Physical Layer Proposal for the 802.16.1 Air Interface Specification

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Purpose:

This presentation is intended to provide an overview of the submission IEEE 802.16.1pc-00/19, "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

- Review changes from previous proposal
- Discuss current proposal and reasons for the changes
- General overview of PHY architecture
- Description of Mode A downstream PHY
- Description of Mode B downstream PHY
  - Comparisons of different architectures
- Review of upstream PHY
- Results comparing static and dynamic modulation
- Key differences between the two proposals
- Conclusions

Changes from previous proposal

- Two downstream PHY definitions
  - Mode A: Continuous transmission format
  - Mode B: Burst transmission format
- New transmission convergence sublayer
  - No MPEG header required

General PHY architecture

Downstream PHY structure

	Mode A	Mode B
TC layer	Single pointer byte	
Preamble requirements	Synch. byte per codeword	Preamble per burst
Outer code	Reed-Solomon over GF(256)	
Interleaver	Yes	No
Inner code	Convolutional code or None	None
Modulation	QPSK, (8-PSK, 16-QAM, 64-QAM)	QPSK, 16-QAM, (64-QAM)
Duplexing	FDD only	FDD, H-FDD, TDD
Different modulation levels supported	Frequency domain	Time domain

Upstream PHY structure

TC layer	None
Preamble requirements	Preamble per burst
Outer code	Reed-Solomon
Interleaver	None
Inner code	None
Modulation	QPSK, (16-QAM)
Duplexing	FDD, H-FDD, TDD
Different modulation levels supported	Time domain per burst

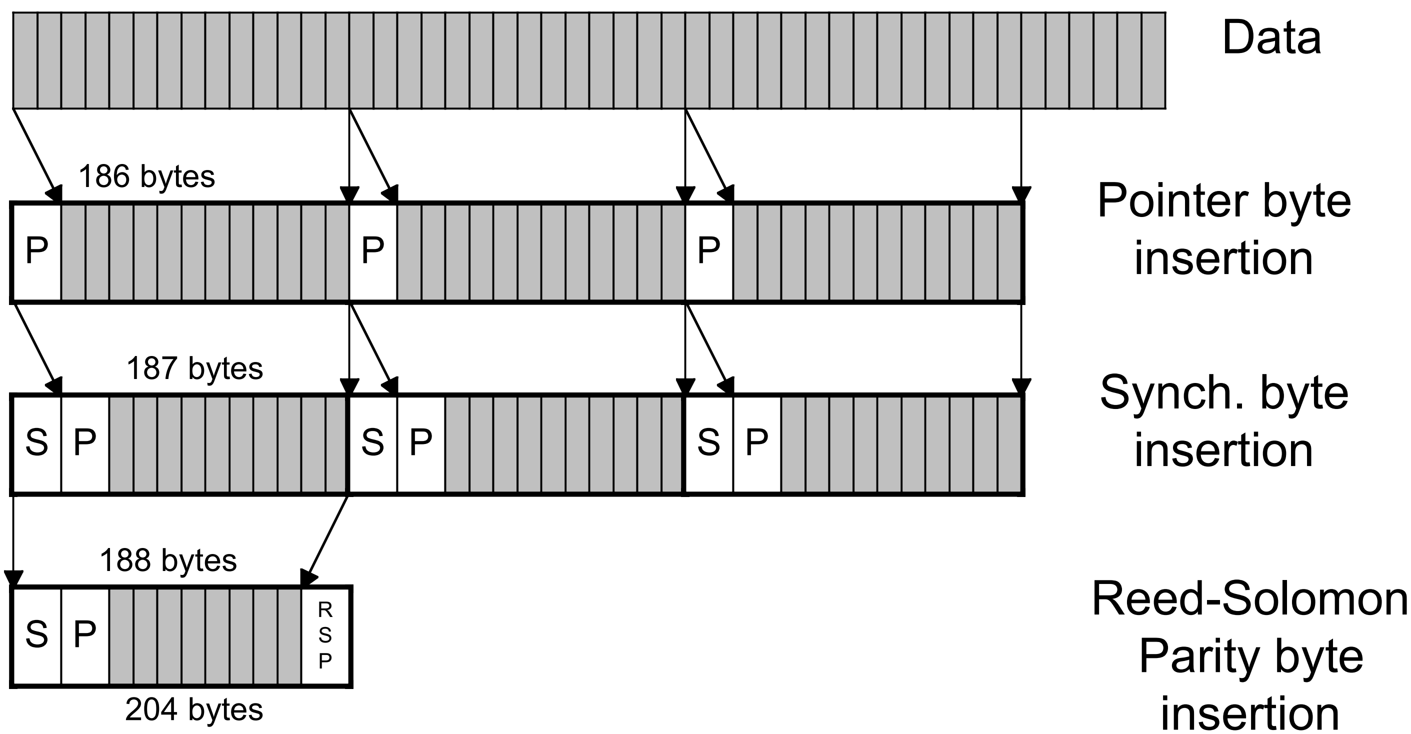
General PHY architecture (cont.)

