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PHY Layer Proposal for BWA

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Jay Klein, Lars Lindh, Carl Eklund, Petri Bergholm, Naftali Chayat

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Venue:

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Purpose:

This proposal should be used as a baseline for a PHY standard for BWA

Notice:

Release:

IEEE Patent Policy:

PHY Layer Basis for BWA

Jay Klein – Lars Lindh – Carl Eklund
Petri Bergholm – Naftali Chayat – Paolo Baldo

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Issues Covered

- Proposal History
- Spectrum and Channel BW Considerations
- Modulation & Adaptive Modulation
- Multiple Access Schemes
- Framing & Slot Structure
- FEC and PHY/TC interaction

Contributors & Supporters

- Based on proposals sumitted by **Klein** (Ensemble) and **Lindh** (Nokia) from Session #4 (Kauai, 11/99)
- **Chayat** (BreezeCOM) supports for LMDS type systems
- **Aldo** (Siemens) joins for Session #6

Revision History

- **Session #5 Joint proposal**:
  - Identifies “burst” operation as the preferred mode for both TDD and FDD (HDX)
  - Resolves major FDD (HDX) issues
  - Emphasizes the need for a constant envelope uplink modulation scheme to cost reduce ODU
  - Identifies subscriber based adaptive modulation
  - Introduction of variable length coding (RS, PC)
  - ETSI/BRAN Harmonization
- **Session #6**:
  - 2 Uplink (terminal) modes: High capacity (QAM multi-level) and Reduced cost (CQPSK)

Spectrum Considerations

- Preferred frequency allocations are millimeter wave bands (above 10 GHz)
  - Suitable for large block allocations
  - Line of Sight (LOS) required
- PMP, Cellular-like architecture
  - Small cells due to limited power of PA and susceptibility to rain attenuation
- Architecture enables large channel BW
  - Directional antennas @CPE, Sector antennas @BS
    - *Low delay spread*
    - *Equalization effort minimal even for burst communication (uplink or downlink)*

Channel BW considerations

- Europe ***traditionally*** follows:
  - 7, 14, 28, … MHz
- North America ***usually*** follows:
  - 10, 20 or 40 MHz or 25 or 50 MHz
  - MWS in Europe (~40 GHz) might be allocated by variable size blocks
- Larger BW = Better statistical gain
  - Increasing the “pool size” by a factor F1, increases the number of users by a factor of F2>F1
- PHY and MAC implementation considerations impose an upper limit (Max. Baud Rate ≈50M)
- Functional Requirements of 802.16 guideline the minimum

Bandwidth & Baud Rates

Baud Rate (MB)	US Channel (MHz)	Minimum ETSI Channel BW (MHz)
16	20	-
20	25	28
32	40	-
40	50	56

- Only a ***few options*** needed
- Root Raised Cosine with roll off of 0.25 assumed. For the ETSI case either higher roll off factors or higher baud rates could be achieved
- The exact BW to be used depends on frequency. For LMDS Block A, 25 MHz is the preferred option

Recommended BW

- Analyze the worst case scenario
  - QPSK like
  - Efficiency (i.e., Coding rate 0.75 typical)
  - Near zero uplink OR near zero downlink bandwidth allocated (For example, ETSI requires capabilities of 25 Mbps (up+down) peak rates)
- 25/1.5/0.75 ≈ 20 MBaud
- 25 MHz seems to be a good choice
- 28 MHz chosen by ETSI/BRAN HA

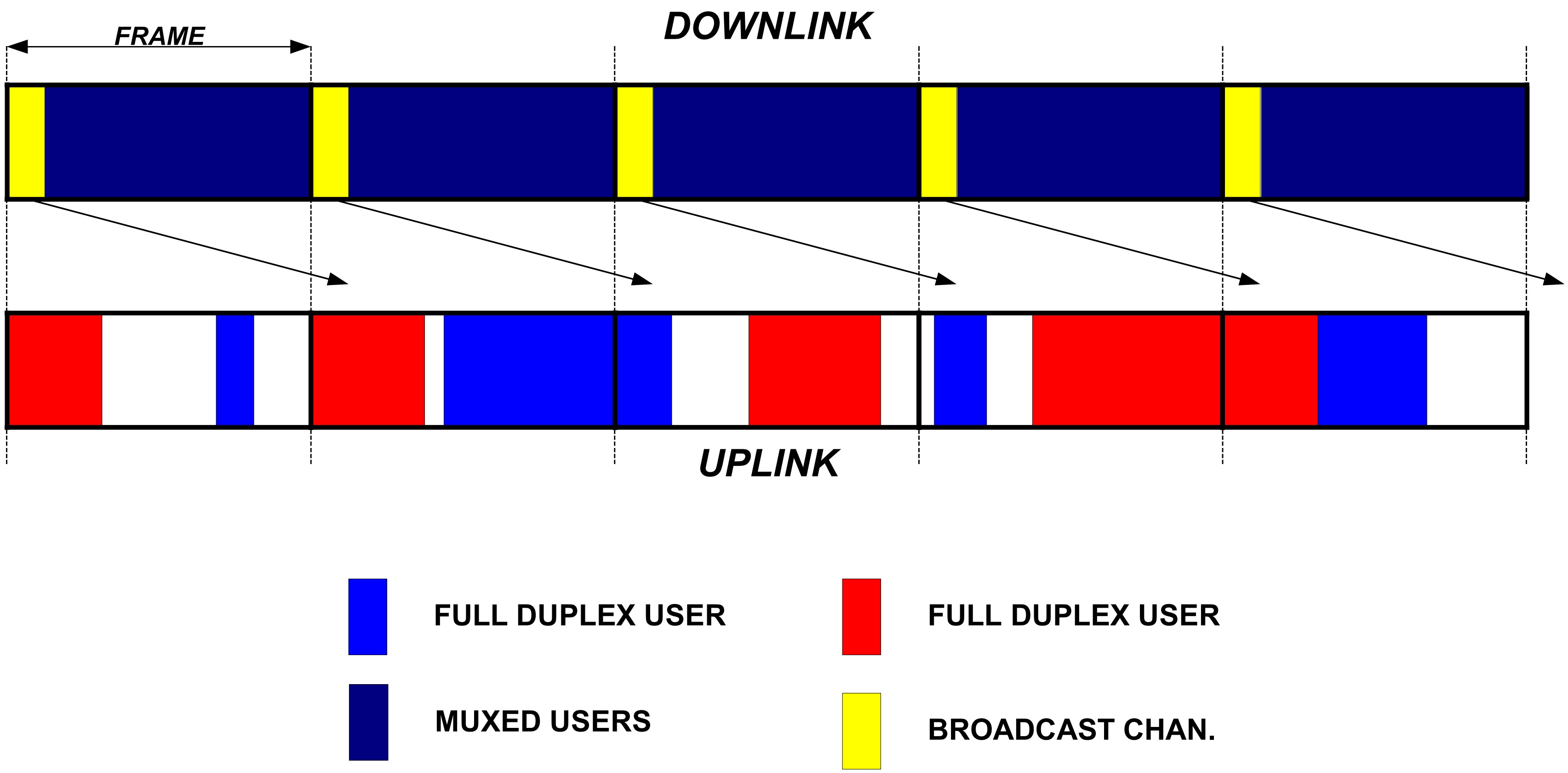
Roll Off Factor (ROF)

- Small ROFs increase spectrum efficiency but RF cost becomes more expensive
  - PA back-off requirements
- There is a need to compromise:
  - ROF↓,Rate ↑ & PA Power ↓ ,Cell size ↓,Capacity/per user ↑, #equipment/cell ↓ & # of cells ↑
  - ROF ↑,Rate ↓ & PA Power ↑ ,Cell size ↑,Capacity/per user ↓, #equipment/cell ↑ & # of cells ↓
  - Base station cost structure = Site cost + Equipment cost
- Only a few ROFs should be supported due to implementation
- **0.25** is a **good trade-off** between power loss and capacity
  - 0.35 is 1 dB better in terms of power, 8% less capacity
  - 0.15 is 1 dB worse in terms of power, 8% better capacity

What is Half Duplex FDD ?

