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PHY Layer Proposal for BWA

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Purpose:

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

PHY Layer Basis for BWA

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Issues Covered

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

Joint Proposal History

- Contributors share same view
- Emphasizing the need for a constant envelope modulation scheme (for the Uplink)
- Rectifying major H/FDD issues
- Elaboration of coding schemes and introducing variable length coding
- Some of core ideas are already accepted by ETSI/BRAN

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*

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 10 or 50 MHz 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	US Channel BW (MHz)	ETSI Channel BW (MHz)
40	50	56
32	40	-
20	25	28
16	20	-
10	12.5	14
8	10	-

- **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)

- QAM must be pulse shaped for limiting spectrum occupancy
  - Root Raised Cosine, RRC
- 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
- 0.25 is a compromise between power loss and capacity

Duplex Scheme Variants

- FDD
  - Traditional, full duplex
- Half Duplex FDD
  - Cannot 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

Modulation

- QAM, Multi-level
- Subscriber Level Adaptive Modulation (SLAM)
  - Supported modulation levels:
    - *QPSK, QAM-16 and QAM-64*
    - *CQPSK(TFM) replaces QPSK on uplink*
  - 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
- SLAM concept adopted by ETSI/BRAN HA
- SLAM concept allows simple future upgrades

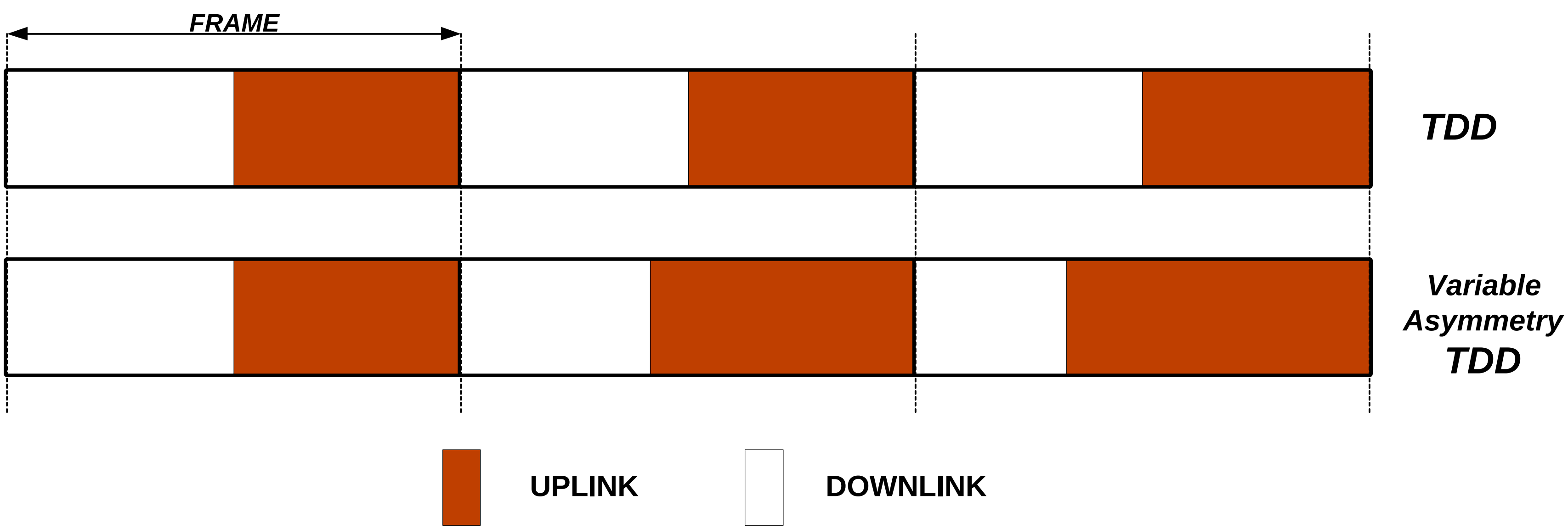
Multiplexing & Multiple Access

- 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

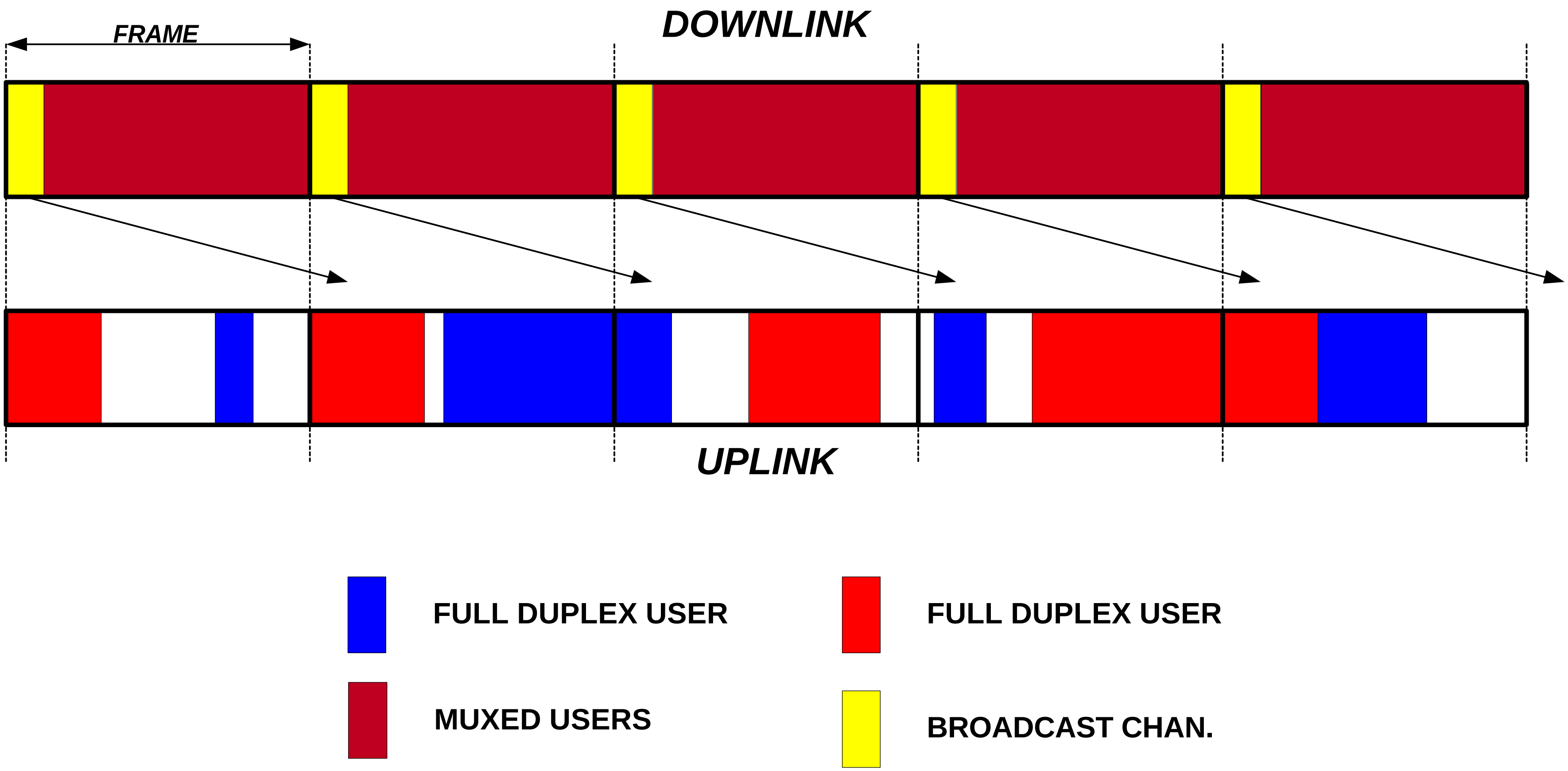
Frames

- 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

TDD (TDM/TDMA)