Motivations for having 2 DS PHY definitions:

- Primary benefits of Mode A (continuous mode)
  - Based on mature chip sets that can be made readily available
  - Technology is proven and is currently being deployed by several participating companies
  - Allows for low risk, rapid deployment of standardized equipment
  - Efficiently supports statically provisioned higher order modulation.
  - Supports larger cell sizes for reduced cost deployments (utilizing the greater coding gain of the RS+interleaving+convolutional coding)
- Primary benefits of Mode B (burst mode)
  - Potentially yields higher capacity links when a small number of carriers is available in a sector
  - Allows for higher capacity during clear air for applications that do not require a constant bandwidth with a guaranteed availability

Standardized equipment should support either mode of operation, while not requiring all equipment to support both modes, resulting in lower equipment costs by not having the burden of both modes on single chip solutions.

Mode A Downstream TC sublayer



Pointer byte points to the beginning of a MAC packet or the beginning of any stuff bytes (0xFF).

Mode A Downstream PMD sublayer (cont.)

Summary of Downstream Physical Layer Parameters

Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000 on every 8th codeword
Reed-Solomon Coding	(204,188) based on GF(256) with T=8 byte errors 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

Mode A Downstream PMD sublayer (cont.)

Flexible parameters:

- Inner convolutional code rate
- Roll-off factor
- Modulation level (higher than QPSK optionally supported)

Justification for having flexibility:

- Allows vendors to maximize spectral efficiency based on acceptable power constraints
- Additional flexibility comes at relatively little cost

Modulation Mode A	Inner Code Rate	Roll-off	bps/Hz	Capacity Change (%)	System Gain Change (dB)	
QPSK	1.00	0.35	1.35	0%	0.00	Nominal case
QPSK	1.00	0.15	1.59	17%	-2.00	
QPSK	0.88	0.35	1.18	-13%	3.40	
QPSK	0.83	0.35	1.13	-17%	4.05	
QPSK	0.75	0.35	1.01	-25%	5.00	
QPSK	0.67	0.35	0.90	-33%	6.00	
QPSK	0.50	0.35	0.68	-50%	7.80	

Mode A Downstream PMD sublayer (cont.)

Some practical implications having a series of flexible downstream parameters

- Need downstream channel acquisition process and/or installation provisioning
- Recommend having a set of commonly used settings in order to hasten acquisition
- The following table is an example of some possible recommended initial settings.

Setting	Modulation	Inner code rate	Roll-off	Symbol rate	Channel size
1	QPSK	7/8	0.35	**TBD**	**TBD**
2	QPSK	1	0.15	**TBD**	**TBD**
3	16-QAM	7/8	0.35	**TBD**	**TBD**
4	16-QAM	1	0.15	**TBD**	**TBD**

Downstream Burst Architectures

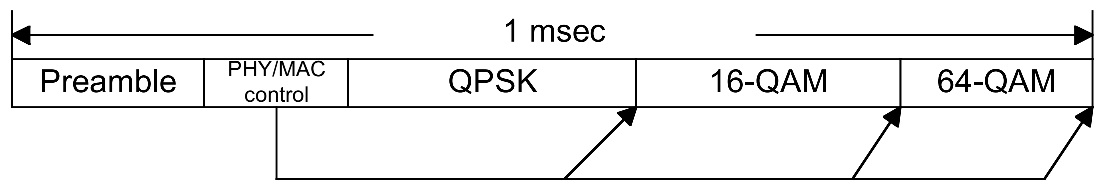
Considerations when looking at different burst architectures:

- Need method for obtaining frequency and symbol timing (relatively slow changes)
- Need method for tracking phase (worst case is uncorrelated from burst-to-burst).
- Need method for determining modulation level changes

Architectural implications and decisions:

- Explicit framing in the downstream channel allows for:
  - Consistent tracking of frequency and symbol timing.
  - Consistent reference for initial phase tracking
- Control of modulation level changes must be very reliable to ensure robust operation and meet required BER.

E+ Approach to DS Burst Architecture



Example of E+ approach for FDD using a PHY control message

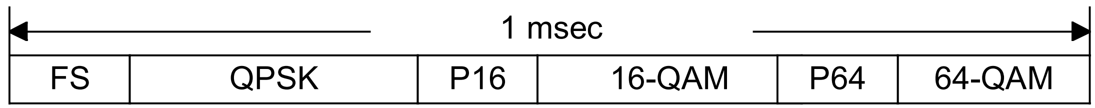
Benefits:

- Single Preamble and PHY control message helps to identify modulation boundaries

Drawbacks:

- Susceptible to errors on PHY control message (especially for H-FDD system)
- Susceptible to delays incurred when decoding the first codeword
- Requires close operation between the PHY and MAC

Alternative Approach to DS Burst Mode (Mode B)



Alternative approach using unique preambles for differentiating modulation levels (combining concepts that have been presented by the E+ proposal, proposals submitted to ETSI, and our current US burst architecture)

Benefits:

- Requires no PHY control map
- Minimal delays incurred for identifying modulation boundaries
- No real time PHY/MAC handshaking required at the CPE

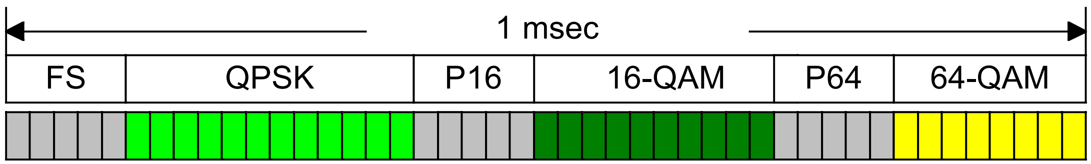
Drawbacks:

- Less efficient, in some cases, based on the preamble length requirements calculated.

In the interests of having multiple burst mode architectures considered by the working group, we chose to continue investigating this particular architecture.

Physical Slot Structure for Mode B

- The downstream frame is divided into a contiguous sequence of physical slots, where each slot corresponds to 4 symbols (same as revised E+ proposal)