- **Traditionally in FDD the downlink is a continuous waveform**
  – Continuous TDM stream, all data from users multiplexed
  – Terminal demodulator+Base station modulator are CW based
  – Terminal must demodulate downlink completely and retrieve by addressing means its data
- **The FDD TDMA uplink is burst**
  – Terminal modulator + Base station demodulator are burst based

FDD (TDM/TDMA)


FRAME
DOWNLINK
UPLINK
FULL DUPLEX USER
FULL DUPLEX USER
MUXED USERS
BROADCAST CHAN.

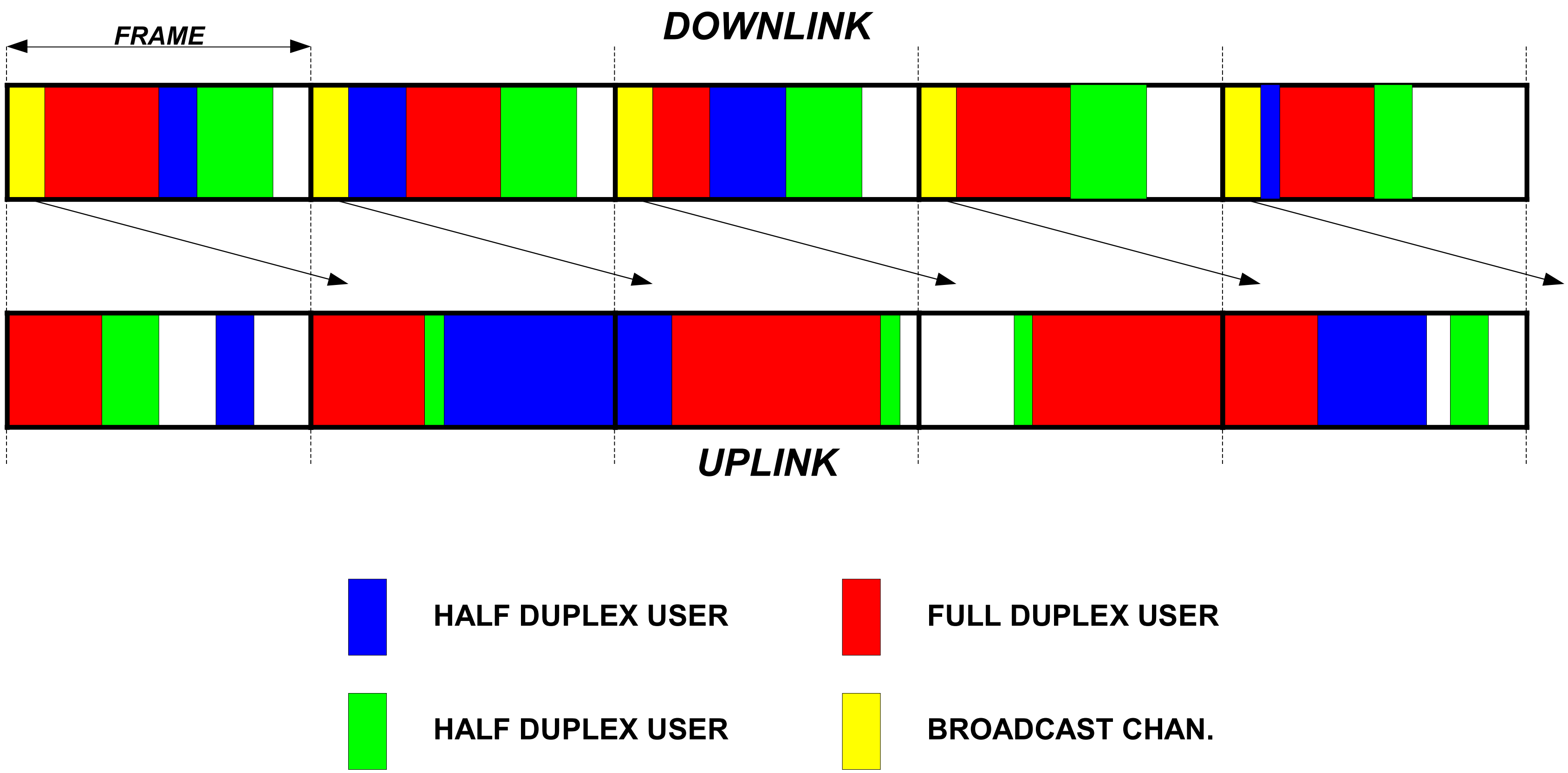
What is Half Duplex FDD ? – *cont.*

- **If the TDM stream is arranged user after user, all user information gathered together within the same frame then…**
  - The downlink remains continuous, full duplex
  - Terminal is pointed out to the exact time location of its downlink data
  - No need for the terminal to demodulate completely the full downlink stream
  - The terminal receiver may be turned off when no demodulation occurs
  - The terminal may transmit at these instances with no desensitization

Hence…

The terminal is effectively HDX while the Base station is FDX

FDD with HDX support (TDMA²)

