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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

Notice:



Release:



IEEE Patent Policy:

# PHY Layer Basis for BWA

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**IEEE 802.16.1 Session #6    March 2000**

# 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 submitted by **Klein** (Ensemble) and **Lindh** (Nokia) from Session #4 (Kauai, 11/99)
- **Chayat** (BreezeCOM) supports for LMDS
- **Baldo** (Siemens) joins for Session #6
- **Kennard** (DMIC), **Nascimbene** (Ericsson), **Gray** (Lucent), **Kostas** (Adaptive Broadband) join for Session #7

# 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)

# Revision History – *Cont.*

- **Session #7:**
  - Refine framing-slot numbering parameters for a cleaner support of QAM
  - Introduce additional FEC options, build-up a better FEC story
  - More details on framing and baud rates for different spectrum allocations
  - Correct various “typos” in document

# 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)*
- Traffic requirements point out the need of a large channel BW for the **uplink**
  - Business
  - Symmetric

# Channel BW considerations

- 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

# Why do we need a finite set of BW choices ?

- **Worldwide, for BWA (millimeter wave) applications there is a finite set of choices**
  - **Europe: 7, 14, 28, 56 … MHz**
  - **US: 20, 25, 40, 50 … MHz**
- **The price to pay in BW flexibility is not in the Silicon (i.e., base band, low IF)**
- **The price to pay in BW flexibility is in the RF and Millimeter wave Front End**
  - **Synthesizer/Tuner design**
  - **Up/Down conversion stages**
    - **Unified IF/RF design**
  - **IF/RF Filtering**
- **Finite set of BW choices could lead to a lower cost ODU which is the primary contributor to CPE cost**

# Why do we need pair allocations for FDD ?

- Pair allocations = Channel BW for uplink and downlink are the same
- The differences between spectrum allocations worldwide is the available duplex spacing
  - Some allocations are paired (former PtP bands, 39 GHz)
  - Some allocations are blocked (MWS, LMDS)
- Better radio economy when the uplink/downlink channels are identical
  - Conversion chain for up-conversion is offset by a constant amount relative to the down-conversion chain
    - Single synthesizer design
  - 1st and 2nd stage IF/RF can desing-fixed, ignorant of band restrictions

# Why do we need pair allocations for FDD ? – *cont.*

- If smaller uplink channels are justified (yet it is not justified by traffic requirements) then sub-channeling of the main channel is preferred
  - Base band processing for sub-channel modem, no need to up/down convert in RF domain
- Smaller uplink channels could lead to higher cost mainly due to phase noise performance requirements of synthesizer
  - Major impact for mmWave
  - Minor impact for MMDS or Cable modems

# Bandwidth & Baud Rates

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

- 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)
- $25/1.5/0.75 \approx 20$ MBaud
- 25 MHz seems to be a good choice
- 28 MHz chosen by ETSI/BRAN HA

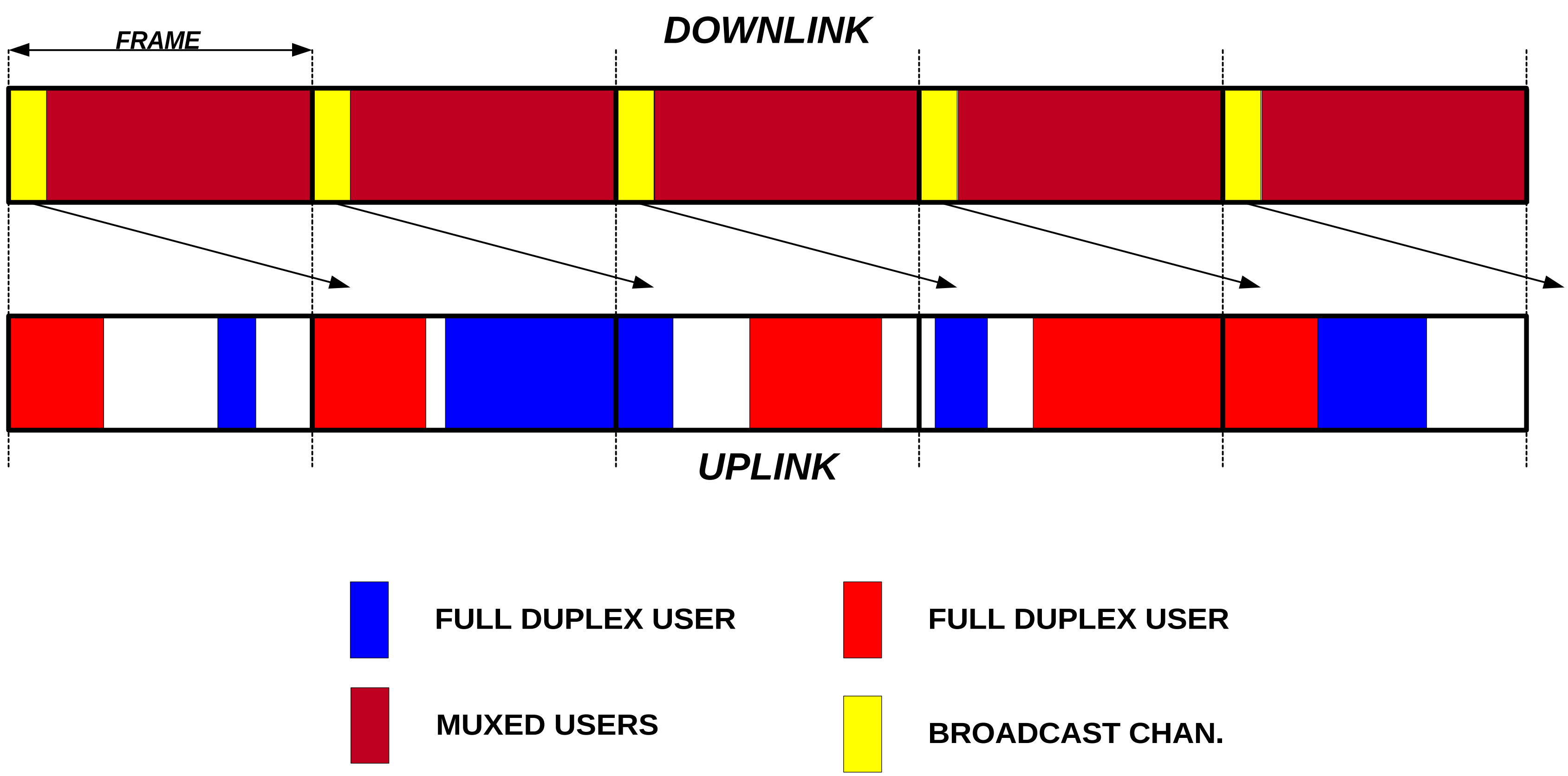
# Roll Off Factor (ROF)