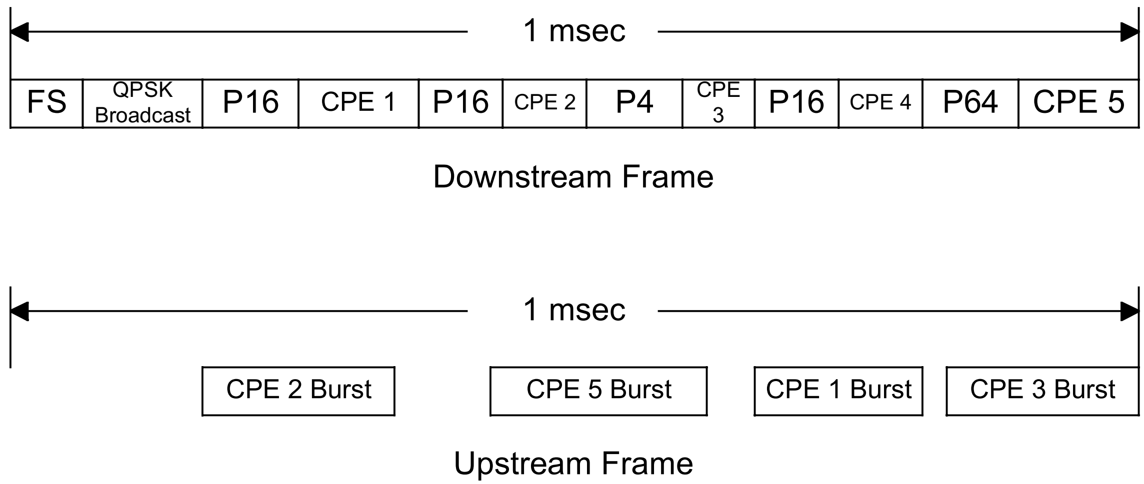


Physical slots

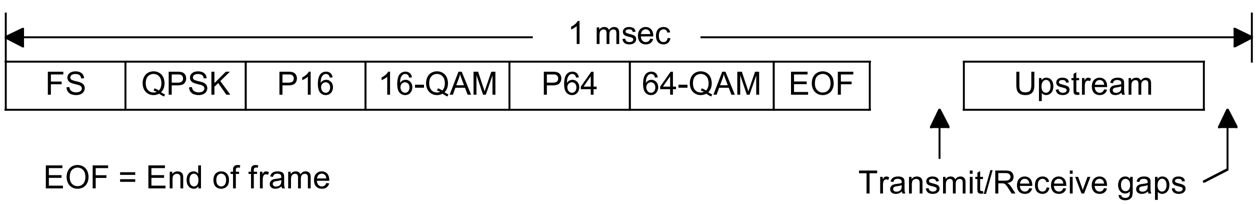
- An integer number of physical slots should exist within the frame to allow for continuous modulation (same as revised E+ proposal).
- 4 symbols per physical slots is one byte for QPSK symbols, two bytes for 16-QAM, and three bytes for 64-QAM
- Places simple constraints on codeword lengths.

Framing Options for Mode B

Framing options and support for other duplexing techniques



H-FDD Frame (or FSDD)



TDD Frame

Preamble Requirements for Mode B

- For FDD and TDD, we assume the modulation formats go from lowest to highest order modulation in the frame (QPSK to 16-QAM to 64-QAM).
  - Allows for coherent detection of preamble within frame.
- For H-FDD, preambles assumed to use non-coherent detection.
- Target BER = 10e-10
- Design P_{md}=10e-11 and P_{fa}=10e-12 for coherent detection.
- Design P_{md}=10e-11 and P_{fa}=10e-14 for non-coherent detection.

Preamble	**Recommended Length**
FS (FDD,TDD,H-FDD)	24 symbols
P16 (FDD,TDD)	32 symbols
P64 (FDD,TDD)	32 symbols
EOF (TDD)	32 symbols
P4 (H-FDD)	60 symbols
P16 (H-FDD)	60 symbols
P64 (H-FDD)	60 symbols

Comparison Between Mode B and E+ Method

The following comparisons include all preambles and any DS map overhead.

	E+ Burst Mode	Mode B
FDD overhead with QPSK and 16-QAM only and coherent detection of preamble	48 symbols (0.24% of frame)	56 symbols (0.28% of frame)
FDD overhead with QPSK,16-QAM, and 64-QAM and coherent detection of preamble	48 symbols (0.24% of frame)	88 symbols (0.44% of frame)
TDD overhead with QPSK and 16-QAM only and coherent detection of preamble	48 symbols (0.24% of frame)	88 symbols (0.44% of frame)
TDD overhead with QPSK,16-QAM, and 64-QAM and coherent detection of preamble	48 symbols (0.24% of frame)	120 symbols (0.60% of frame)
H-FDD with 10 subscribers per 1 msec frame, which assumes non-coherent detection of the preamble	292 symbols (1.46% of frame)	624 symbol (3.12% of frame)

PHY control word may be more appropriate for H-FDD systems, assuming proper error control is applied to the control word.