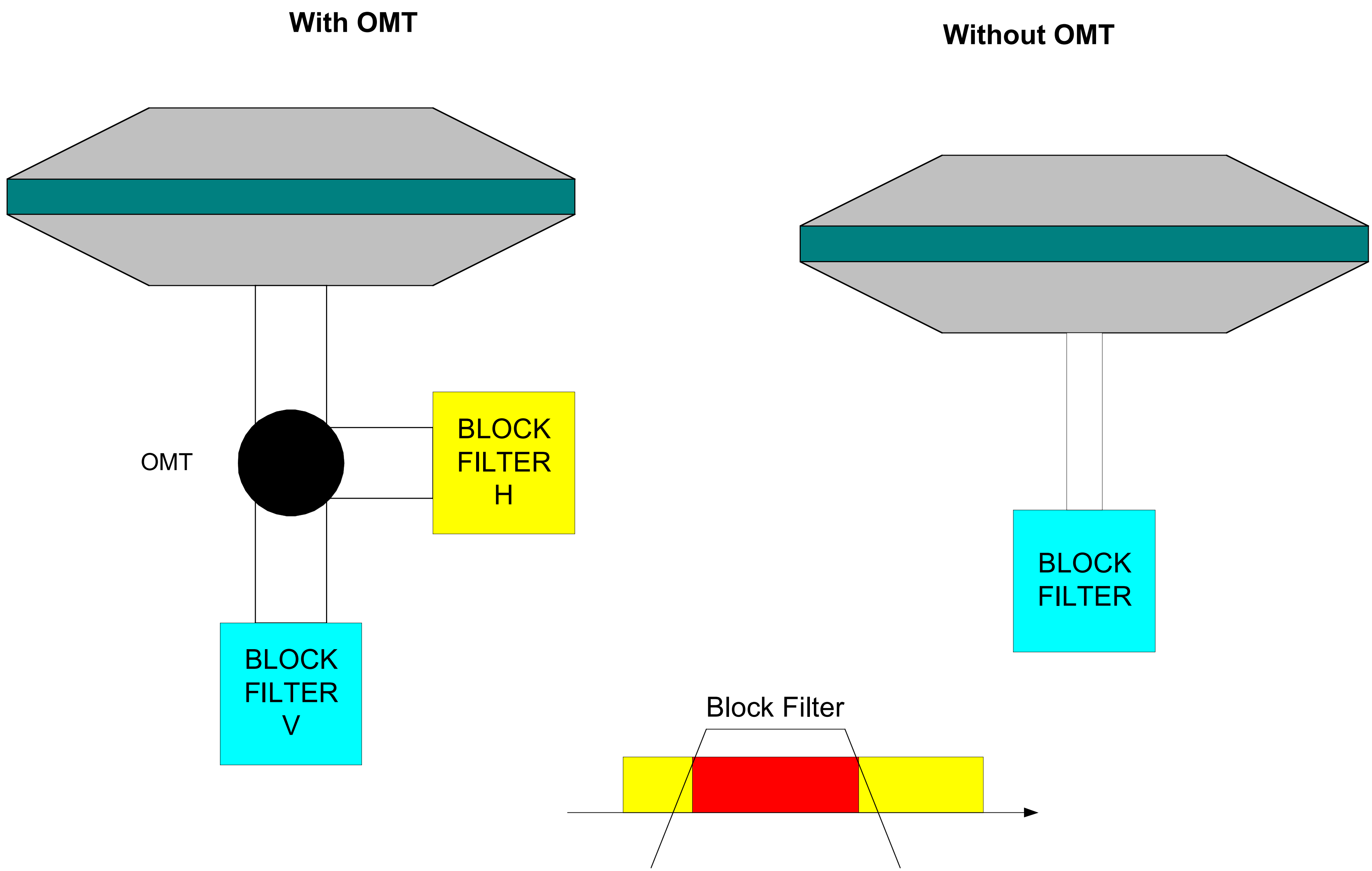


Duplex Scheme Variants Support

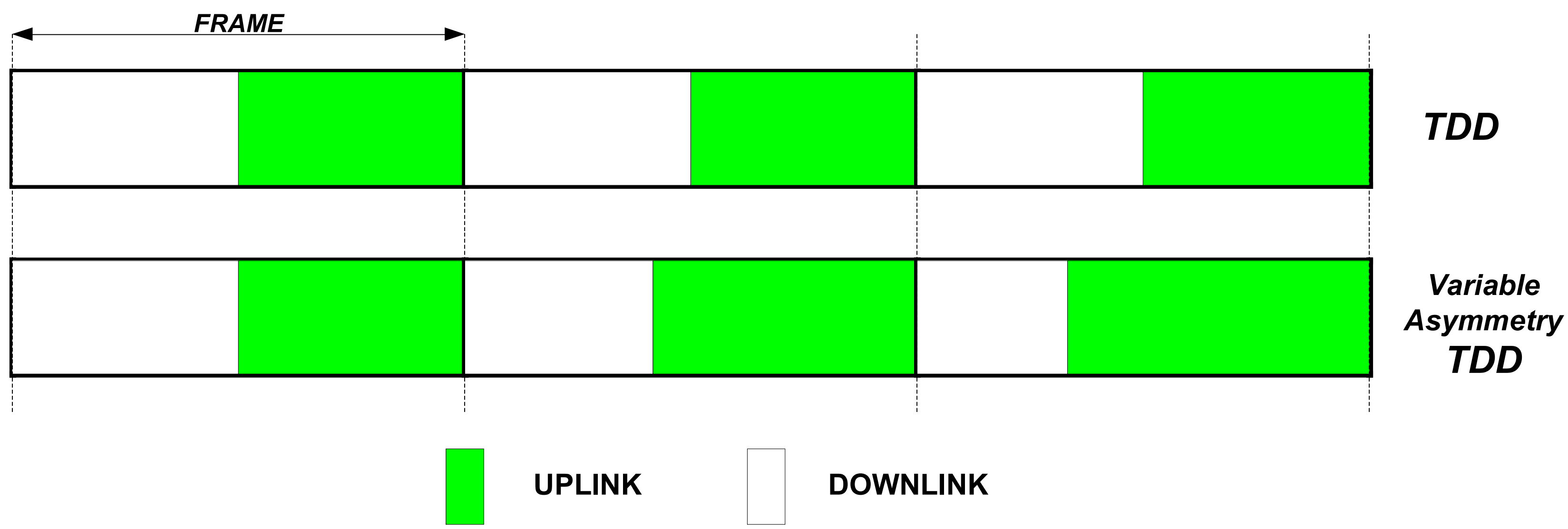
- FDD
  - HDX - Terminal may not transmit & receive instantaneously
  - Reduced cost CPE, RF cost issues are resolved by MAC
  - Must be supported according to ETSI-BRAN HA
  - Recognized as the most effective way to cost reduce the radio similar to PCS/Cellular handsets or WLL terminals
- TDD
  - Traditional or with Variable Asymmetry Support
  - Downlink & Uplink occupy the same channel BW
    - Mainly due to business users which require similar peak rates in either direction

Why H/FDD ?

- The only other alternative is a dual polarized approach
  - OMT, different polarizations for Rx/Tx
- Potentially higher cost
  - OMT requires twice the millimeter wave Front-End spectrum block filters (one for Rx and one for Tx)
  - At the base station, the antenna infra-structure doubles as commercially available sector antenna are single polarized
    - Roof top or pole-space problem for a high capacity system
    - Availability of high performance dual polarized sector antennas is a problem
  - OMT is more expensive than a switch and cannot alone supply the isolation requirements of a FDD terminal
    - Could be limited to QPSK only if designed incorrectly


With OMT
Without OMT
OMT
BLOCK
FILTER
H
BLOCK
FILTER
V
BLOCK
FILTER
Block Filter

TDD (TDM/TDMA)



Modulation

- **Subscriber Level Adaptive Modulation (SLAM)**
  - Supported modulation levels:
    QPSK, QAM-16 and QAM-64
      For downlink and high capacity terminal
    CQPSK (TFM)
      For reduced cost terminal
  - Each channel can adapt its modulation independently for each user per burst
  - uplink modulation may differ from downlink per user as it is influenced by C/(N+I) and not C/N
- **SLAM** is more efficient than traditional CLAM
  - Example - Channel set to QAM-64, users which can support QAM-4 can not use channel even if under utilized
- **SLAM** fine tunes RF planning in a “real time” fashion
  - LMDS like frequencies have slow fade characteristics which enable modulation tracking
- **SLAM** concept adopted by ETSI/BRAN HA
- **SLAM** concept allows simple future upgrades

Adaptive Modulation & Frequency Re-use

- Frequency re-use (FR) defines how many times the available spectrum is used per cell site
  - **Aggressive** re-use is defined for **FR>0.5**
- **What is the highest FR achievable?**
  - Answer: **FR=2** (at most, see next slides)
  - Reason:

    For FR=4 the interference scenario is at least 4.4 dB worse than FR=2 due to cell orientation (4 sector), Stronger FEC required

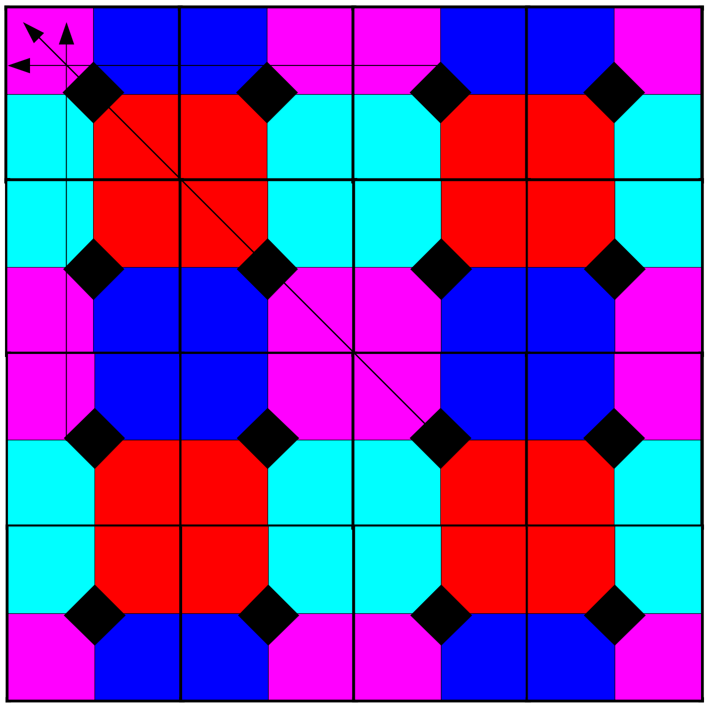
    This is achievable by reducing the coding rate (throughput) from 70%-80% to 35%-40%