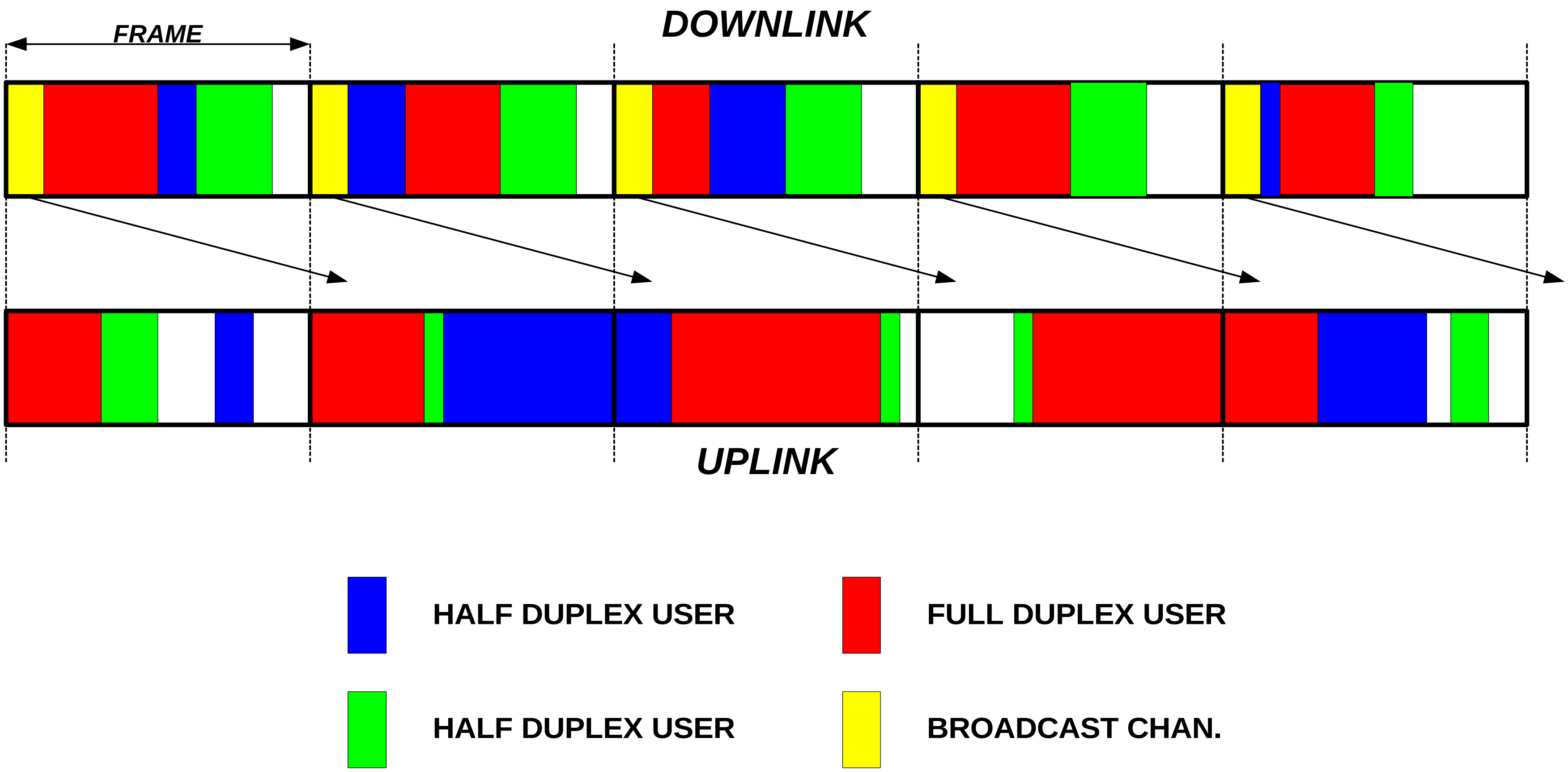


FDD (TDM/TDMA)



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

FDD & H/FDD (TDMA^2)