Methods for Improving PHY Control Word Approach

The following changes could be considered for improving the performance of a system using a PHY control word (could be relevant for H-FDD systems or improving the Mode B definition in the merged proposal submitted by Jay Klein):

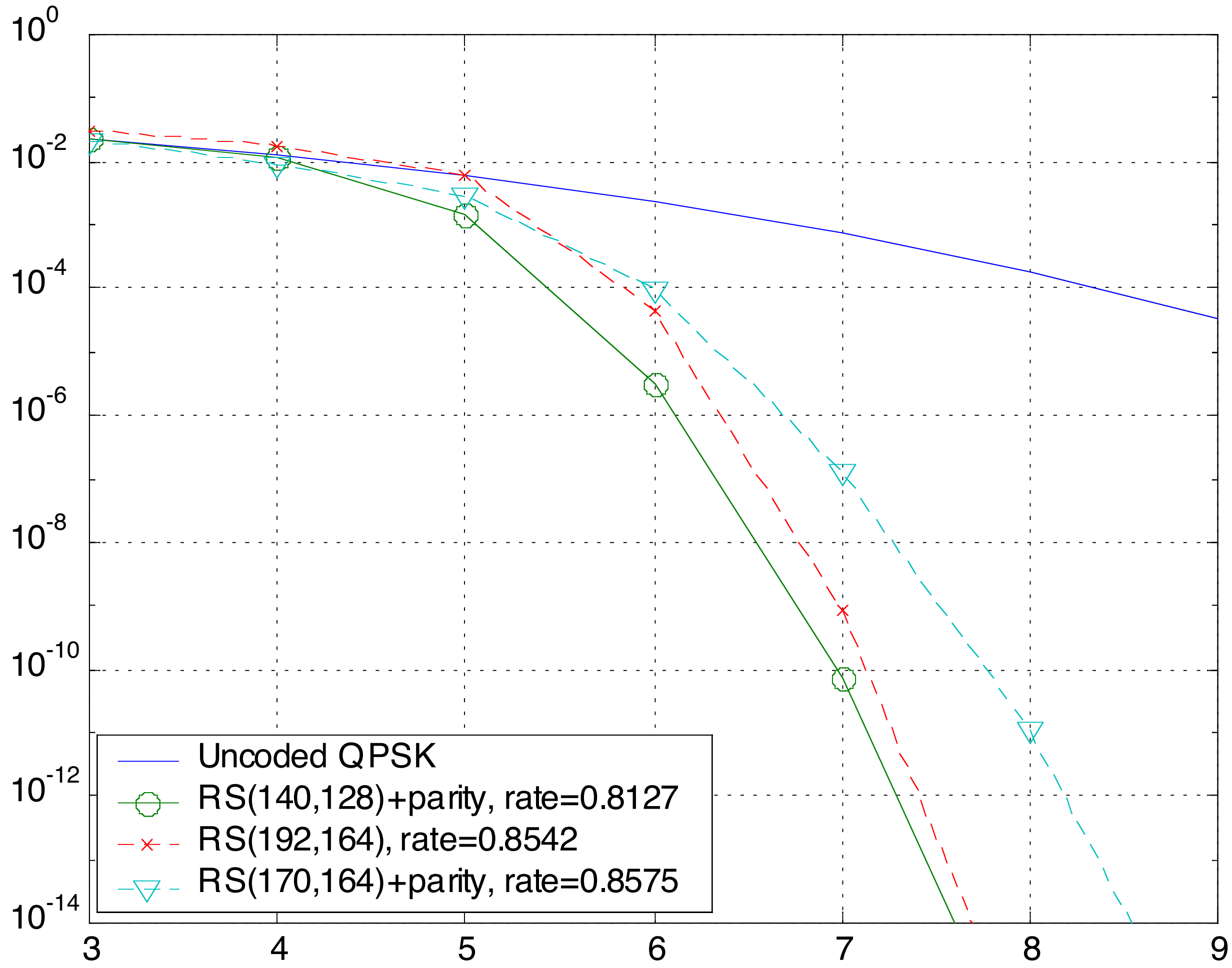
•**Decoding delay for PHY control message**: Ensuring a minimum number of QPSK symbols following the Frame Start preamble or at least a bound on acceptable delay will ensure the decoder processes the first codeword in time to determine the modulation boundaries.

