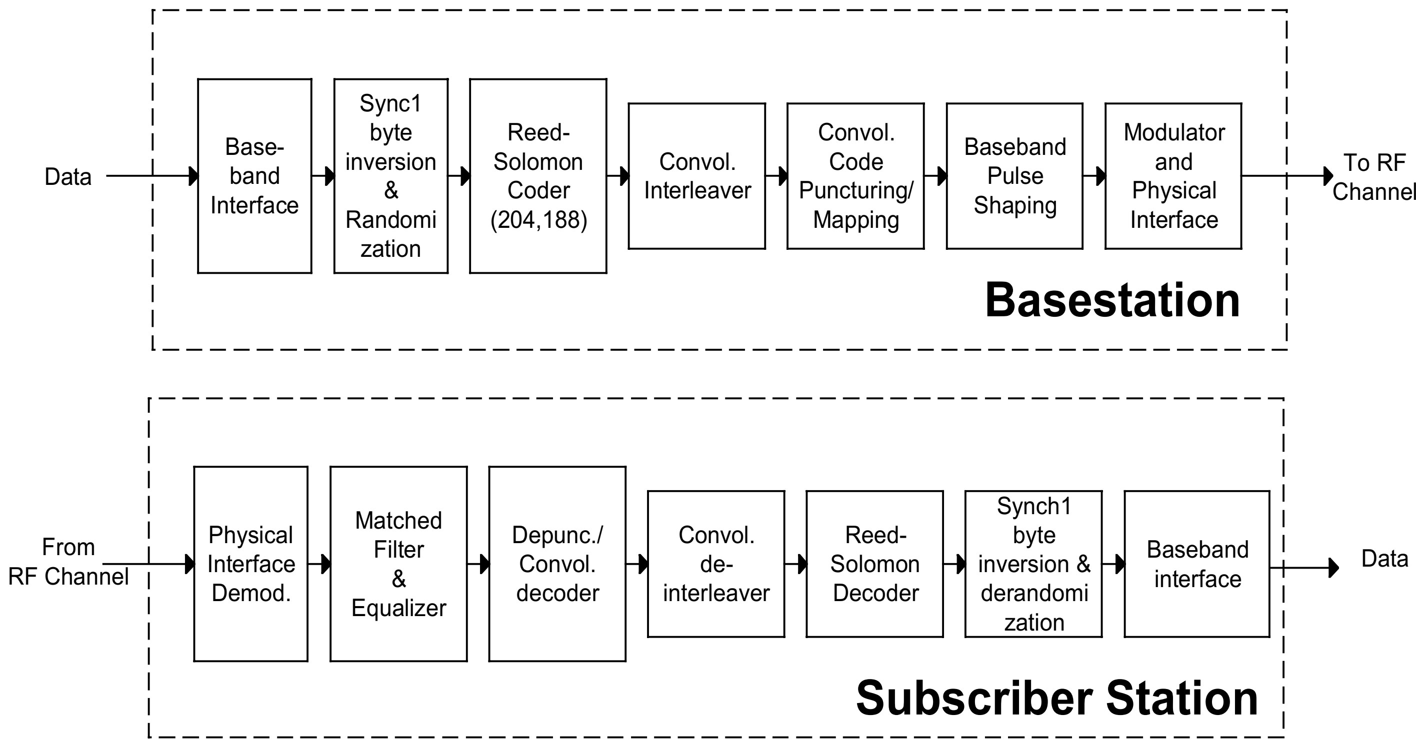
Review of current proposal (cont.)

PHY layer options

- Options need not be implemented to be standards compliant
- When an "option" is implemented, it shall comply with the specification as given in the present document
- This approach to standardization allows for the following:
  - Rapid time to market using existing and mature technologies identified by the required PHY layer elements
  - Defines a method for supporting higher order signal constellations
    - Overall system cost and deployment requirements need to be taken into account to determine the benefits of higher order signal constellations

Review of current proposal (cont.)