- Small ROFs increase spectrum efficiency but RF cost becomes more expensive
  - PA back-off requirements
  - Adjacent Channel Interference Issues (ACI)
- 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 an **excellent 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 are Half Duplex FDD Terminals?

- **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)


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

# What are Half Duplex FDD Terminals? – *cont.*

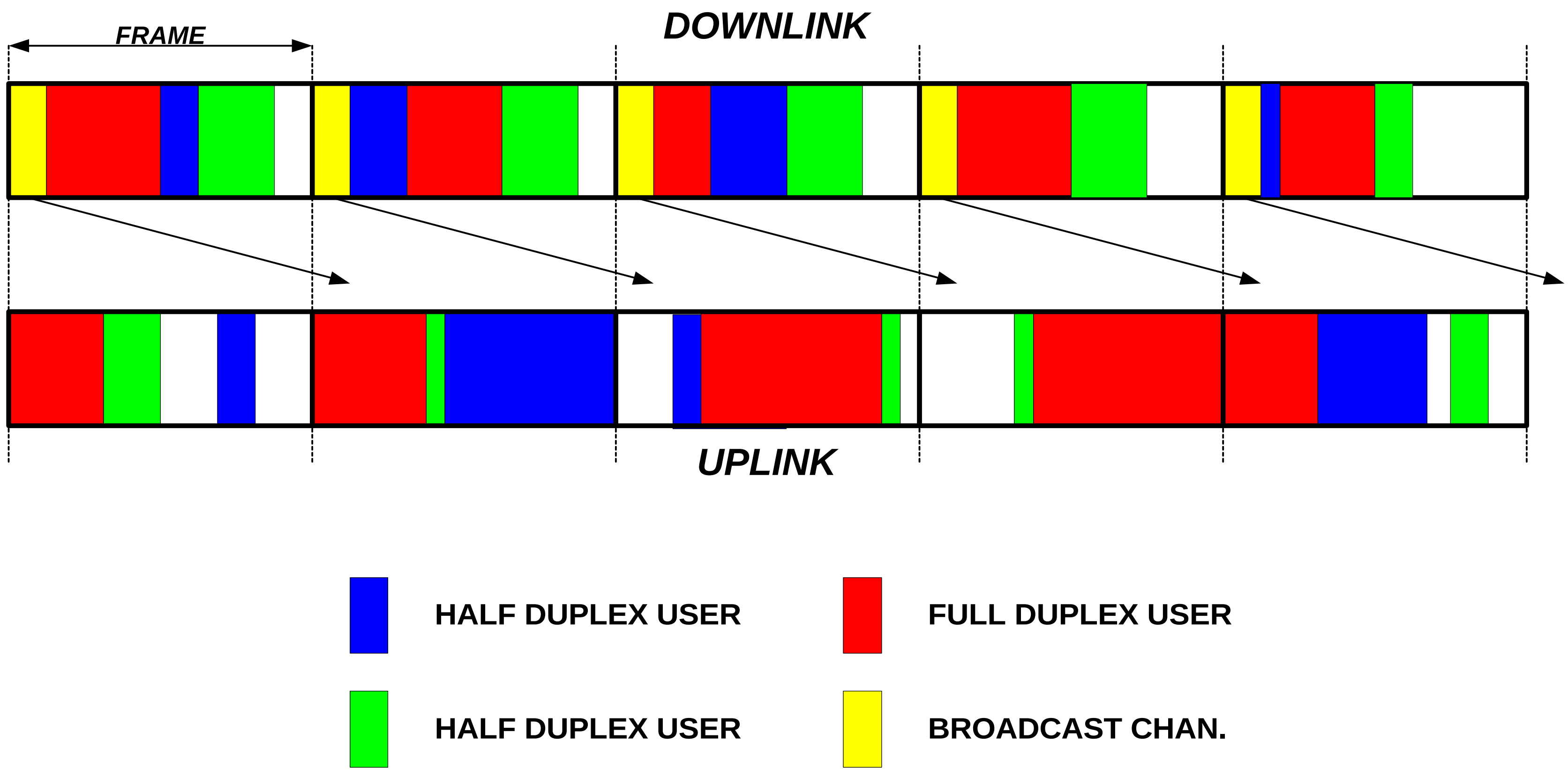
- **If the TDM stream is arranged user after user, all user information gathered together within the same frame then…**
  - The downlink remains continuous, full duplex
  - Terminal is pointed out to the exact time location of its downlink data
  - No need for the terminal to demodulate completely the 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**