    If throughput was reduced by a factor of 2 then this cancels the FR increase completely

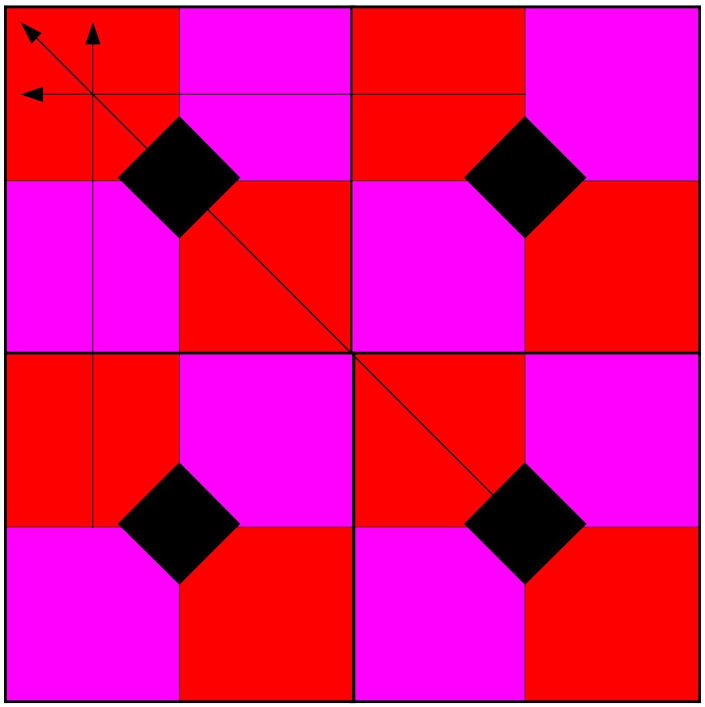
    Furthermore – FR=4 is **impractical** as it requires to double the hub radios and increases susceptibility of deployment to uncorrelated rain fades

FR=2,4 Analysis

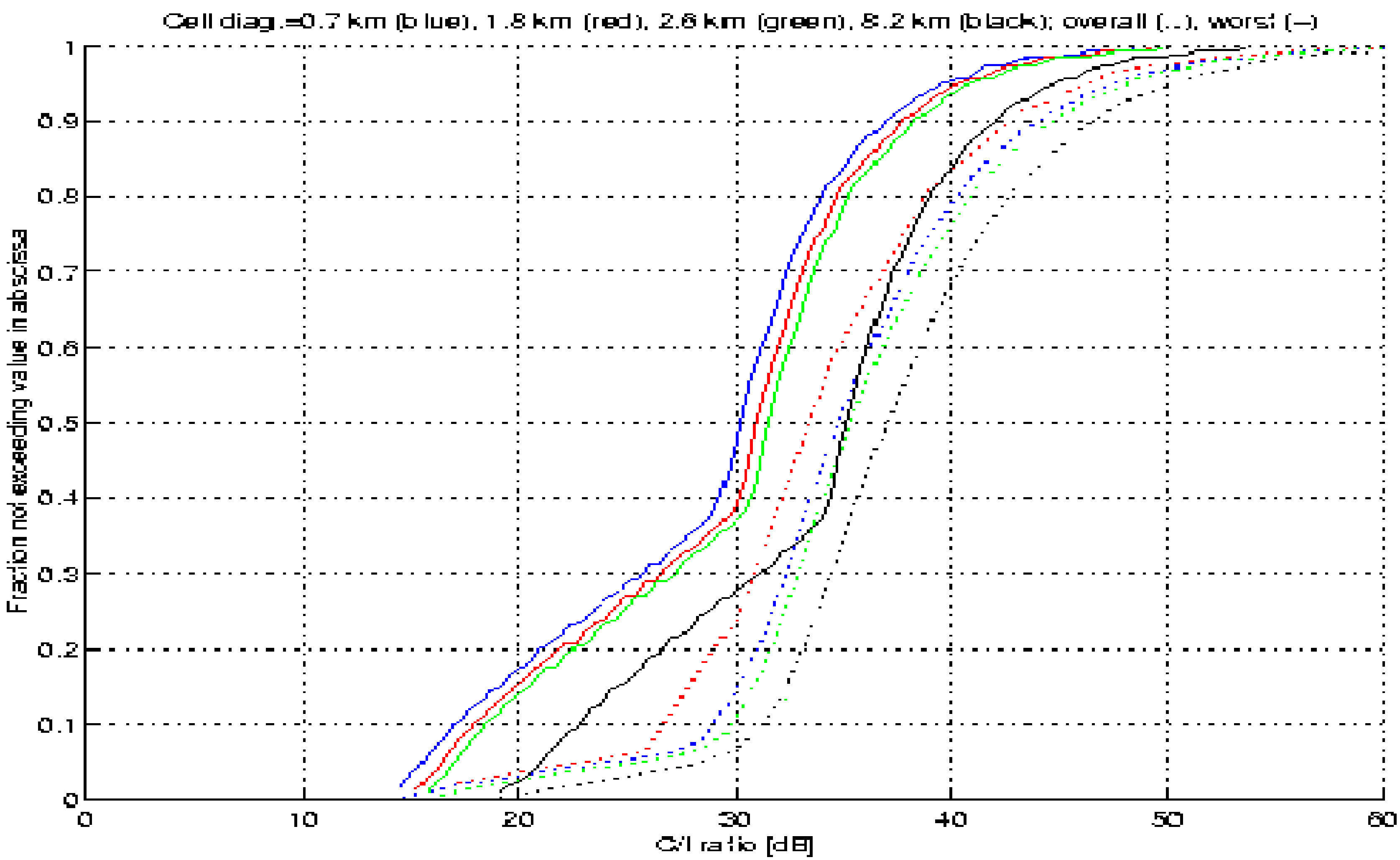
FR=2



FR=4



FR=2 Downlink (Source: ERICSSON ETSI/BRAN)



FR=2 Uplink

- For the ***worst case*** where LOS conditions exist for all interfering terminals, QPSK (or CQPSK) would be used as the interference is bursty and unpredictable
- For more ***practical*** scenarios it can be shown that depending on the LOS conditions of interferers the uplink modulation level could be increased and packet loss rate would be decreased
- Combined with services which would allow **ARQ**, lost packets are replaced with re-transmistted ones and the modulation level could be easily increase with no QoS degradation

Multiplexing & Multiple Access

- Downlink - TDM or TDMA, uplink - TDMA
- In TDM all users are multiplexed into a single stream
  - Stream per modulation, User demodulates the whole stream
  - Preferred approach for TDD
- In TDMA, dedicated burst per user
  - Scheduled based access (i.e., user data)
  - Contention based access – uplink only (i.e., registration)
  - Shorter preambles for the downlink case
  - TDMA/downlink is the preferred approach for H-FDD
    - Similar concept in ETSI/BRAN HL/2
- FDD and H-FDD concurrent support
  - Limitations of CPE are recognized in registration

Frames

- Downlink and Uplink are frame synchronized
- Frame length is 1 mSec for both Downlink and Uplink
  - 1 mSec is small enough to minimize PHY latency
  - 1 mSec is big enough to justify PHY overhead
- In the case of TDD the frame length remains 1 mSec and is sub divided into a Downlink portion and a Uplink portion