•**Protection of the PHY control message**: The first codeword should have at least a BER of 10e-12 for an overall BER of 10e-10 for H-FDD systems (minimal or no change required for FDD or TDD, assuming the receiver properly handles the errored PHY control message). If the minimum desired C/I is 9 dB (theory), then a possible code rate of (78,64)+parity code may be sufficient.

Coding Considerations for DS Burst Mode B

- Code is constrained to be compatible with burst format.
- Possible coding methods:
  - Reed-Solomon only
  - Reed-Solomon + parity
  - Reed-Solomon + convolutional code (with tail biting)
  - Turbo code (convolutional or block)
- For simplicity in a burst mode, we chose to focus mainly on the first two options. The last option is studied in further detail in other submissions.
- Further discussion regarding FEC options should continue to take place after the draft standard is selected to ensure all requirements are met and the "best" method is supported in the standard.

Coding Considerations for DS Burst Mode B



Coding Considerations for DS Burst Mode B

Conclusions regarding coding choice:

- No inherent performance benefit from using Reed-Solomon + parity bit (for long codewords, which are appropriate for TDM)
  - only potential benefit is reduced complexity for RS decoder
- Chose RS(192,164) since it has a slightly higher code rate, it has better burst error protection than RS(140,128)+parity, and it easily fits into an integer number of physical slots (192 is divisible by 2 and 3).
- Other coding options and desired code rates should be considered based upon further discussion.
- Should also consider further the complexity comparison of different codes and their performance in channels with phase noise, multipath, and PA non-linearities (especially for higher order modulations) for final code choice.

Summary of Mode B DS PMD Sublayer

Summary of Mode B downstream PHY:

Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000 on a burst-by-burst basis
Reed-Solomon Coding	(192,164) based on GF(256) with T=14 byte error correction capability
Preamble insertion	On a burst and modulation change basis
Modulation	QPSK, 16-QAM, or (64-QAM)
Spectral shaping	α=0.15 or 0.35
Spectral inversion	inverted or non-inverted

Comparisons between Mode A and B DS PHYs

	Mode A	Mode B
Convergence sublayer	Single pointer byte	Single pointer byte
Preambles	Synch. byte per codeword	Preamble per burst and per modulation change
Outer code	RS(204,188) based on GF(256)	RS(192,164) based on GF(256)
Interleaver	I=12 convolutional	None
Inner code	Convolutional rate ?-1 (disabled)	None
Shaping	RRC with α=0.15 or 0.35	RRC with α=0.15 or 0.35
Modulation	QPSK, (8-PSK), (16-QAM), or (64-QAM)	QPSK, 16-QAM, or (64-QAM)
Shortened last codeword	No (not necessary in FDD implementation with TDM)	Yes
Modulation level support	Can support load balancing and higher order modulation on separate carriers.	Can support different modulations on a single carrier.

Upstream PMD sublayer

Summary of Upstream parameters

Reed-Solomon Coding over 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)
Differential encoding	Selectable on/off
Spectral shaping	α=0.15, 0.25, 0.35

Upstream PMD Sublayer (cont.)

Justification for flexible parameters:

- Different deployment scenarios may have different requirements. For example:
  - Different ratios of DS BW: US BW have different coding requirements for DS and US (4:1 and 2:1 are most common)
  - Sector may be DS limited if higher order modulations are used, which suggests little coding would be required on US
  - Could target coding performance to specific services to improve efficiency.
- Upstream channel and burst characteristics can be easily configured with MAC messages.
- Very little additional cost to support flexibility.

Comparison Between Static and Dynamic Mod.

Example comparison between a system using static modulation vs. a system designed to support dynamic modulation:

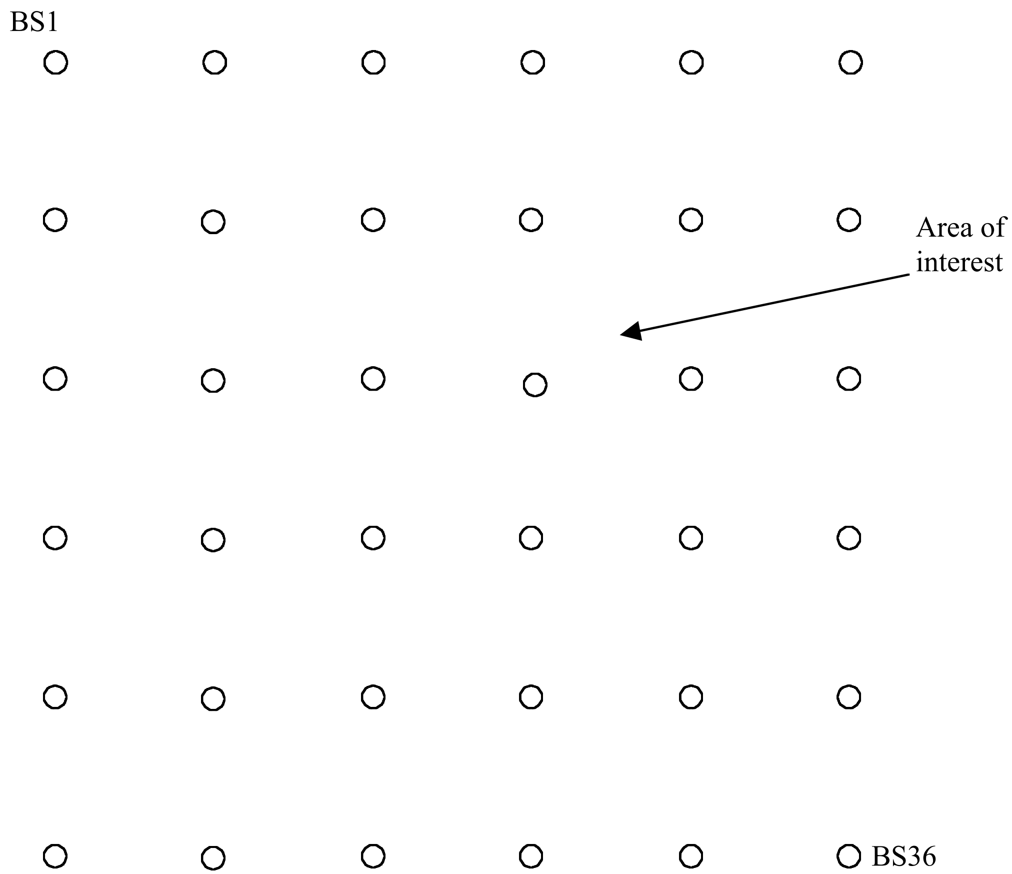
- Simulations were performed using Telcordia's RF Planning Software: Winplan, to study the distribution of C/I within a sector
- Adjacent sectors are orthogonally polarized using a frequency re-use of 83% per sector (get similar results if adjacent sectors are co-polarized with a frequency re-use of 42%).
- Simulation includes interference from 7 x radii distances.
- Users are uniformly distributed in the cell (for comparison purposes).
- Carrier BW = 1.25 x Rs = 14 MHz (for comparison purposes).
- Based on distribution of C/I within a sector, % of population that could support QPSK and 16-QAM were determined.
- For fairness, spectrum assigned to QPSK and 16-QAM was chosen to make bps/(km)^2 for QPSK users >= that for 16-QAM users.

Comparison Between Static and Dynamic Mod.

- The following codes were chosen for the simulation:
  - [1] Reed-Solomon (204,188) + rate 7/8 convolutional code (Mode A)
  - [2] Reed-Solomon (140,128) + parity check code (E+ proposal)
- Different carriers are used to support different modulations with [1]. It is assumed a large number of carriers are available to efficiently allocate the spectrum between QPSK and 16-QAM.
- A roll-off factor of 0.25 was assumed.
- Cell sizes were determine by 99.99% availability for QPSK users.
- QPSK and 16-QAM were allowed to transmit at different power levels.

Code	**Modulation**	**Min. C/I requirements**	**Implementation loss**	**Actual C/I reqs.**	**Spectral Efficiency (bps/Hz)**	**Cell radius**
[1] Reed-Solomon (204,188) + rate 7/8 convolutional code	QPSK/ 16-QAM	7.7 dB / 13.7 dB	1 dB/ 2 dB	8.7 dB / 15.7 dB	1.29 / 2.58	4.3 km
[2] Reed-Solomon (140,128) + parity check code	QPSK/ 16-QAM	9 dB / 16 dB	1 dB/ 2 dB	10 dB / 18 dB	1.30 / 2.60	4.1 km

Comparison Between Static and Dynamic Mod.