  - **Frequency Switched Division Duplex (FSDD)**

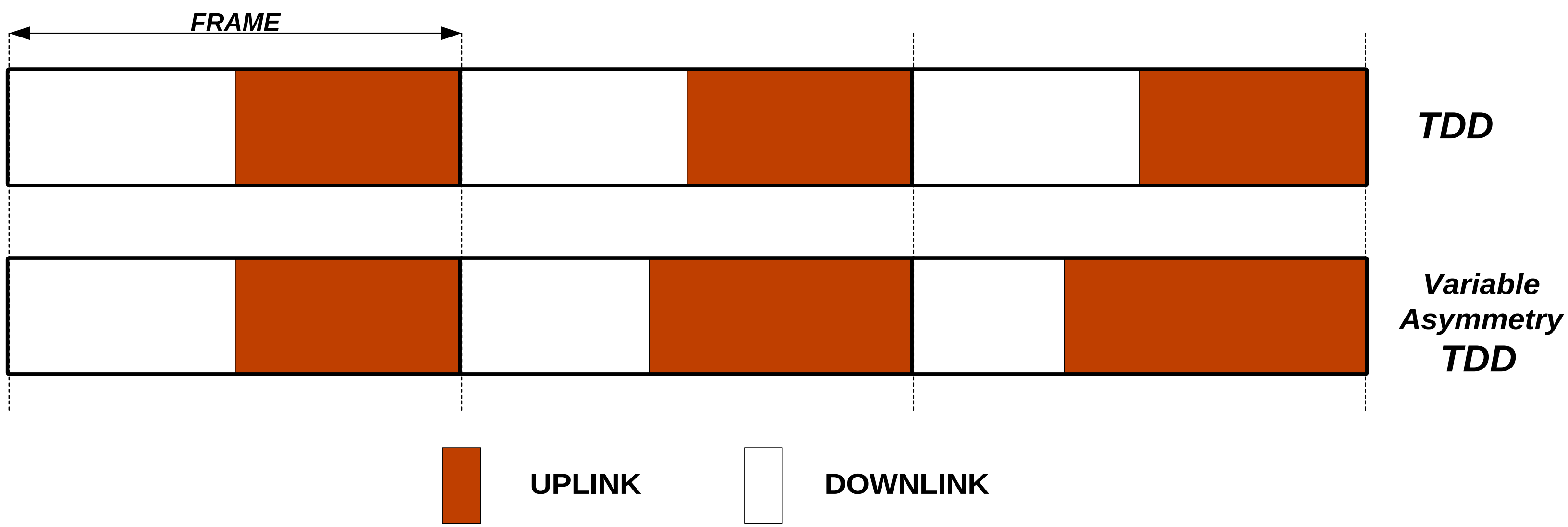
# FDD with HDX support (TDMA$^2$)



# 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 and WLL microwave terminals
- TDD
  - Downlink & Uplink occupy the same channel BW
    - Mainly due to business users which require similar peak rates in either direction

# TDD (TDM/TDMA)



# Modulation

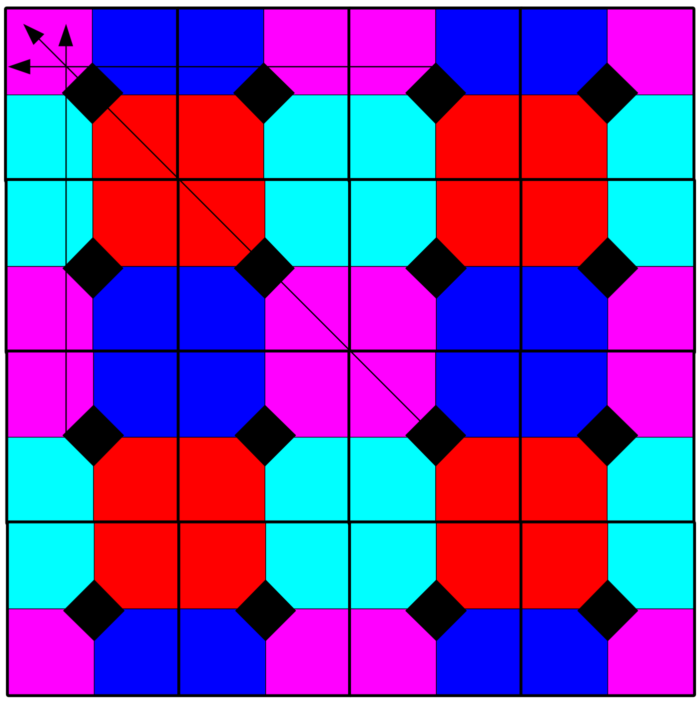
- **Subscriber Level Adaptive Modulation (SLAM)**
  - *QPSK, QAM-16 and QAM-64*
    - *For downlink and high capacity terminal uplink*
    - *CQPSK/TFM for reduced cost terminal*
  - Channel can adapt its modulation independently per user per burst
  - Uplink modulation may differ from downlink per user as it is influenced by mainly by C/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