Reducing Power Amplifier Requirements

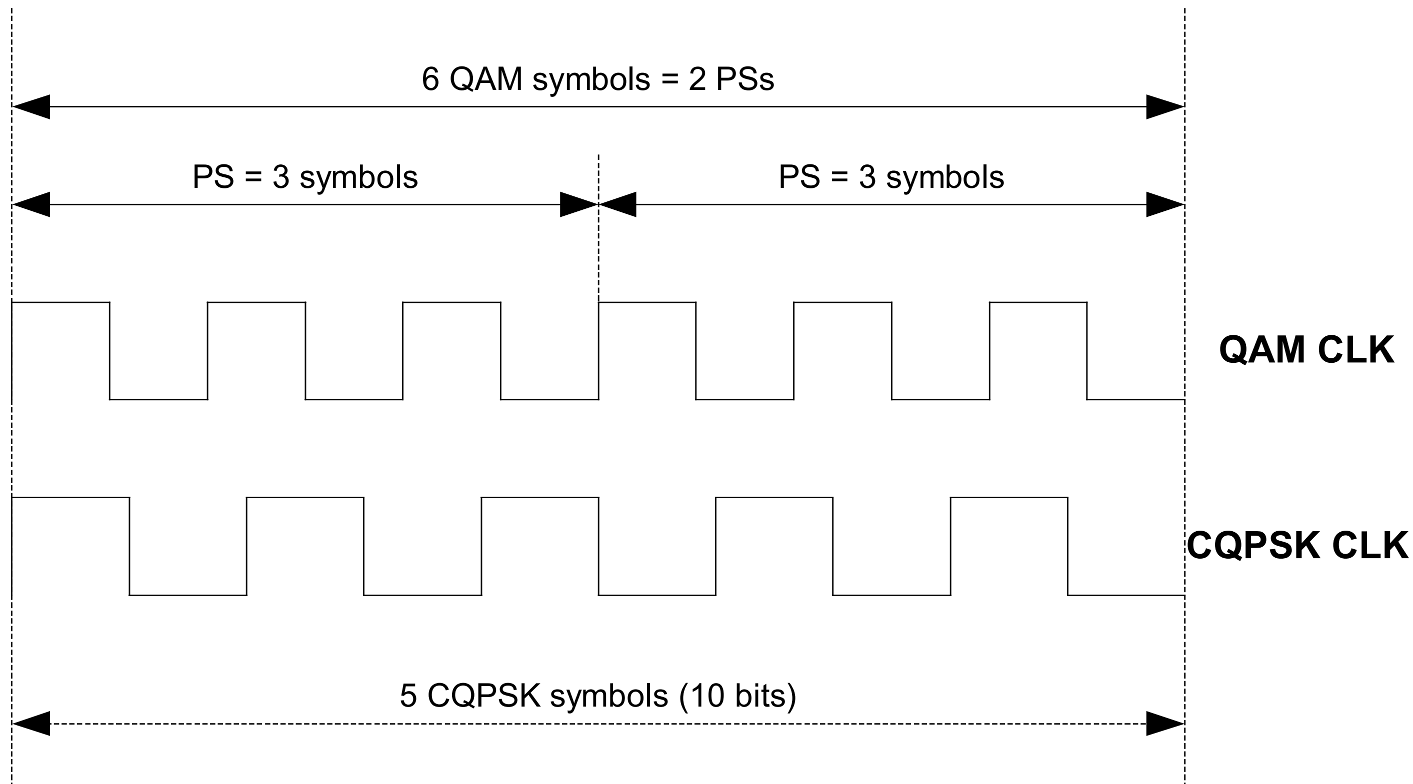
- The PA is the main cost driver of the ODU
  - Linear PAs are DC inefficient
- CEM - Constant Envelope Modulation
  - TFM (Tamed FM) or CQPSK (Constant Envelope QPSK)
    - Similar performance as QPSK with ROF=0.5
  - Practically multi-level options are inefficient
  - π/4-QPSK & OQPSK have no linearity advantage for ROF<0.5
  - CEM multi-level options are inefficient and implementation is complex
- For the CPE it will be advantageous to choose the lowest order modulation scheme as CEM
  - Low cost CPEs use CEM with either H/FDD or TDD
  - Regular CPEs support higher order modulation options and operate full duplex where applicable

Supporting different Baud Rates

- For the same channel BW, regular QAM could pack a higher baud rate signal than CQPSK
- For simplified implementation integer ratio between the QAM baud rate and the CQPSK baud rate is required
- Recommended ratios:
  - 5/6 for ROF=0.25, 4/5 for ROF=0.2
  - 33 1/3 Mbps in a 25 MHz channel
  - QAM rate is 20 MS/s (ROF=0.25)

Physical Slot Concept

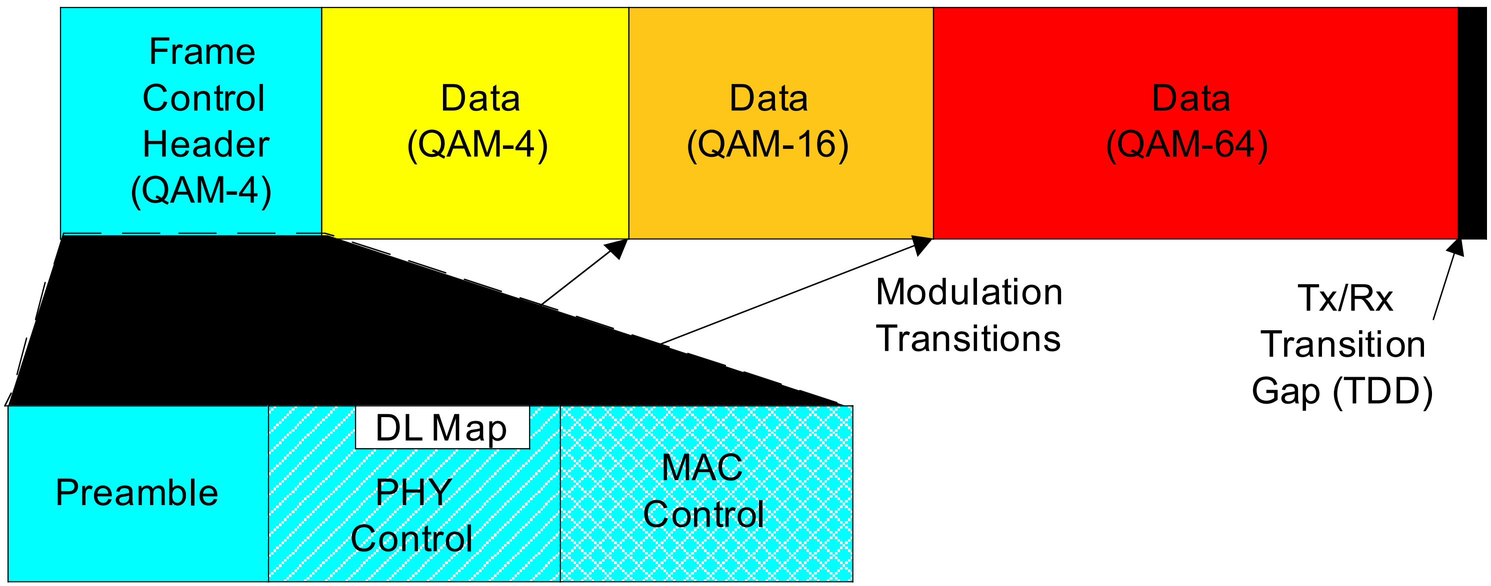
- Basic **Time** Unit for Allocation **and** Management
- Size respects recommended ratio for QAM/CQPSK