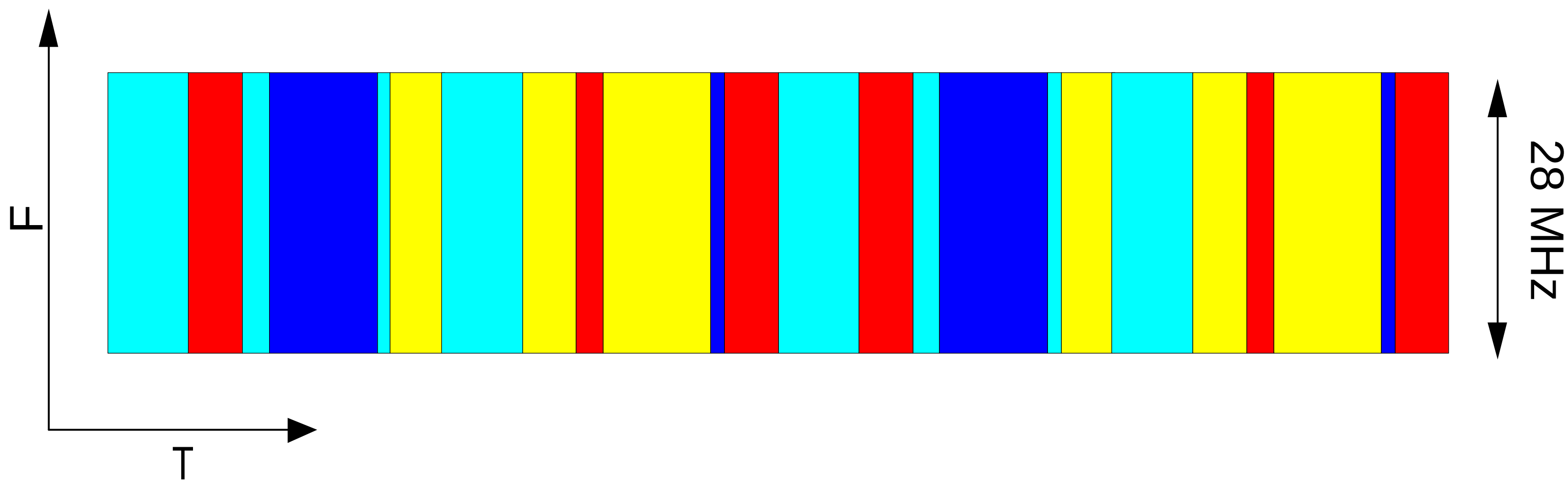
Reducing Power Amplifier Requirements

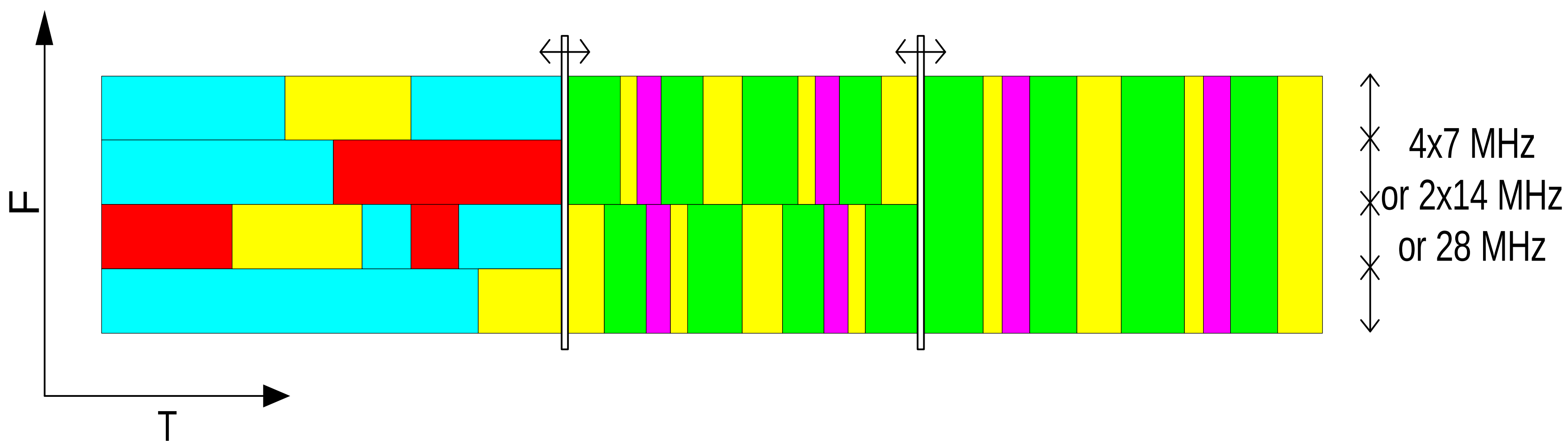
- **The PA is the main cost driver of the ODU**
  - **Linear PAs are DC inefficient**
- **CEM - Constant Envelope Modulation**
  - **TFM (Tamed FM) or CQPSK (Constant Envelope QPSK)**
    - **Similar performance as QPSK with ROF=0.5**
  - **Practically multi-level options are inefficient**
  - **π/4-QPSK & 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**

CQPSK (TFM)