Downstream Physical Layer



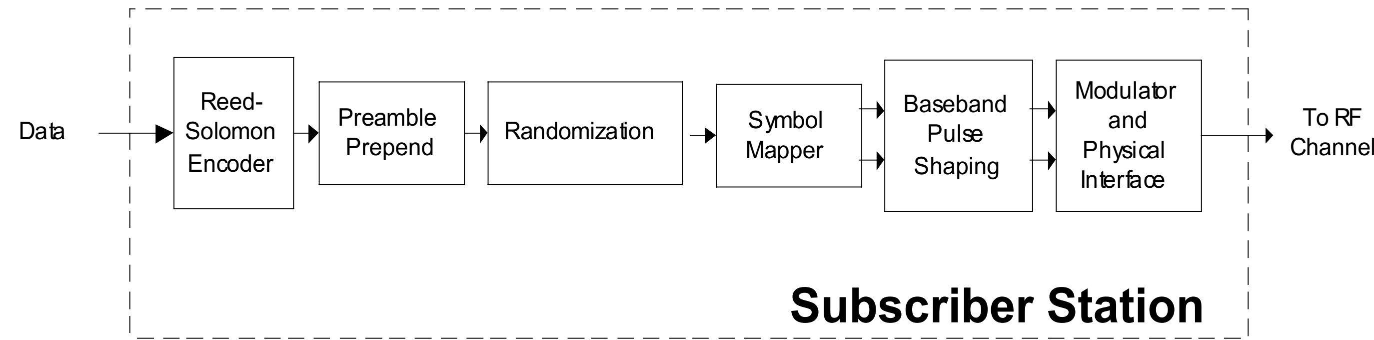
Review of current proposal (cont.)

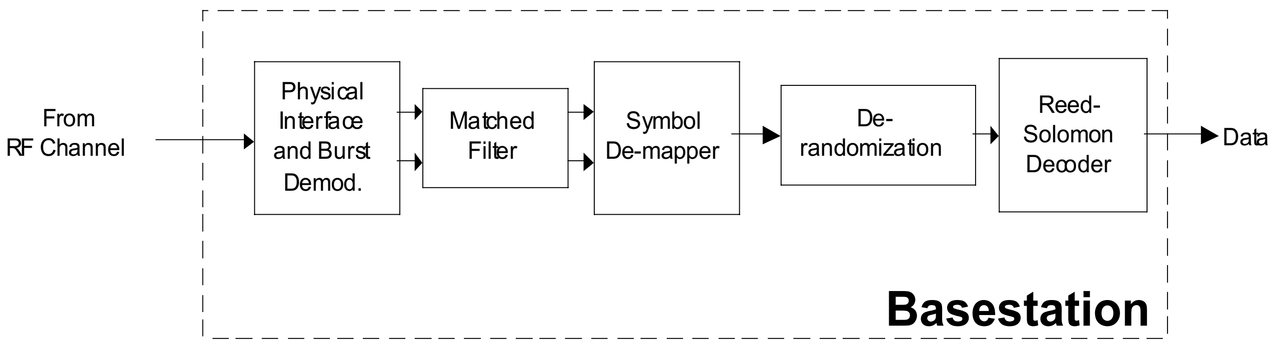
Summary of Downstream Physical Layer Parameters

Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000
Reed-Solomon Coding	(204,188) based on GF(256) with T=8 byte error correction capability
Interleaving	Convolutional with depth I=12.
Convolutional coding	Selectable: rate ?, 2/3, ?, 5/6, 7/8, or 1 (disabled)
Modulation	QPSK, 8-PSK (optional), 16-QAM (optional), or 64-QAM (optional)
Differential encoding	enabled/disabled (only enabled when convolutional coding is not employed)
Spectral shaping	α=0.15 or 0.35
Spectral inversion	inverted or non-inverted
Achievable symbol rates	10-40 Mbaud

Review of current proposal (cont.)

Upstream Physical Layer





Review of current proposal (cont.)

Summary of Upstream Physical Layer Parameters

Reed-Solomon Coding	Based on GF(256) Codeword lengths: 18-255 bytes T=0-10
Randomization	$x^{15}+x^{14}+1$ Initialization seed: 15-bit programmable
Preamble	Programmable length: 0-1024 bits Programmable value
Modulation	QPSK or 16-QAM (optional)
Differential encoding	Selectable on/off
Spectral shaping	α=0.15, 0.25, or 0.35
Achievable symbol rates	5-30 Mbaud

Review of current proposal (cont.)