Preambles & Guard Intervals

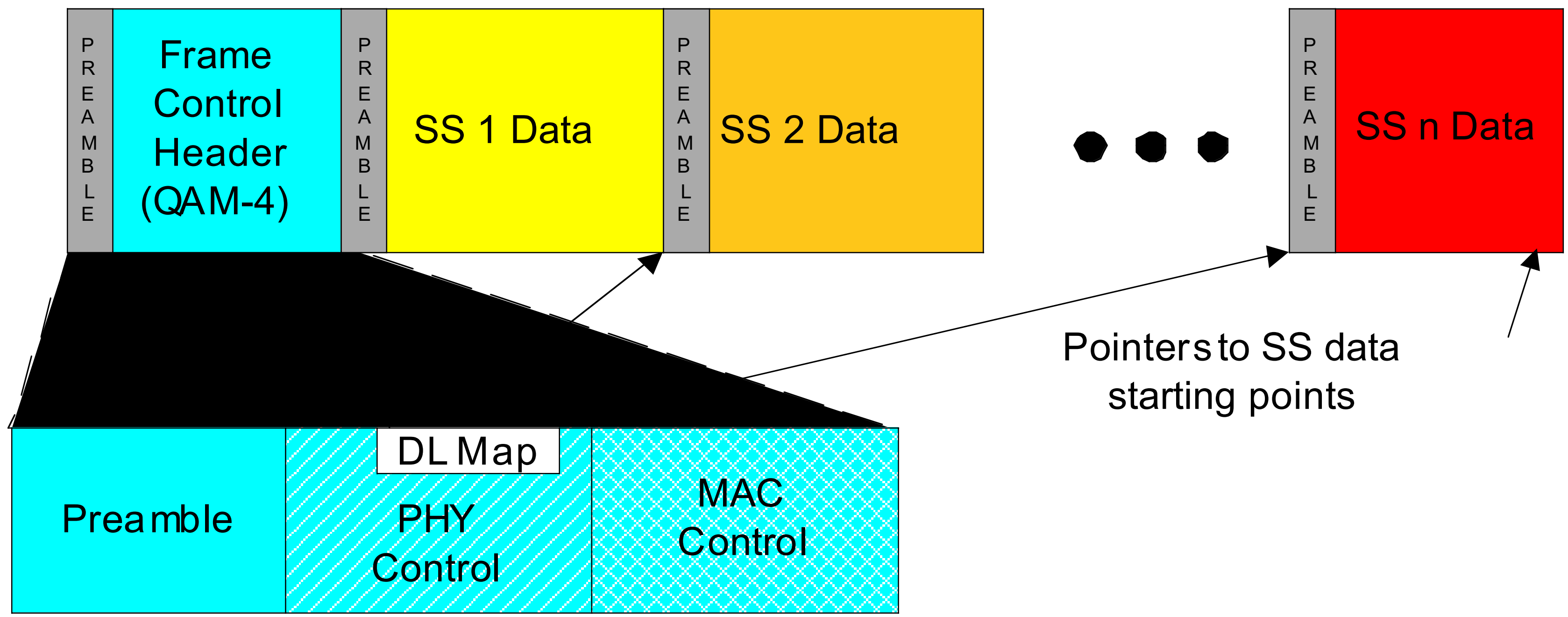
- Preamble per burst required for TDMA
  - Preambles occupy an integer number of PSs
- For Downlink frame start a preamble assists CPEs to frame synchronize and various parameters
  - Recommended: 8 PSs (24 QAM symbols)
- For Downlink/TDMA, preamble can be short (phase reference re-evaluation) as the preamble of the frame start did most of the job
  - Recommended: 4 PSs (12 QAM symbols)
- For Uplink/TDMA, required preamble is longer
  - Recommended: 8 PSs (20 CQPSK bits or 24 QAM symbols)
- Guard Interval is required for the TDMA uplink bursts
  - Integer number of PSs (8 recommended), Overlap ramp-up and ramp-down to minimize overhead
- TDD requires guard time between downlink and uplink
- MAC scheduler issues

Downlink Sub-frame (TDM case)

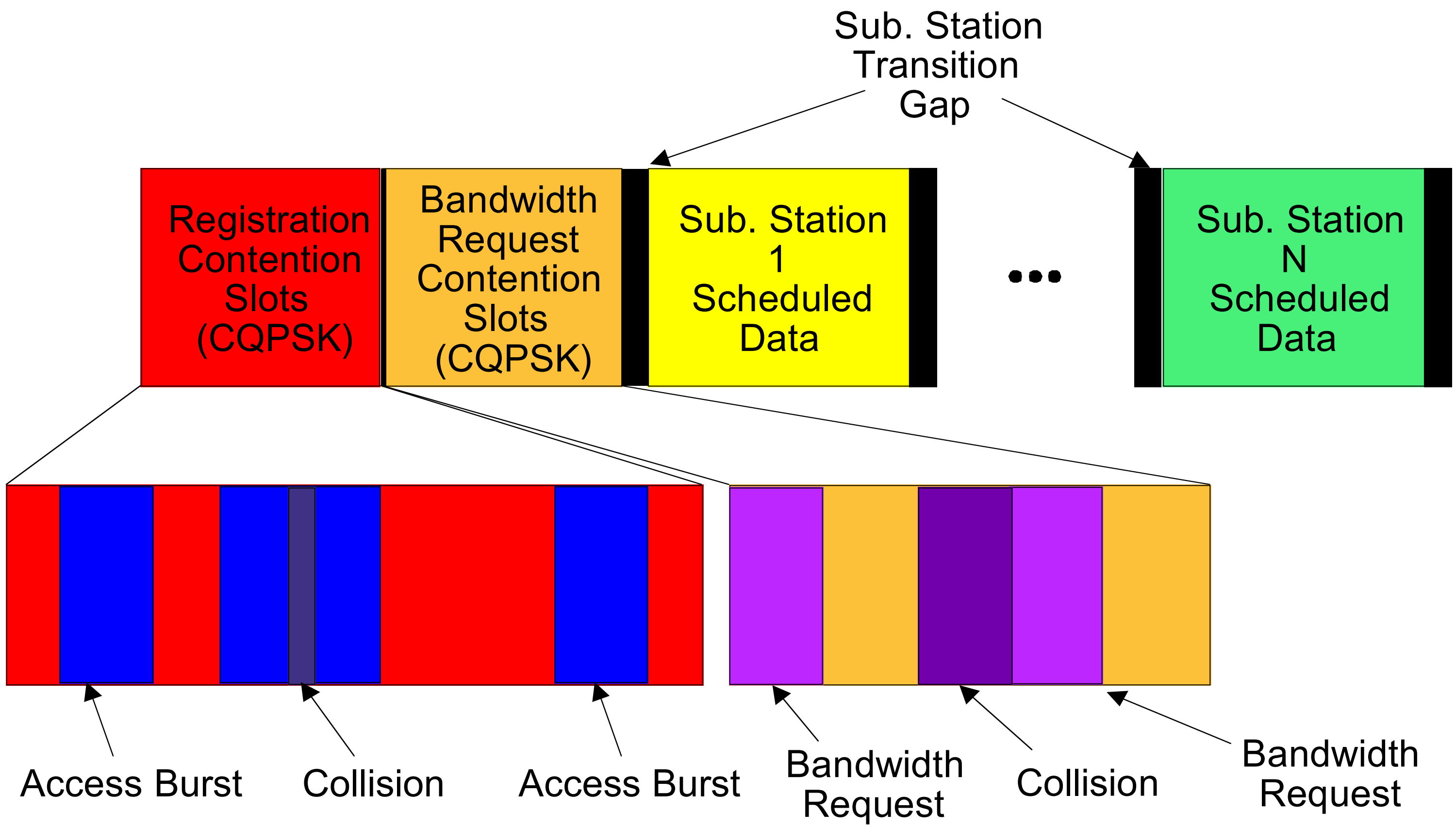


- **Multiple constellations simultaneously: QAM-4, -16, -64**
- **Nearby users can use QAM-64, distant ones use QAM-4; QAM-16 in between**

Downlink Sub-frame (TDMA case)



Uplink Sub-frame



FEC & Interleaving

- “Strong” FEC schemes require concatenation of 2 codes with long-effective interleaving
  - Degraded performance if interleaver is shortened or removed
    - Up to 2.5 dB loss in high rate modes
- In cable modems there are cable-plant issues which impose interleaving requirements
  - Only a downlink issue (Mux-Amplifier clipping)
    - First cable modem standards used only one code (RS) + interleaver
  - The existence of the interleaver is now part of a concatenated scheme (2 codes or TCM+code)
- In BWA operating in short range, millimeter wave frequencies with LOS conditions there are no inherent “plant” issues promoting similar interleaving requirements to cable modem