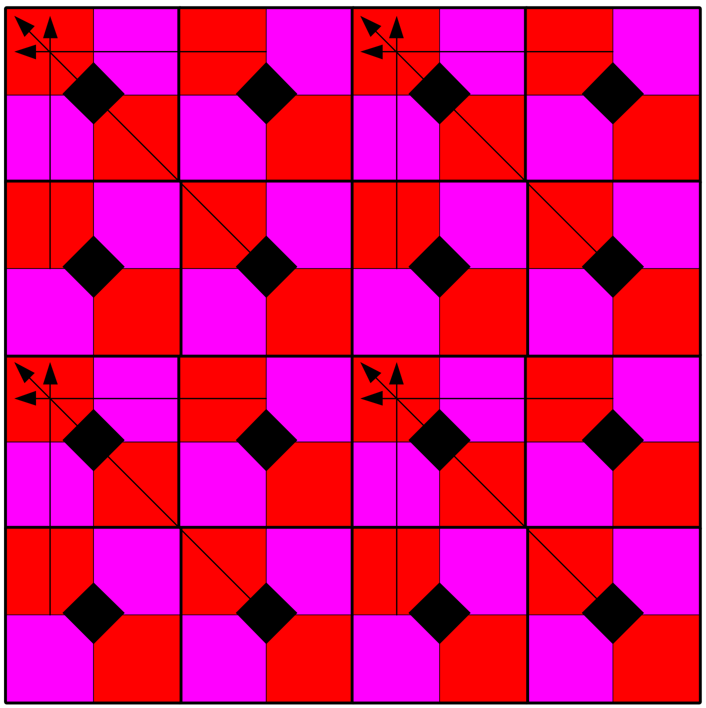
- Frequency re-use (FR) defines how many times the available spectrum is used per cell site
  - **Aggressive** re-use is defined for **FR>0.5**
- **What is the highest FR achievable?**
  - Answer: **FR=2** (50% of spectrum used per sector at most, see next slides)
  - Reason:
    - For FR=4 (100% of spectrum used per sector) 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% (for the same coding architecture)
    - If throughput was reduced by a factor of 2 then this cancels the FR increase completely
    - 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