Upstream channel descriptors

Parameter description	Parameter needed from MAC	Meaning
Mini-slot size	8-255 (M)	Number of bytes per mini-slot, which is the smallest unit of time slot size
Framing mode	0 or 1	enabled/disabled
Frame time	0-255 (N)	Frame time is Nx125 usec N=0 indicates framing is disabled
Mini-slots per frame	0-65,535 (P)	Number of mini-slots per frame
Symbols per mini-slot	0-1024 (Q)	Integer number of symbols per mini-slot period (independent of modulation used for transmission)
Roll-off factor	0=0.15 1=0.25 2=0.35	
Spectrum inversion	0= inverted, 1=non-inverted	
Scrambler tap coefficients	16 bits	Each tap is either on (1) or off (0)
Upstream center frequency	0-60 GHz	in KHz

Review of current proposal (cont.)

Burst Profiles

Parameter description	**Parameter needed from MAC**
Modulation	2=QPSK, 4=16-QAM
Preamble length	0-1023 bits
Preamble pattern	0-1023 bits
RS information bytes	16-255 bytes
Error correction of codeword	0-10 bytes
Last codeword length	1=fixed; 2=shortened (**optional**)
Guard time	0-255 symbols
Scrambler seed	15 bits
Differential encoding	on/off
Maximum burst size	0-255 mini-slots
Scrambler	on/off

Review of current proposal (cont.)

Radio Sub-system Control

- Synchronization
  - –MAC to control ranging alignment through periodic polling
  - –Downstream demodulator should have the capability to provide a reference clock that is phase locked to the downstream symbol rate
  - –Framing can be controlled by the MAC and convergence layer
- Frequency
  - –MAC to control ranging alignment through periodic polling
  - –US and DS RF frequencies should reference each other to allow for low cost CPE equipment
- Power
  - –MAC to control ranging alignment through periodic polling
  - –US power level should reference DS received power level to correct for correlated fades (possibly due to rain or other shadowing)

Review of current proposal (cont.)

Physical Layer Transmitter Characteristics

- Some characteristics are listed in the paper
- These can be defined and discussed at a later date

Review of current proposal (cont.)

Evaluation Table

•Meets system requirements
•Spectrum efficiency

Downstream:
assuming α=0.15 or 0.35 and a payload of 183 bytes.

Modulation	Inner Code Rate	bps/Hz (1.15)	bps/Hz (1.35)
QPSK	0.5	0.78005115	0.66448802
	0.666666667	1.0400682	0.88598402
	0.75	1.17007673	0.99673203
	0.833333333	1.30008525	1.10748003
	0.875	1.36508951	1.16285403
	1	1.5601023	1.32897603
8-PSK*	0.666666667	1.5601023	1.32897603
*	0.833333333	1.95012788	1.66122004
*	0.888888889	2.0801364	1.77196805
16-QAM*	0.75	2.34015345	1.99346405
*	0.875	2.73017903	2.32570806
*	1	3.1202046	2.65795207
64-QAM*	1	4.68030691	3.9869281

* = “option”

Upstream: As an example: 4 byte preamble, 1 byte guard time, roll-off of 0.25, and QPSK modulation.

bps/Hz=1.247 (RS(63,53) code with differential encoding)

Review of current proposal (cont.)

Evaluation Table (cont.)

- Simplicity of implementation
  - leverages existing standards
- CPE cost optimization
  - leverages existing standards
- Spectrum resource flexibility
  - proposal contains several flexible parameters including: symbol rates, roll-off factors, modulation, coding
- System diversity flexibility
  - convergence layer is MAC independent
- Protocol interfacing complexity
  - convergence layer is MAC independent
- Implications on other network interfaces
  - convergence layer is MAC independent

Review of current proposal (cont.)

Evaluation Table (cont.)

- Reference system gain
  - Assumptions: BER=10^(-10), 40 MHz DS channel, 10 MHz US channel, DS and US assumes a 0 dBW transmitter, 0 dB NF LNA, noise floor = -174 dBm + 10log(BW).

Modulation	**Inner Code**	**Eb/No (dB)**	**C/N (dB)**	**Backoff (dB)**	**RSG (dB)**
Downstream					
QPSK	5/6	6	7.85	4	116.13
Upstream	**Code rate**	**Eb/No (dB)**	**C/N (dB)**	**Backoff (dB)**	**RSG (dB)**
QPSK (differential encoding)	53/63	11	13.25	4	116.75

Note that the above numbers include an implementation loss of 0.8 dB in the downstream and 2 dB in the upstream.

Review of current proposal (cont.)

Evaluation Table (cont.)

- Robustness to interference
  - PHY layer uses QPSK modulation with flexible code rates to accommodate different channel conditions
- Robustness to channel impairments
  - PHY layer uses QPSK modulation with flexible code rates to accommodate different channel conditions

Review of current proposal (cont.)