- **Lars Lindh Presents**

Option for Further Reducing RF Cost



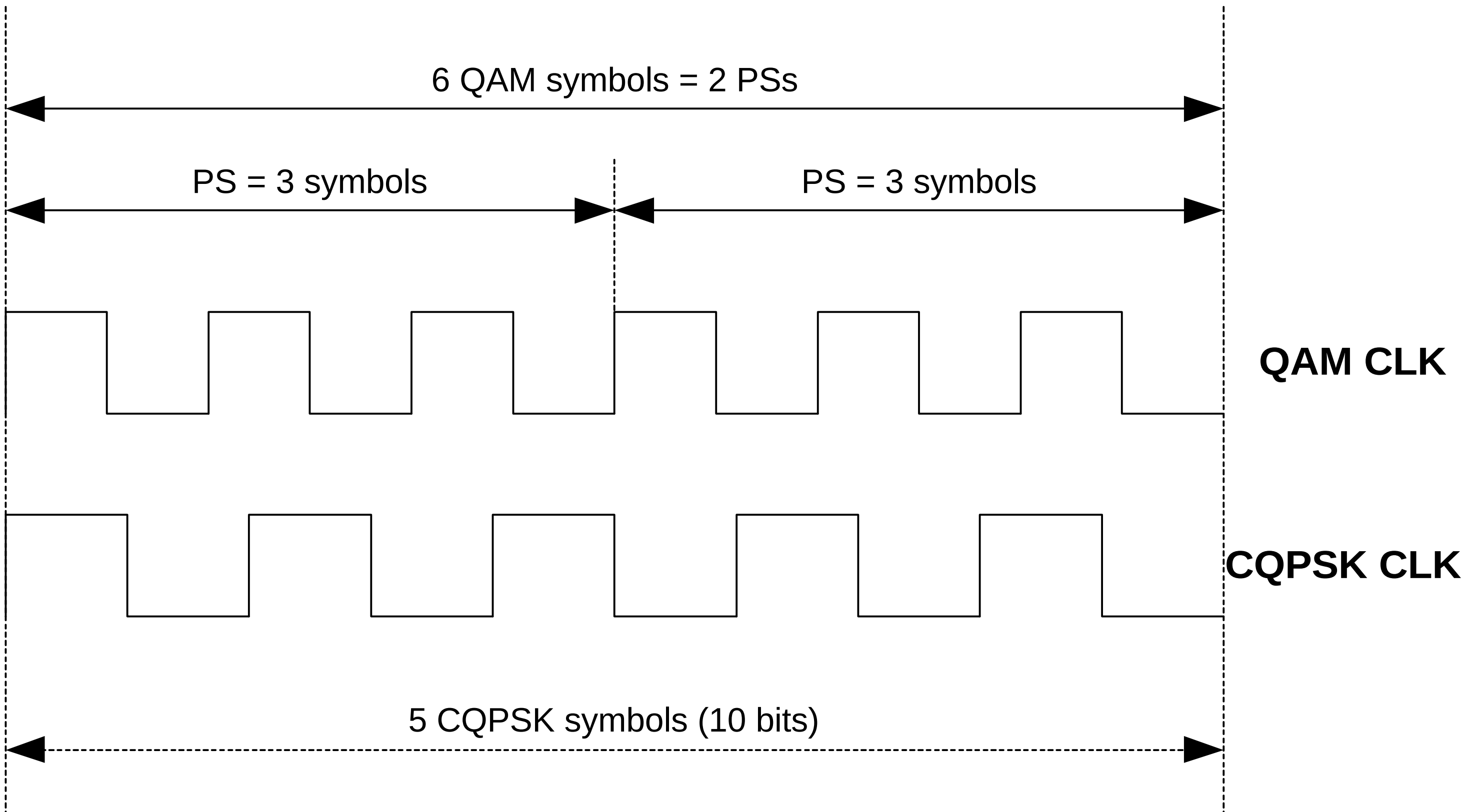


Supporting different Baud Rates

- 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

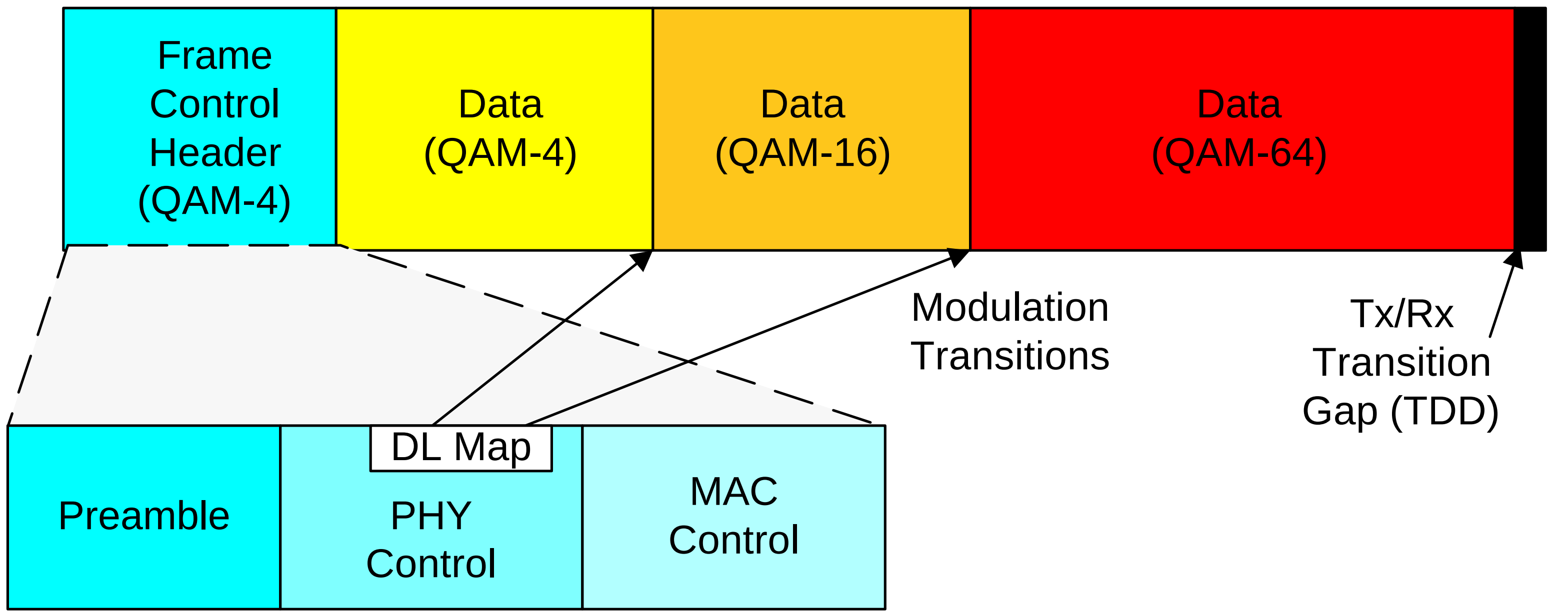
- Basic **Time** Unit for Allocation **and** Management
- Size respects recommended ratio for QAM/CQPSK