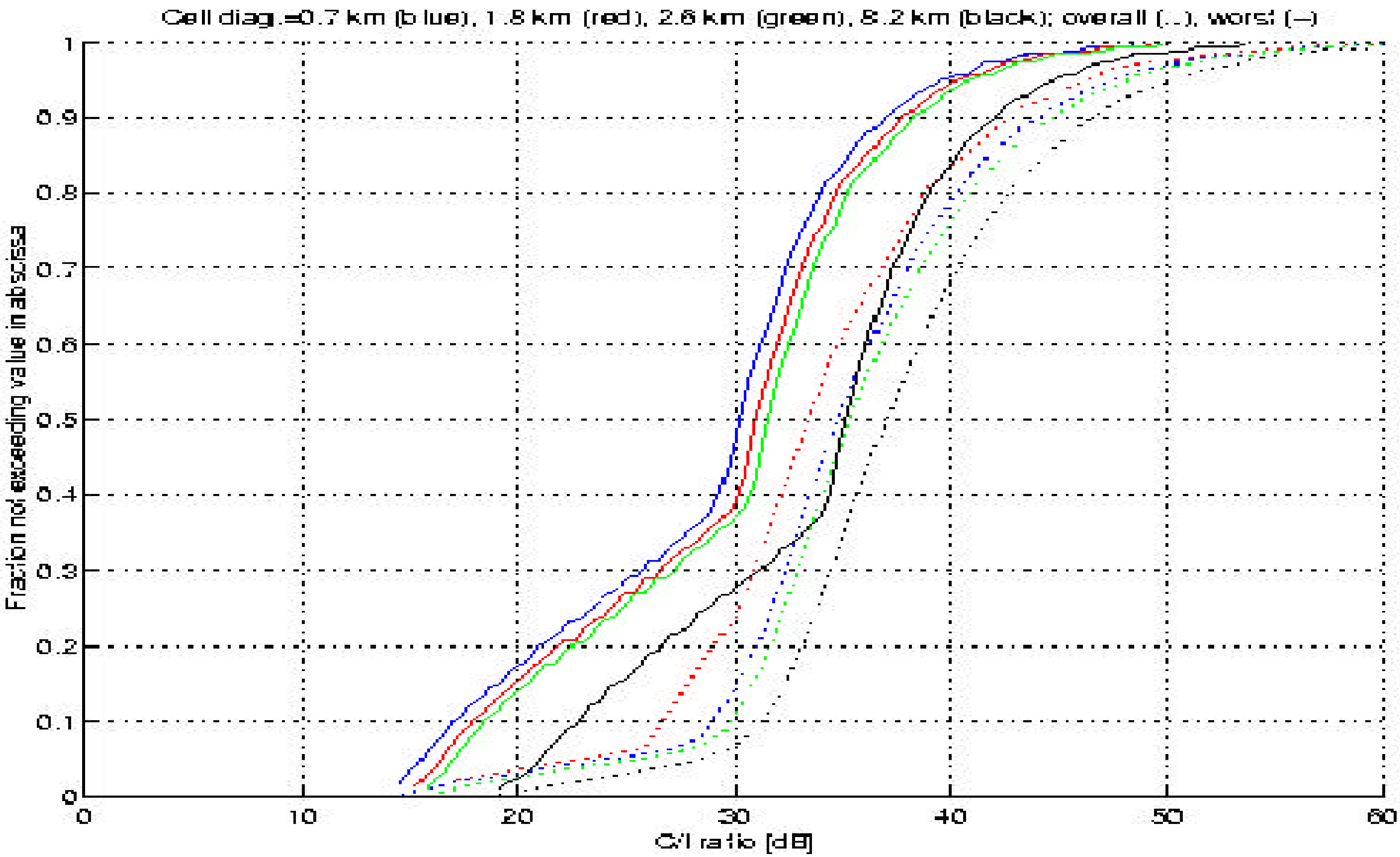
FR=2



FR=4

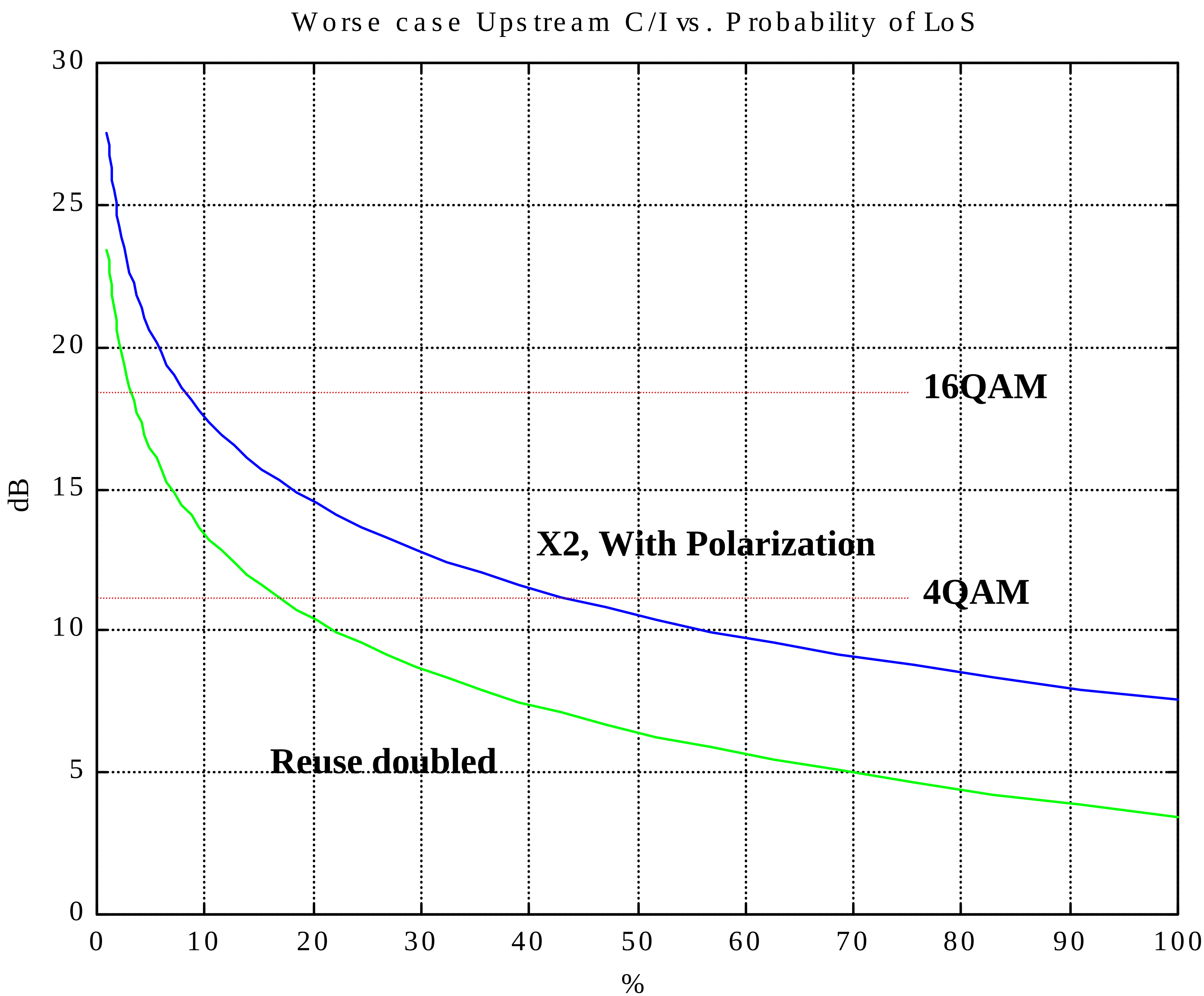


# FR=2 Downlink (Source: ERICSSON ETSI/BRAN)



# 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


Worse case Upstream C/I vs. Probability of LoS
dB
%
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
16QAM
X2, With Polarization
4QAM
Reuse doubled