Limitations of Proposal

- Added flexibility may require provisioning during installation or negotiation with MAC layer
  - Accurate pointing of antennas at installation could be critical, so local configuration of the subscriber station may be acceptable
  - Use of "smart card" type techniques could allow for user provisioned subscriber stations
  - Automatic receiver detection algorithms

Review of current proposal (cont.)

Benefits of Proposal

- Flexible, reliable, low cost PHY layer that enables rapid time to market for this standard
- Limited number of options that describe methods for supporting higher order modulations
- Proven reliability in deployed systems for satellite channels, cable channels, as well as BWA channels in 10-60 GHz
- Leverages existing international standards for world-wide acceptance

Why FDD centric?

- Three different duplexing techniques are being considered for BWA:
  - Frequency division duplexing (FDD)
  - Half-duplex frequency division duplexing (H-FDD)
  - Time division duplexing (TDD)

- Perceived main benefits of the other duplexing techniques
  - H-FDD claims to result in cheaper radios
    - Cost difference between an OMT and RF switch is minimal
  - TDD claims to be more flexible when separating US and DS BW
    - Flexibility comes at a cost of reduced frequency reuse due to co-channel interference considerations

- First, highlight benefits of FDD and continuous mode DS transmission
- Then, compare the different proposals and continuous vs. burst transmission
- Finally, topics for discussion on how to move forward with the standards process...

Why FDD centric? (cont.)

- **Benefits of FDD**
  - Proven technology
    - Coexistence practices well established
  - Time to market - chips available today can be easily modified to be fully standards compliant
  - High channel bandwidths can easily be supported using available technology
    - Higher bandwidth = greater statistical multiplexing = greater over-subscription of bandwidth = greater revenues
  - Hardware advantages (mature, low cost, reliable)
  - High frequency reuse to maximize capacity and revenues
  - Fewer antennas and radios required for deployments

Why FDD centric? (cont.)

Bandwidth and RF Propagation Issues

- FDD, through duplex channels, maximizes data rate up to coherency bandwidth of RF channel
  - Higher data rate advantageous for better statistical multiplexing
- Other methods (e.g. time duplex) require 2 x BW for same data rate
  - exceeds channel coherency - expensive equalizers required
  - for symmetrical services, occupied BW = coherence BW, then available BW for US/DS = 1/2 coherence BW which results in less statistical multiplexing gain
- Equalization for continuous mode transmission is well-known

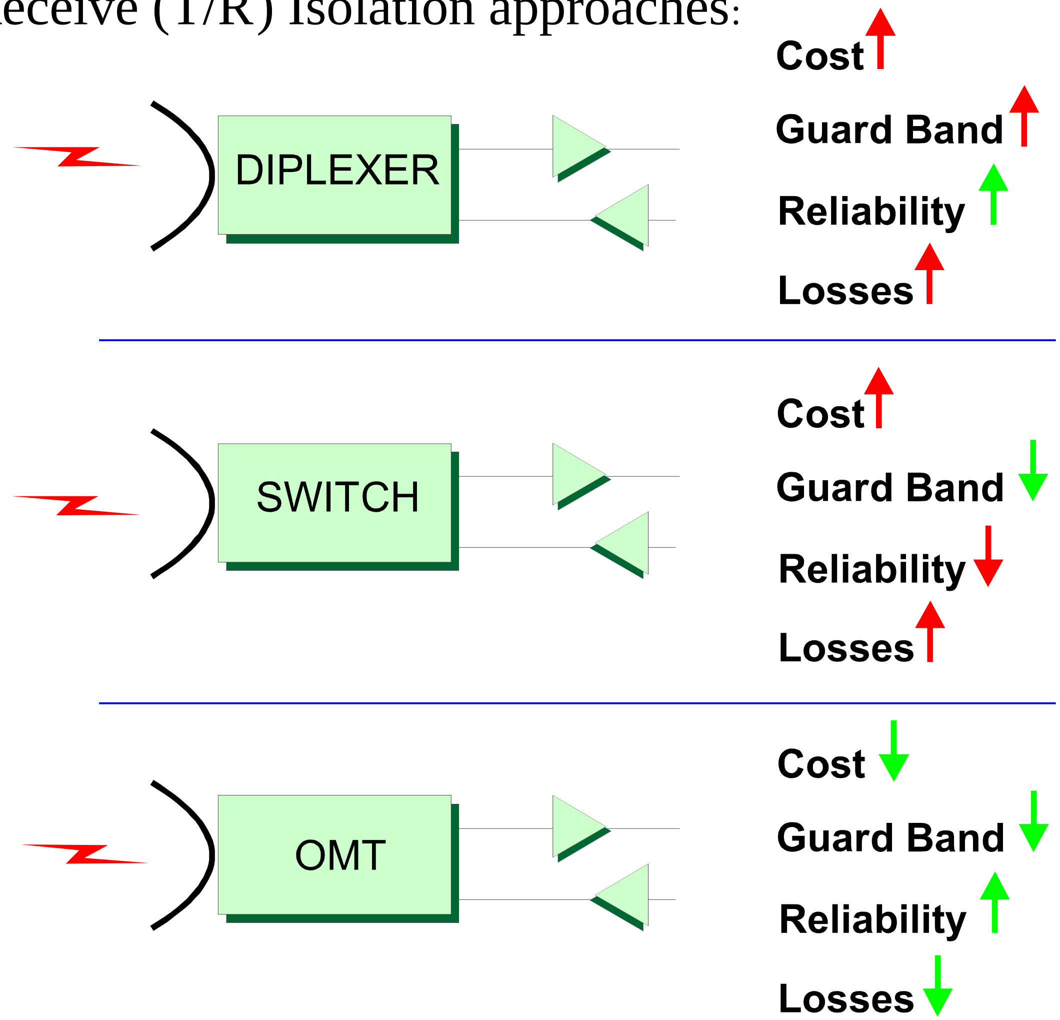
  and can be configured to track a range of multipath time-variations