Preambles & Guard Intervals

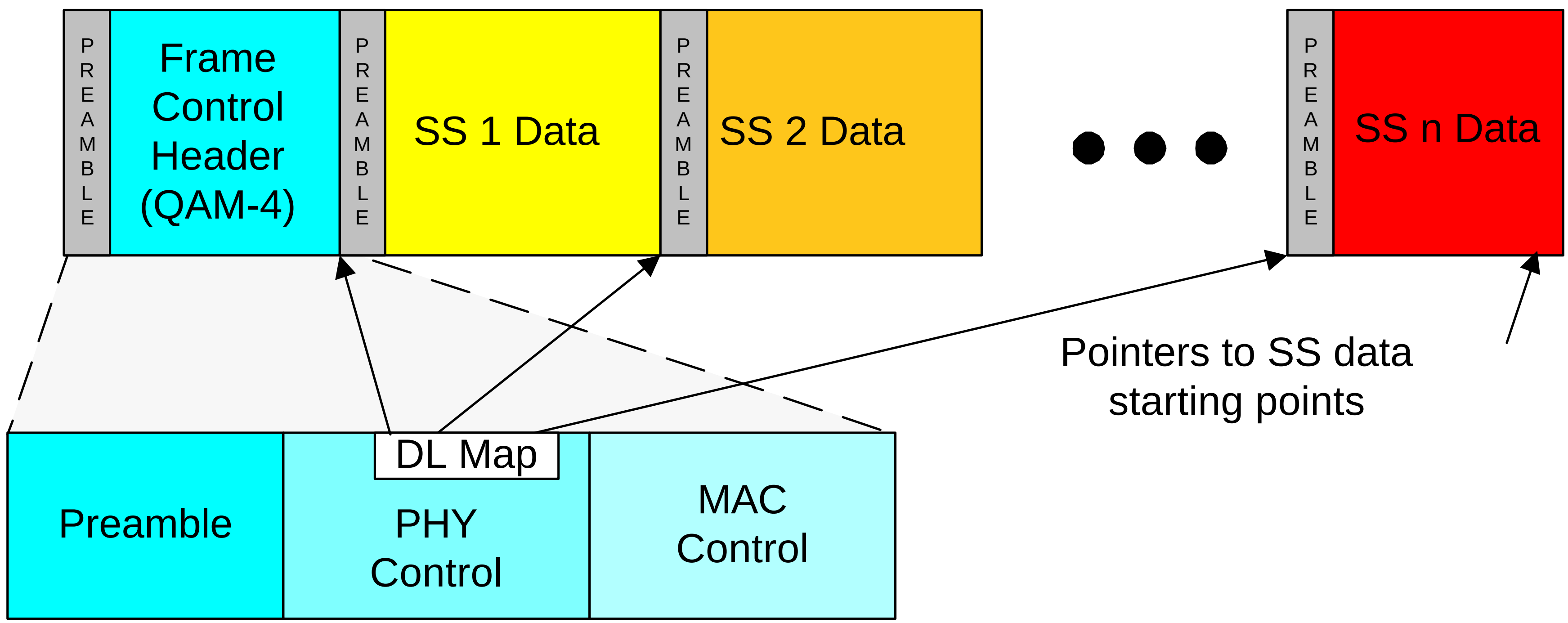
- Preamble per burst required for TDMA
  - Preambles occupy an integer number of PSs
- For Downlink frame start a preamble assists CPEs to frame synchronize and various parameters
  - Recommended: 8 PSs (24 QAM symbols)
- For Downlink/TDMA, preamble can be short (phase reference re-evaluation) as the 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)