# Adaptive Modulation Gains (Source: ETSI, Alcatel)

**Traffic driven deployment**

**Practical, Re-use 2**

| Number of sites | Number of sectors | Capacity /4QAM average min max | | |
|---|---|---|---|---|
| 2x2 | 16 | 2,94 | 2,75 | 3,00 |
| 3x3 | 36 | 2,79 | 2,54 | 2,94 |
| 4x4 | 64 | 2,68 | 2,32 | 2,94 |
| 5x5 | 100 | 2,57 | 2,30 | 2,93 |
| 6x6 | 144 | 2,48 | 2,08 | 2,94 |
| 8x8 | 256 | 2,34 | 1,98 | 2,94 |

# 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
- Full duplex and half duplex terminals - concurrent support
  - MAC problem
  - Limitations of CPE are recognized in registration

# Frames

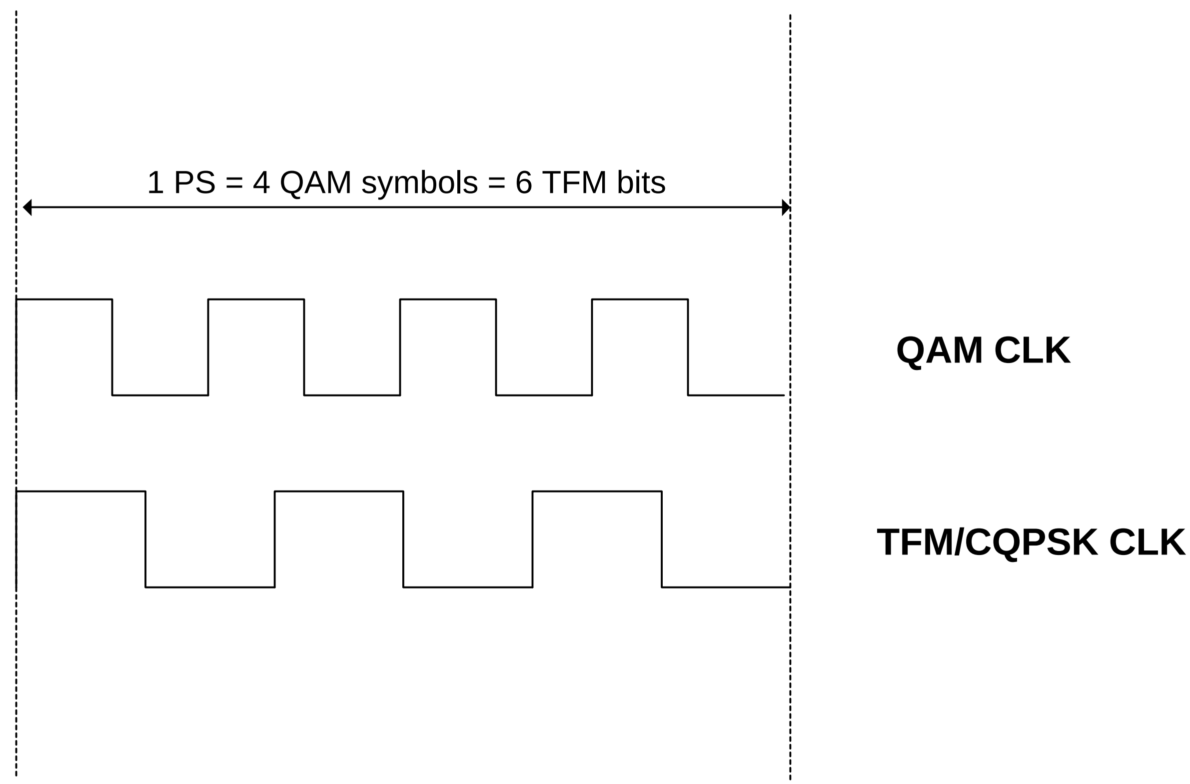
- Downlink and Uplink are frame synchronized
- Recommended frame length for LMDS is 1 mSec for both Downlink and Uplink
  - 1 mSec is small enough to minimize PHY latency
  - 1 mSec is big enough to justify PHY overhead
- In the case of TDD the frame length remains 1 mSec and is sub divided into a Downlink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

# 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:
  - 3:4 for ROF=0.25
  - 30 Mbps in a 25 MHz channel
  - QAM rate is 20 MS/s (ROF=0.25)
  - QAM & CQPSK safely co-existing one with each other (i.e., spectrum masks)

# Physical Slot (PS) Concept

- Basic **Time** Unit for Allocation **and** Management
- Size respects recommended ratio for CQPSK/QAM (3:4)