  (for example, wind blowing antennas could cause phase rotations of multipath…1 cm distance variation @ 30 GHz = 2π rotation)

Why FDD centric? (cont.)

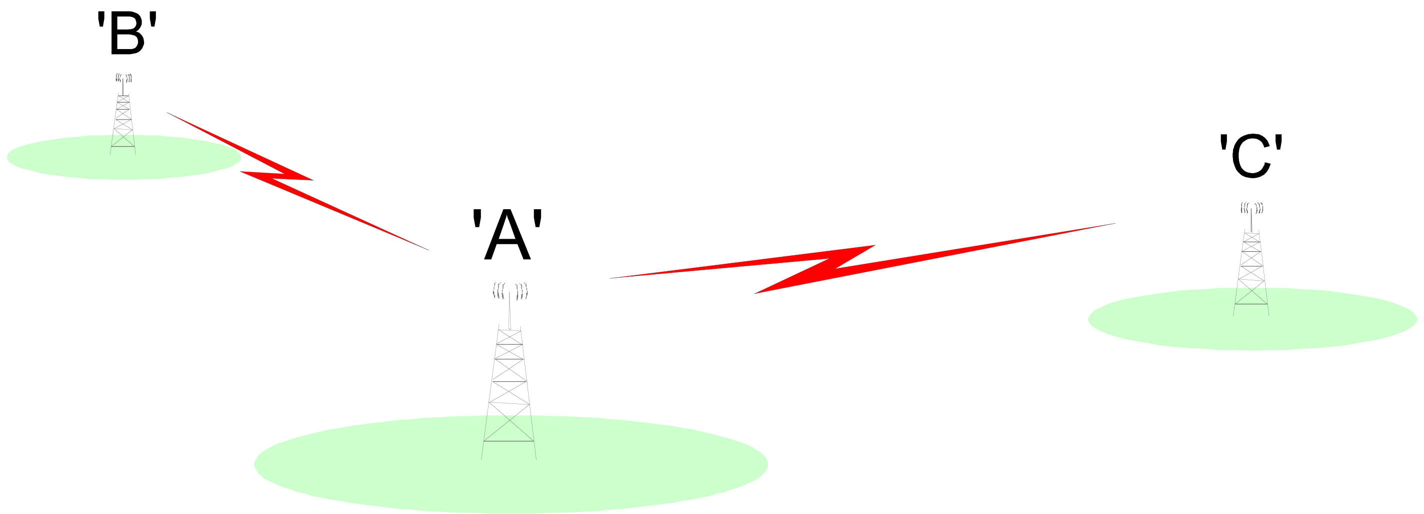
Hardware Considerations

- Transmit-Receive (T/R) Isolation approaches:



Why FDD centric? (cont.)