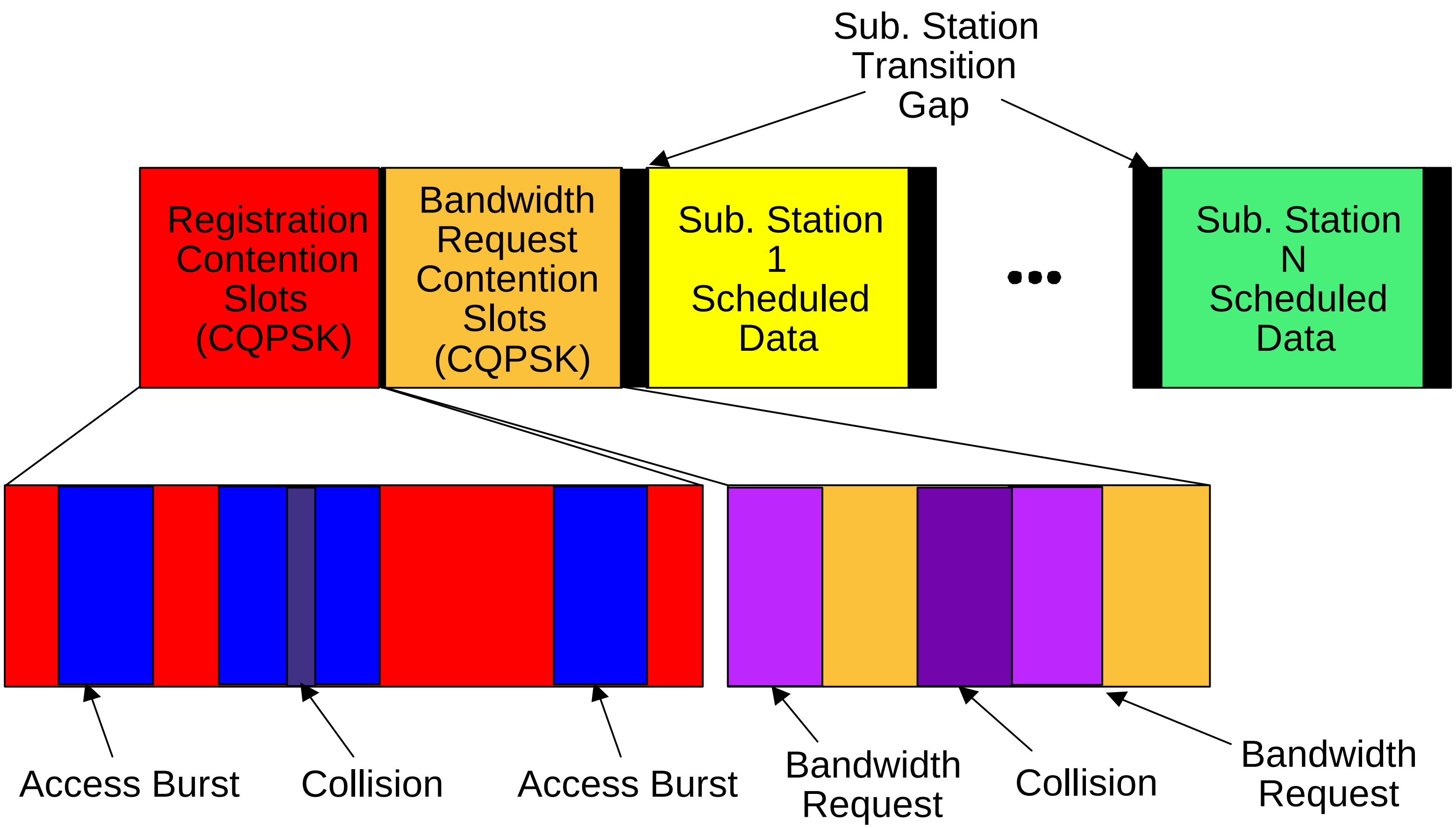


- **Multiple constellations simultaneously: QAM-4, -16, -64**
- **Nearby users can use QAM-64, distant ones use QAM-4; QAM-16 in between**

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**
- **TCM + RS with short interleaving**
  - **TCM scheme must have a small number of states (i.e., 8) as it influences the length of error bursts**
  - **Further investigation required to determine exact parameters**
- **Stand alone TCM (no concatenation)**
  - **Some codes offer an advantage of ~2 dB over the RS approach**
  - **Some implementation complexity penalty (~200 K gates)**
- **BTC (Block Turbo Code)**
  - **As we require Low latency *<u>AND</u>* High code rate (>70%) there is no clear advantage when compared to non-turbo schemes**