FEC & Interleaving – *cont.*

- In BWA there are different plant issues
  - Slow fading - handled by power control
  - As uplink and downlink baud rates are similar the uplink becomes more susceptible to interference
  - Low level ARQ is more effective for the uplink
- In BWA long interleaving should be avoided
  - In the business environment services are delay sensitive in contrast to one-way broadcast or home-internet applications which are not
- The preferred approaches are:
  - *Concatenation with restricted interleaving length or <u>none</u>*

    Interleaving <u>cannot</u> be core necessity for delivering FEC performance
  - *Optimize a single level coding scheme*

FEC Alternatives

- Shortened Reed Solomon
  - Simple implementation (~20 K gates)
    - Operates at “symbol” rate and not “bit” rate
  - Well suited for burst errors and QAM, Hard decision
- BTC (Block Turbo Code)
  - As we require Low latency, small blocks *AND* High code rate (>70%) the advantages of these schemes are not apparent

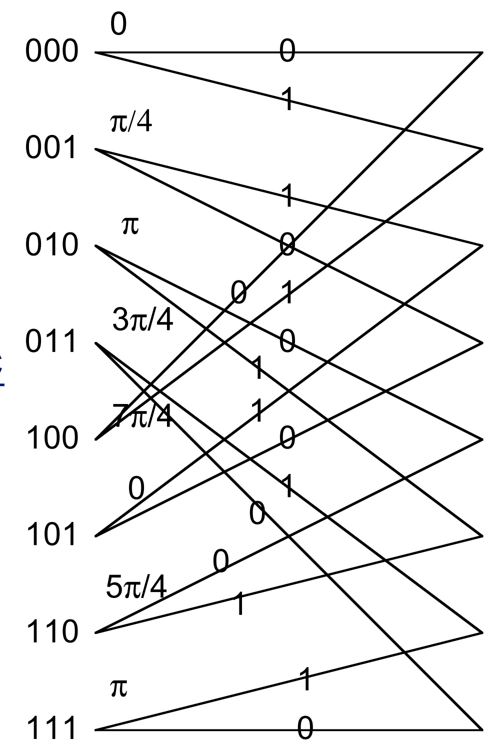
    PPC (parity product codes) has a small advantage in very short blocks (a few bytes, high coding rate) but in this case overall PHY efficiency is influenced by preambles and ramp-up/down times

Soft Decoding + RS

- RS codes do not perform well at high BER/low SNR conditions
- Bit parity check has simple options for soft decoding
- Simple scheme: To each RS symbol we add a parity check bit prior to modulation
- At the receiver, soft information from the demodulator is used for soft decoding the parity check code (SDPC)
- The RS decoding process is applied after the SDPC process
- Asymptotically coding gain could be increased by more than 1.5 dB
- “danger zone” for RS codes is right shifted about 1-1.5 dB
  - RS coding gain may be increased by adding more redundancy symbols yet in low SNR the code is more susceptible to decoding failure
- No interleaving is necessary for achieving this performance

FEC for CQPSK

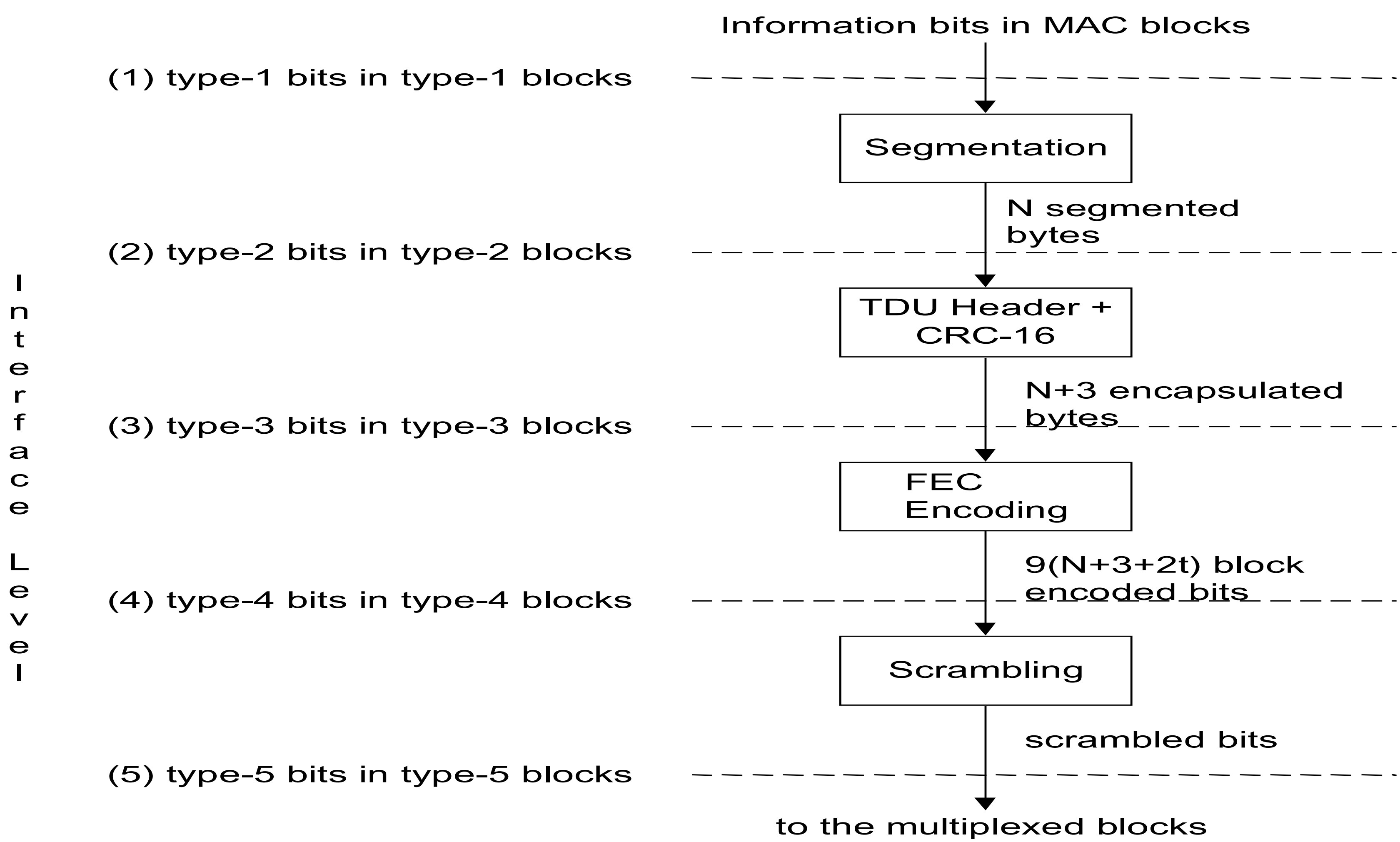
- The optimal demodulator for CQPSK/TFM is a Viterbi decoder
- Research done by Fidel Morales (1994) and Martin Bosset (1998) present a systematical approach for combining a convolutional code with the TFM scheme to be decoded by a single trellis decoder
- The best CC with r=0.75 delivers 4.8 dB asymptotic coding gain
- The conclusion is that a RS code approach is preferred (better performance at high SNR)
- If the TFM Viterbi decoder is built with soft output capabilities it can be interfaced to the SD+RS scheme presented previously



FEC parameters

- RS code is based on GF(256)
  - RS symbols are bytes
  - Shortened code
- Parity check is performed byte wise
  - Each byte is transformed into 9 bits
- Let P be the block size in bytes prior to encoding and t be the number of correctable byte errors. Fixed configuration parameters are:
- (1) PHY and MAC control portions & data transport use P=128, t=5
- (2) Registration portion uses P=14, t=3
- (3) Contention based access portion uses P=5, t=2
- Only for data transmission, FEC parameters *may* be programmable. The recommended values for data transmission are P=128, t=5. In all cases the TC operation adds a 16 bit CRC for reducing the probability of miss detected errors to a minimal value.