Comparison Between Static and Dynamic Mod.

Code	Modulation	% spectrum allocated to QPSK	% spectrum allocated to 16-QAM	Overall sector capacity (bps/Hz)	Delta sector capacity	Delta # of base stations to cover 1000 km^2	
[1] in Rain	QPSK only	100 %	0 %	1.29	0 %	0 %	**Nominal**
[1] in Rain	QPSK/16-QAM	23 %	77 %	2.28	+ 77 %	0 %	
[2] in Rain	QPSK/16-QAM	29 %	71 %	2.22	+72 %	+10 %	
[2] in Clear Air	QPSK/16-QAM	4 %	96 %	2.55	+97.5 %	+10 %	

- Significant capacity improvements can be achieved with static modulation (Mode A).
- Little difference in capacity for [1] and [2] in Rain when a large number of carriers can be used to properly allocate QPSK and 16-QAM percentages.
- Capacity difference in Rain vs. Clear Air < 15 %. Note that clear air capacity will not be achieved 100% of the time due to time variability of rainfall
- For a multi-cellular deployment, when a large number of carriers per sector is not available, adaptive modulation may result in greater capacity since QPSK and 16-QAM could be allocated with a finer granularity.
- 64-QAM could improve capacity further for all systems, but results in approximately a 40% increase in CPE radio cost due to linearity and phase noise requirements.

Comparison Between Static and Dynamic Mod.

When is the continuous mode of operation appropriate:

- Large amount of spectrum is available to support multiple carriers per sector and fixed higher order modulation is desired with a guaranteed availability.
- Cells are widely separated so that range is a primary consideration while capacity in bps/Hz is secondary.
- Service provider wants the robustness and low cost associated with QPSK modulation, while improved capacity with higher order modulation is secondary.
- Cost and service model favors static provisioning of modulation order with larger cell sizes and fewer base stations per service area.

When is the burst mode of operation appropriate:

- If a small amount of spectrum is available which limits the number of carriers per sector and higher order modulation is desired.
- Cost and service model favors dynamic provisioning of modulation order to take advantage of rain fade margin.
- To support H-FDD or TDD systems.

Key Differences between D+ and E+ proposals

Not including the DS burst mode architectures, the following key differences still exist between the 2 proposals:

•**Support for CQPSK (or TFM):** It's our opinion that the power savings of constant envelope modulation does not justify the loss of bandwidth efficiency (ETSI has chosen not to pursue TFM as an option for US modulation).

•**Support for ARQ:** No justification for its benefits (as of yet) has been shown for the support of ARQ. FEC techniques are typically the best solution to combat errors due to AWGN, and the slow fading environments seen in BWA systems does not seem to favor ARQ methods, which may be more appropriate for channels with fast fading and/or impulse noise.

•**Roll-off factor of 0.25**: Additional flexibility of having selectable roll-off factors of 0.15 and 0.35 allows for greater power/bandwidth efficiency trade-offs than a fixed factor of 0.25 with little cost impact.

We feel that these issues need to be addressed before potentially including them in a final merged proposal, as proposed by Jay Klein.

Conclusions

- Adopting a draft standard that supports 2 downstream PHY modes should be beneficial to the industry in meeting a diverse set of system requirements and deployment scenarios.
- The main benefits of supporting the Mode A in the standard:
  - Low risk, proven method for supporting BWA systems.
  - Allows vendors to consider capacity, cost of deployments, and time-to-market with standardized equipment.
- Finally, in the interests of moving forward, we would support a merged proposal, as proposed by Jay Klein or a modified version of it, following further discussions of the key differences between our proposals presented on the previous slide (TFM vs. QPSK, ARQ, Roll-off factors). Other items, such as FEC, codeword lengths, symbol rates, etc., can be addressed individually, after further analysis and discussion, once a draft is chosen.