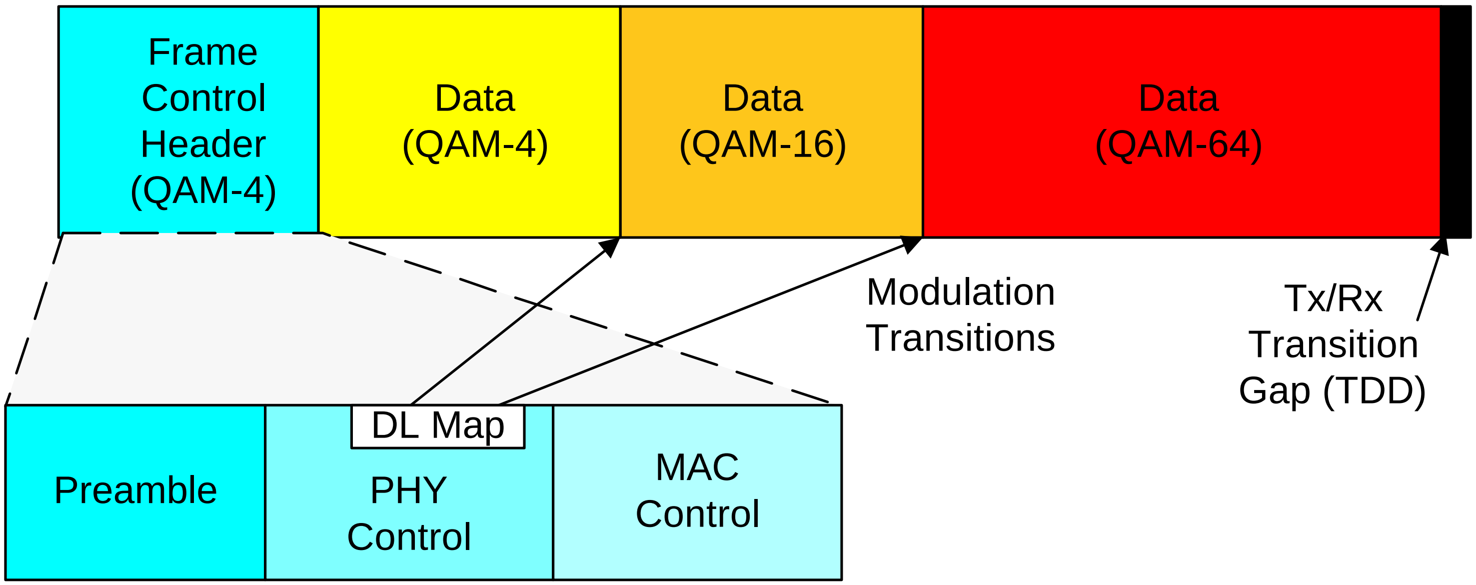
# Frame size and PSs - Recommendation

| | Baud Rate (MBaud) | US Channel Size [MHz] | Frame size (mSec) | Number of PSs/Frame |
|---|---|---|---|---|
| | 40 | 50 | 0.5 | 5000 |
| | 32 | 40 | 0.5 | 4000 |
| LMDS | 20 | 25 | 1 | 5000 |
| | 16 | 20 | 1 | 4000 |
| | 10 | 12.5 | 2 | 5000 |

# Preambles & Guard Intervals

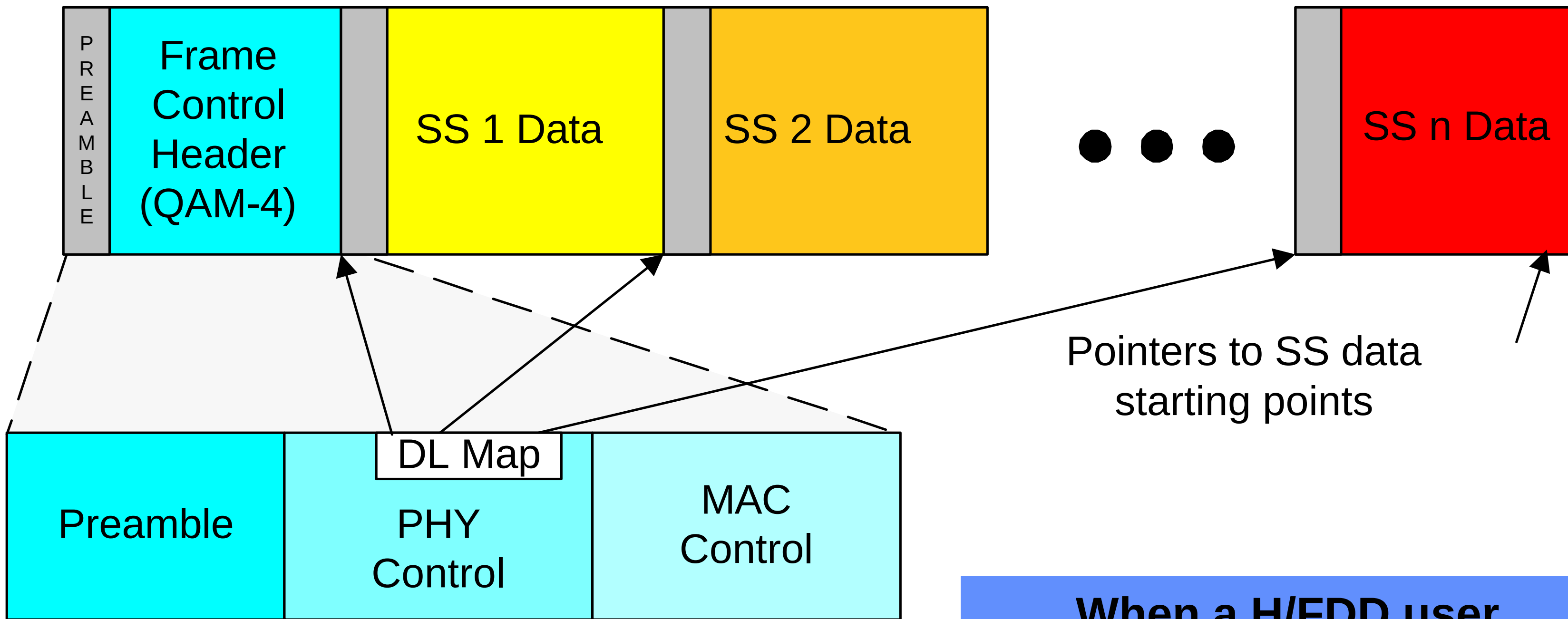
- Preamble per burst required for TDMA
  - Preambles should occupy an integer number of PSs
- For Downlink frame start a preamble assists CPEs to frame synchronize and various parameters
  - Recommended: 6 PSs (24 QAM symbols)
- For Downlink/TDMA, preamble can be short (phase reference re-evaluation) as the preamble of the frame start did most of the job
  - Recommended: 3 PSs (12 QAM symbols)
- For Uplink/TDMA, required preamble is longer
  - Recommended: 6 PSs (24 QAM symbols)
- In the 64QAM case the preamble length is doubled
- Guard Interval is required for the TDMA uplink bursts
  - Integer number of PSs (6 recommended), Overlap ramp-up and ramp-down to minimize overhead
- TDD requires guard time between downlink and uplink