FEC Process



Error_Control_IF.vsd

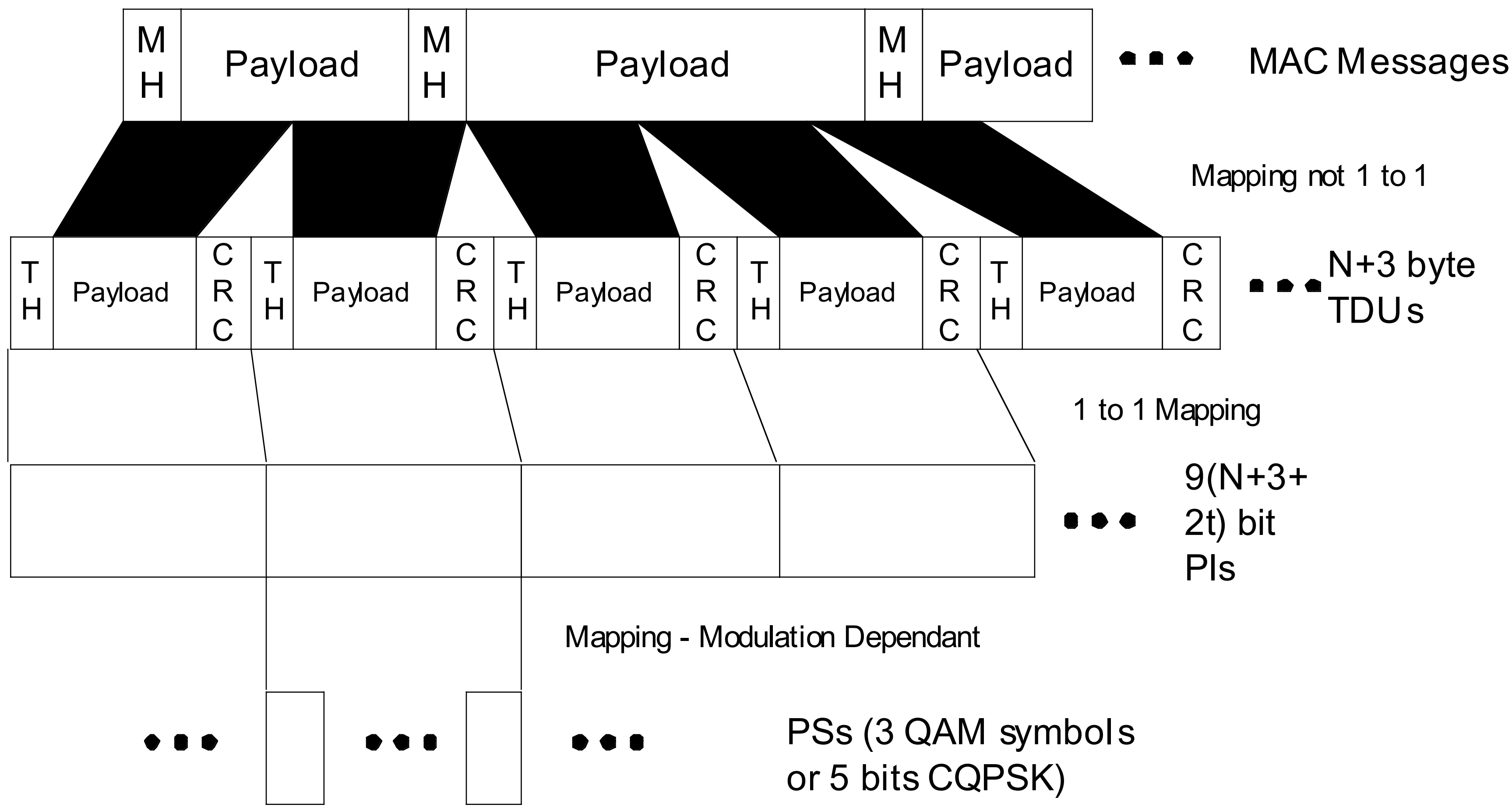
Shortening

- When the number of bytes entering the FEC process M is less than P bytes, the following operation is performed:
  - (P-M) zero bytes are added to the M byte block as a prefix
  - RS Encoding is performed
  - The (P-M) zero RS symbols not associated with the original data are discarded
  - Parity check is performed on remaining symbols
  - The resulting byte block is converted to bit block
- It is expected that the receiver having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

Variable Length Coding

- When the number of bytes entering the FEC process M is greater than P bytes, the following operation is performed:
  - Let K=M
  - Next P bytes entering the FEC are encoded to a 9(P+2t)
  - Subtract P from K, meaning Let K=K-P
  - If K<P go to (5) otherwise go to (2)
  - Shortened FEC is applied to the remaining bytes
- It is expected that the receiver having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

PHY/TC Interaction (both Uplink/Downlink)



TDU Allocation by Modulation

Modulation	PSs required per PI
QPSK	Ceil[9(N+3+2t)/6]
CQPSK	Ceil[9(N+3+2t)/5]
QAM-16	Ceil[9(N+3+2t)/12]
QAM-64	Ceil[9(N+3+2t)/12]

PS based vs. Symbol based allocation

Modulation Scheme	Average bit loss due to PS based allocation
CQPSK	2
QPSK	1
QAM-16	3
QAM-64	3

1	***Meeting System Requirements***	This proposal is believed to meet system requirements of IEEE 802.16
2	***Spectrum Efficiency***	The use of SLAM (Subscriber Level Adaptive Modulation) balances between range and capacity. The average bps/Hz in a typical deployment (FDD or TDD) would be about 3 bps/Hz . In TDD mode correct balance between upstream and downstream could be maintained hence increasing spectrum efficiency. This PHY allows efficient implementation of upstream TDMA taking into account dynamic of user traffic.
3	***Implementation Simplicity***	The core functions of this PHY (i.e., QAM modulation, Reed-Solomon FEC) are well known technologies with simple implementations.
4	***CPE Cost Optimization***	The PHY supports either H-FDD or TDD which allow low cost ODU implementation.
5	***Spectrum Resource Flexibility***	The PHY can be used for any worldwide available spectrum. Modem baud rate can be easily modified to support channels up to 40 Mbaud following ETSI-like channel scheme or US-like schemes.
6	***System Diversity Flexibility***	The PHY may be used for various spectrum allocations (as explained in (5)) and is protocol agnostic meaning that it may support various network architectures.
7	***Protocol Interfacing Complexity***	The PHY uses information elements which are small enough to efficiently carry variable length packets such as IP and efficiently carry fixed length packets as ATM or STM.
8	***RSG***	Actual values are presented in this proposal. These values allow cell radius of a few miles even when availability is set to a high target. SLAM allows to trade-off almost 20 dB between range and capacity.
9	***Robustness to Interference***	The short packet format supported by the PHY (and by the TC/MAC) offers fast recovery if packet loss occurs. SLAM capability of the modem to back-off to QPSK modulation offers robustness to interference.
10	***Robustness to Channel Impairments***	The short packet format supported by the PHY and the SLAM capability of the modem to back-off to QPSK modulation offers robustness to channel impairments. Equalization procedures are easily implemented at the receiver (or pre-equalization at transmitter) to cope with typical multi-path scenarios in PMP/LOS deployments.
11	***Robustness to Radio Impairments***	Not all modulation schemes are mandatory hence that one may choose to implement a lower cost solution with lower capacity targets. The CQPSK option immunes the signal to PA particular perfomance as it works itself near saturation.

Summary

- PHY Optimized for BWA
  - Roots come from various well known ***Wireless Access*** technologies
  - Some of core concepts accepted by ETSI/BRAN HA
    - Ease of harmonization
  - There is no “magic” chipset today (Silicon is not the cost driver of the system)
- Supports efficiently ALL duplex scheme variants
- Implementation cost issues are taken into account
- This is the best TDD/H-FDD/FDD based approach developed by the proposing members until now
- The proposing members *invite* all IEEE 802.16 participants to study the proposal and propose enhancements and modifications