Dynamic Channel Asymmetry Adjustment



- For optimal frequency efficiency, network deployment relies on well understood interference sources (e.g. from other licensees)
  – dynamic T-R split creates unpredictable co-channel interference
- FDD allows network to be adjusted to reflect market customer demand
  – number and size of channels can be varied over time
  – overlaying different technologies on different carriers allows migration path for the future

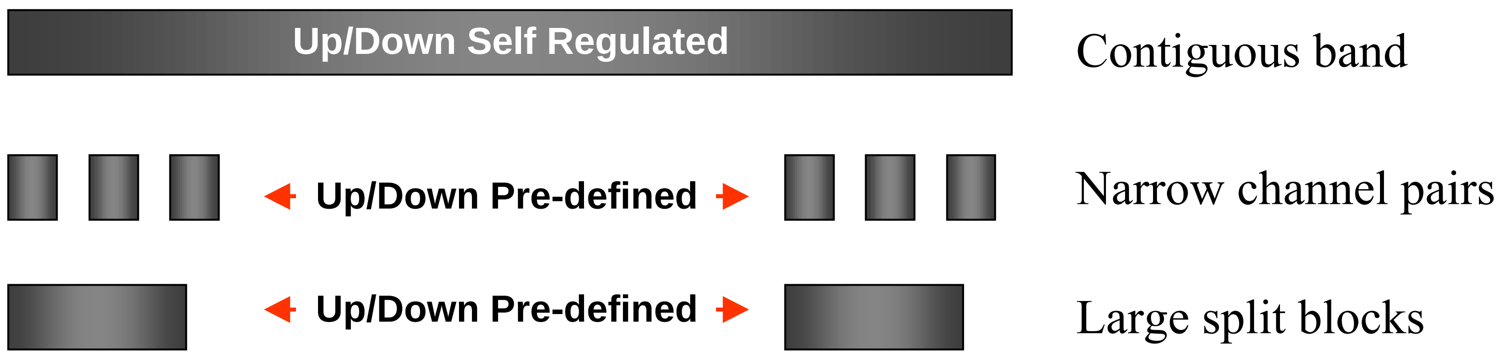
Why FDD centric? (cont.)

Implementation and Capacity Considerations

- Antennas on rooftops - paramount issue
  - Landlord tolerance level ~ 4 pole mounts
- Adopt multi-carrier transmitter strategy
  - assume 4 sectors, X-pol, 40 MHz DS channels, reuse of 1, 1000 MHz (US+DS), symmetrical service, so 12 DS carriers/sector in 500 MHz channel
  - Total downstream bandwidth per cell for FDD ~ 2 GHz
  - total no. of radios/ant pairs = 4 w/ multi-carrier
- Concerns with other duplexing techniques requiring a large number of sectors
  - to reduce co-channel interference in a TDD system, high sectorization is required
  - assume 12 sectors, X-pol, 25 MHz channels, reuse of 1/2, 1000 MHz spectrum, symmetrical service, so 3 carriers/sector and equivalent of 12.5 MHz of DS BW per channel (reuse based on IEEE 802.16cc-99/08)
  - Total downstream bandwidth per cell for TDD ~ 450 MHz
  - total no. of radios/ant pairs = 12 w/ multi-carrier (= 36 w/o multi-carrier)
- Conclusions: FDD has higher capacity (~4x) with less infrastructure

Why FDD centric? (cont.)