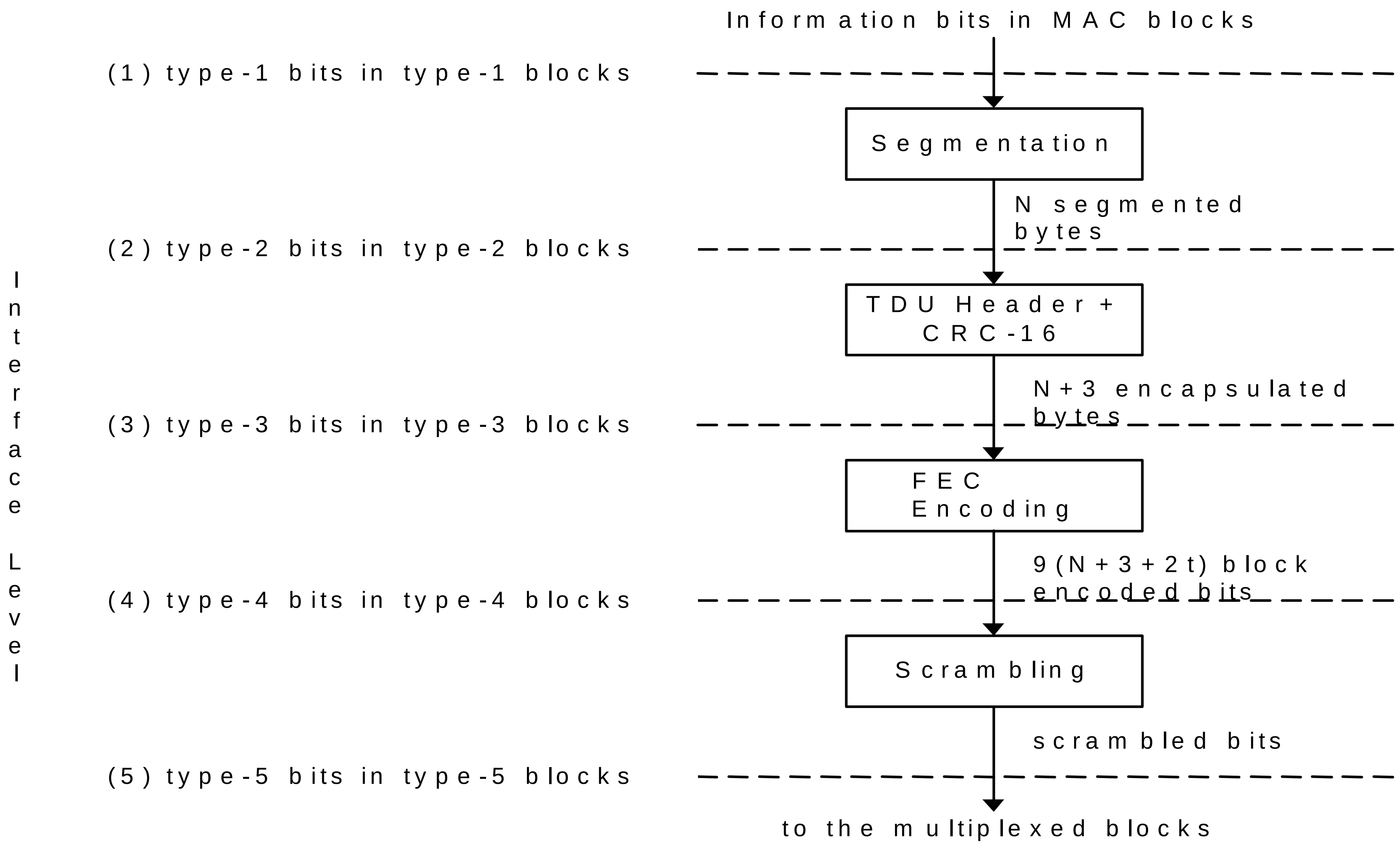
Soft Decoding + RS

- RS codes do not perform well at high BER 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 is increased by more than 2 dB
- “danger zone” for RS codes is right shifted about 1-1.5 dB
- No interleaving is necessary for achieving this performance

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

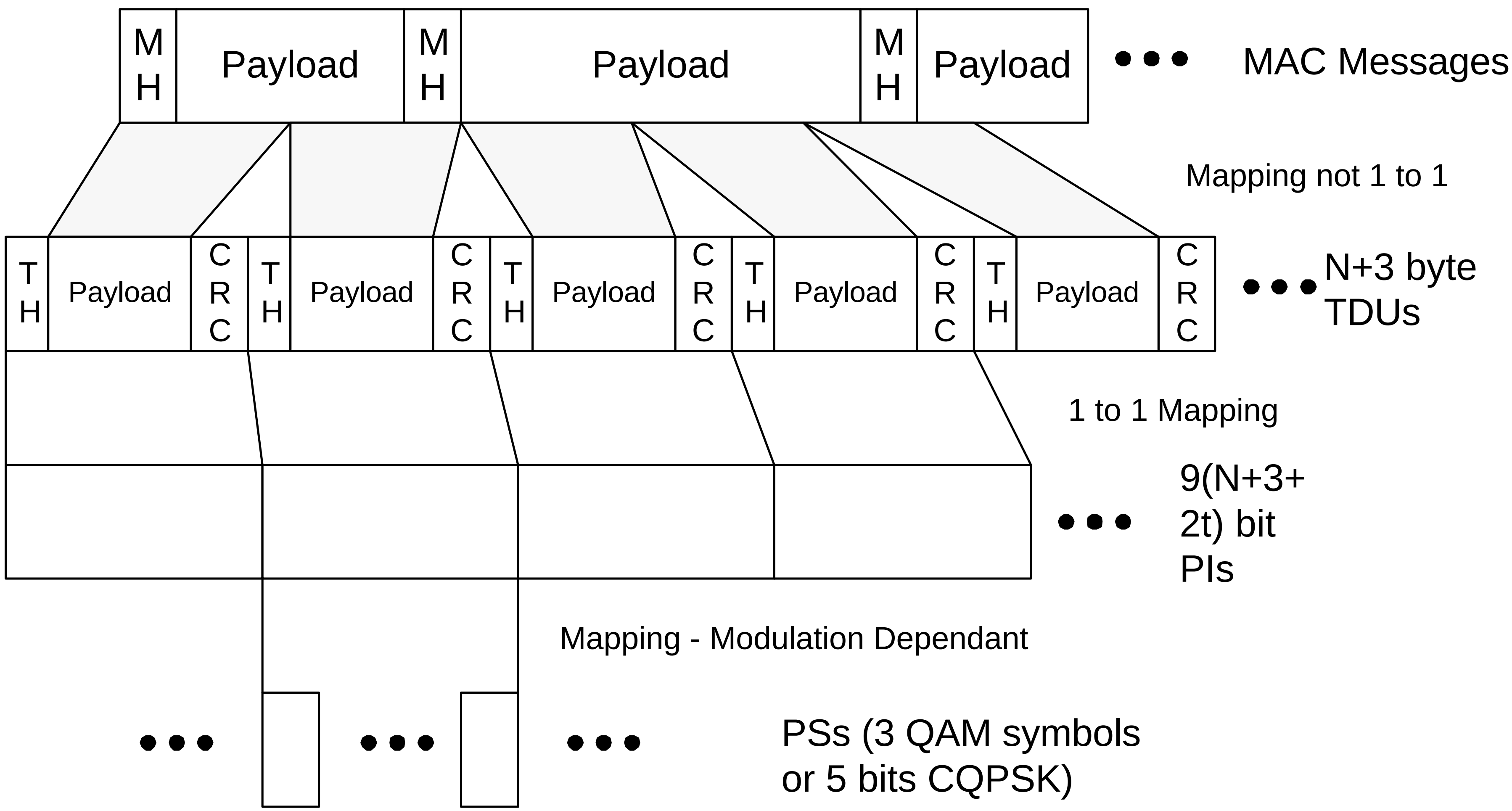
Shortening

- 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



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

Summary

- PHY Optimized for BWA
  - Roots come from various ***Wireless Access*** technologies
  - Some of core concepts accepted by ETSI/BRAN HA
  - There is no “magic” chipset today
- 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