Global License Assignments

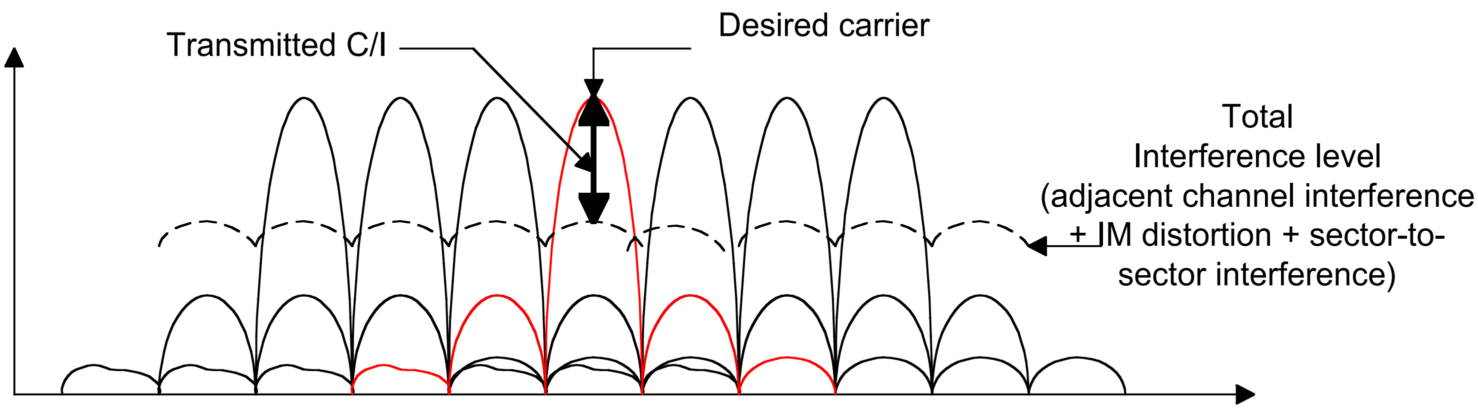


FDD with OMT maps effectively into all three licensed regimes

Why FDD centric? (cont.)

Dynamic Modulation from an implementation perspective

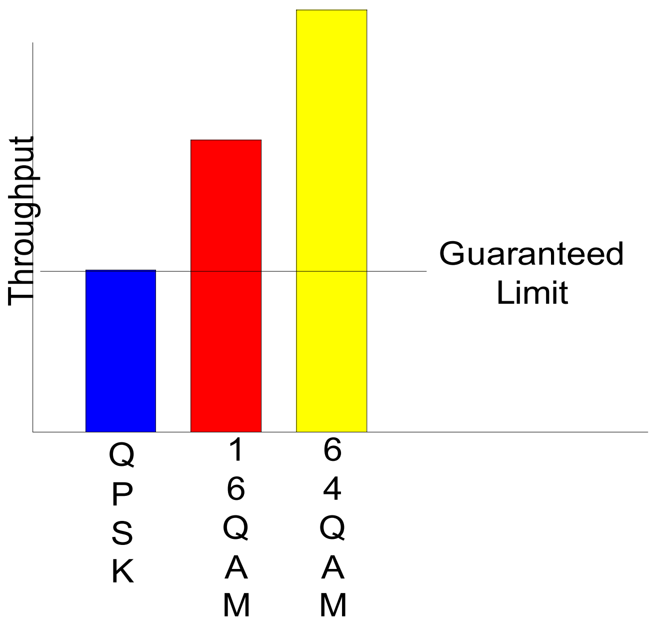
- Dynamic modulation allows systems to take advantage of rain fade margin, BUT this benefit is not necessarily for free!
- For a typical deployment, adjacent channel interference, inter-modulation distortion, and sector-to-sector interference need to be considered at the transmitter:



- Transmitted C/I is a function of many factors: number of carriers, radio linearity, back-off, spectral shaping, carrier spacing
- For different modulations on each carrier, C/I must be designed for highest order modulation which may effect Tx output power and/or cell radius
- Conclusion: supporting dynamic modulation could effect frequency reuse, multi-carrier operation, and/or radio cost (phase noise) to support higher order modulation
- Different modulation on separate carriers can be supported through proper planning

Why FDD centric? (cont.)

Dynamic Modulation from a services perspective



Relative throughput with respect to modulation

- If cells designed based on QPSK, then QPSK is the only bandwidth that can be GUARANTEED.
- Capacity of the sector will be limited to the guaranteed available bandwidth which is typically desired for the business customer
- Requires a market with large number of “best effort” services (peak throughput >> minimum)
- Potential for allowing a connection based on currently available bandwidth and having to drop the connection once that bandwidth is removed
- Adaptive modulation cannot increase the number of guaranteed connections.

Differences between 2 proposals for FDD

Summary of Downstream PHY differences

	Our proposal	**Ensemble consortium**
Convergence sublayer	4-5 byte MPEG header contained in 188 byte packet (error detection performed on MAC packet basis)	1 pointer byte + 2 CRC bytes (for error detection) contained in 128 byte packet
Outer code	RS(204,188) based on GF(256)	RS(138,128) based on GF(256)
Interleaver	I=12 convolutional	none
Inner code	Convolutional rate ?-1 (disabled) (~7.7 dB required C/N variation from rate ? to 1 code)	Parity check code on each RS byte (rate 8/9 code)
Error detection	None (left up to MAC)	2 byte CRC for each RS codeword
Shaping	RRC with α=0.15 or 0.35	RRC with α=0.25
Modulation	QPSK, 8-PSK (optional), 16-QAM (optional), or 64-QAM (optional) (differential or Gray coded)	QPSK, 16-QAM, 64-QAM (optional) (Gray coded)
Shortened last codeword	No (not necessary in FDD implementation with TDM)	Yes
Adaptive modulation	Not defined in current proposal, but can support load balancing and higher order modulation on separate carriers, if desired	Yes

Differences between 2 proposals for FDD (cont.)

Summary of Upstream PHY differences

	Our proposal	**Ensemble consortium**
Convergence sublayer	None (error detection performed on MAC packet basis)	1 pointer byte + 2 CRC bytes (for error detection) contained in 128 byte packet for data
Outer code	Variable rate RS code based on GF(256)	RS(138,128) for data RS(20,14) for registration RS(9,5) for contention, based on GF(256)
Inner code	None.	Parity check code on each RS byte
Error detection	None (left up to MAC)	2 byte CRC on each RS codeword
Shaping	RRC with α=0.15, 0.25, or 0.35	RRC with α=0.25
Modulation	QPSK and 16-QAM (optional) (differential or Gray coded)	QPSK, CQPSK, 16-QAM, 64-QAM (optional) (Gray coded)
Shortened last codeword	Yes	Yes
ARQ	Left up to MAC	Yes
Adaptive Modulation	Yes	Yes

Differences between 2 proposals for FDD (cont.)

Main differences between continuous (FDD) and burst (TDD and H-FDD) mode operation

	Continuous mode	**Burst mode**
Synchronization	Allows symbol clock to be related to network clock and passed on the subscriber station easily	Uses "time stamps" with oscillators that "fly-wheel" through bursts
Phase and frequency tracking	Can use continuously updated, narrow tracking loops. Synch byte enables rapid detection/ recovery of loops following errored states/phase slips	Tracks on a burst by burst basis using a preamble and must wait until next frame to recover from errored states/phase slips
Coding method	Able to use most powerful concatenated code with interleaving in use today combining coding and modulation (1-2.5 dB better)	Limited to block coding schemes due to burst nature
Coding gain variability	Can be achieved by varying inner convolutional code rate with >7 dB required C/N range (at expense of rate)…variability helpful for asymmetrical US and DS links and adds flexibility to deployments	Varying RS error correction adds considerable complexity to the receiver and does not result in significant C/N variation
Equalization	Can use well known algorithms and relatively narrow tracking loop bandwidths	Tracks on a burst by burst basis using preamble. Complexity depends on time variability of multi-path phase.
Symbol rates	Similar chips available today support rates up to 45 Mbaud	Chip availability and symbol rate support?
Adaptive Modulation	Not easily supported with interleaving and convolutional coding. Different modulations can be supported on different carriers, but must consider other cost trade- offs for specific deployments.	Can be more readily supported, but must consider other cost trade- offs for specific deployments (multi-carrier or not, effect on radio cost, effects on traffic guarantees/contracts, etc.)

Problems with "one size fits all"

•Should a single downstream physical layer support both continuous and burst transmission?

- –Current FDD proposal is clearly superior for a continuous mode transmission compared to the other proposal…coding, synchronization, modulation, etc. have been specifically designed for a continuous mode transmission.
- –Some issues regarding TDD that have been raised include: capacity, deployments costs, coexistence practices, maturity, equalization difficulties, coding gain
- –Due to interference considerations, FDD and TDD will not be geographically co-located, so interoperability between these technologies may not be necessary.
- –Forcing a PHY layer that supports both modes will result in a sub-optimal design for both and will not benefit the industry.

Why are we here and how to move forward

- Why are we here?
  - In order to **lower equipment costs** by opening up the market to third party manufacturers that can build industry standard equipment
  - To provide a **technical validation** of the PHY and MAC layers for BWA systems
- How to move forward?
  - Compromise is good as long as it doesn't "cost" anything (performance and $)
  - Downstream and Upstream PHY layers already share many common elements
  - Some major areas for discussion:
    - Which duplexing method should the PHY be optimized for?
    - Should > QPSK be required for all subscriber station modems (does this mean all radios must support these higher order modulations)?
    - What degree of flexibility should be required in the standard?
    - How closely related to the MAC should the PHY layer be (considering MAC and PHY future evolutions)?