# Downlink Sub-frame (TDD/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)

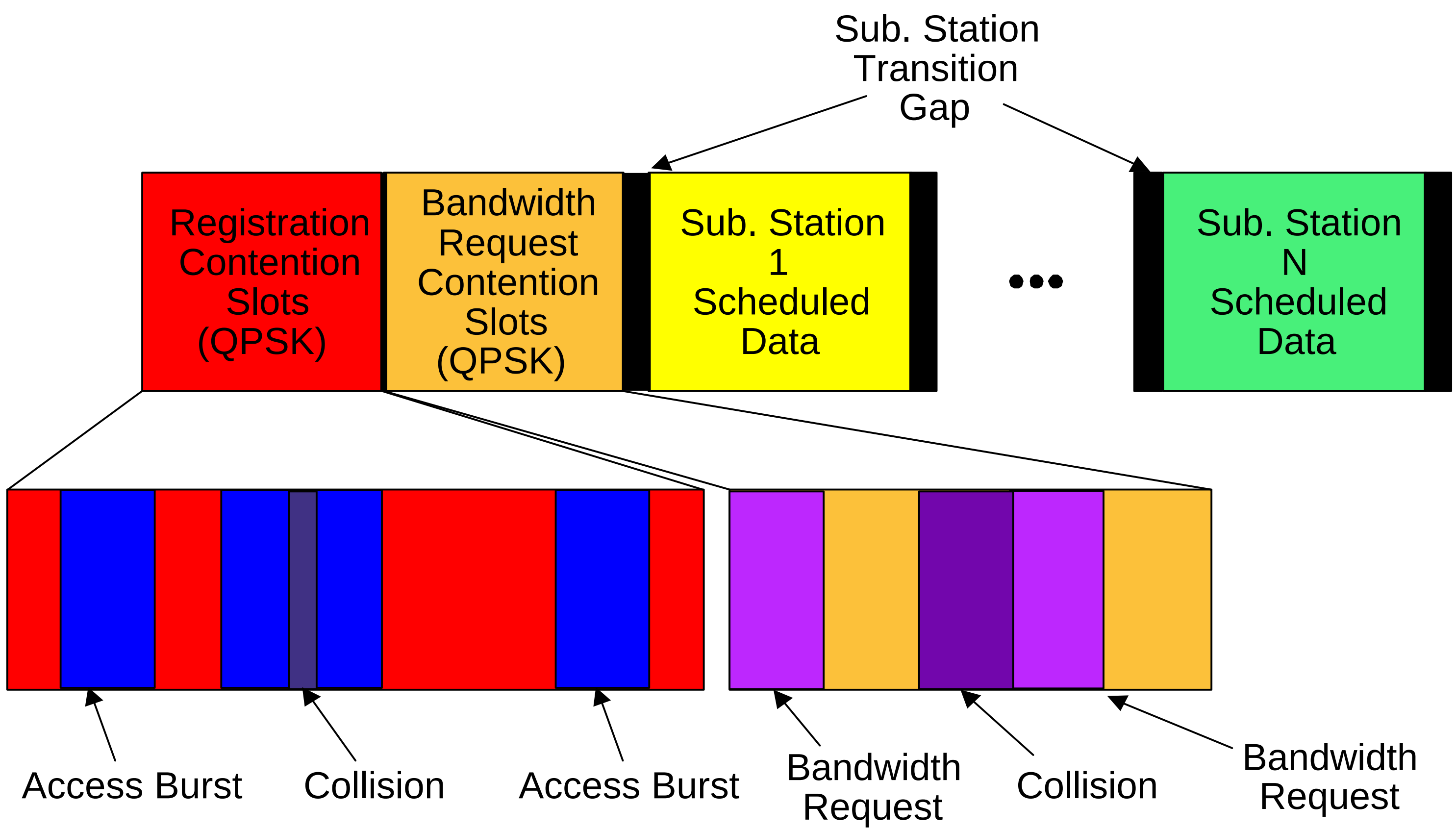



**When a H/FDD user receives it cannot transmit (no uplink allocation allowed)**

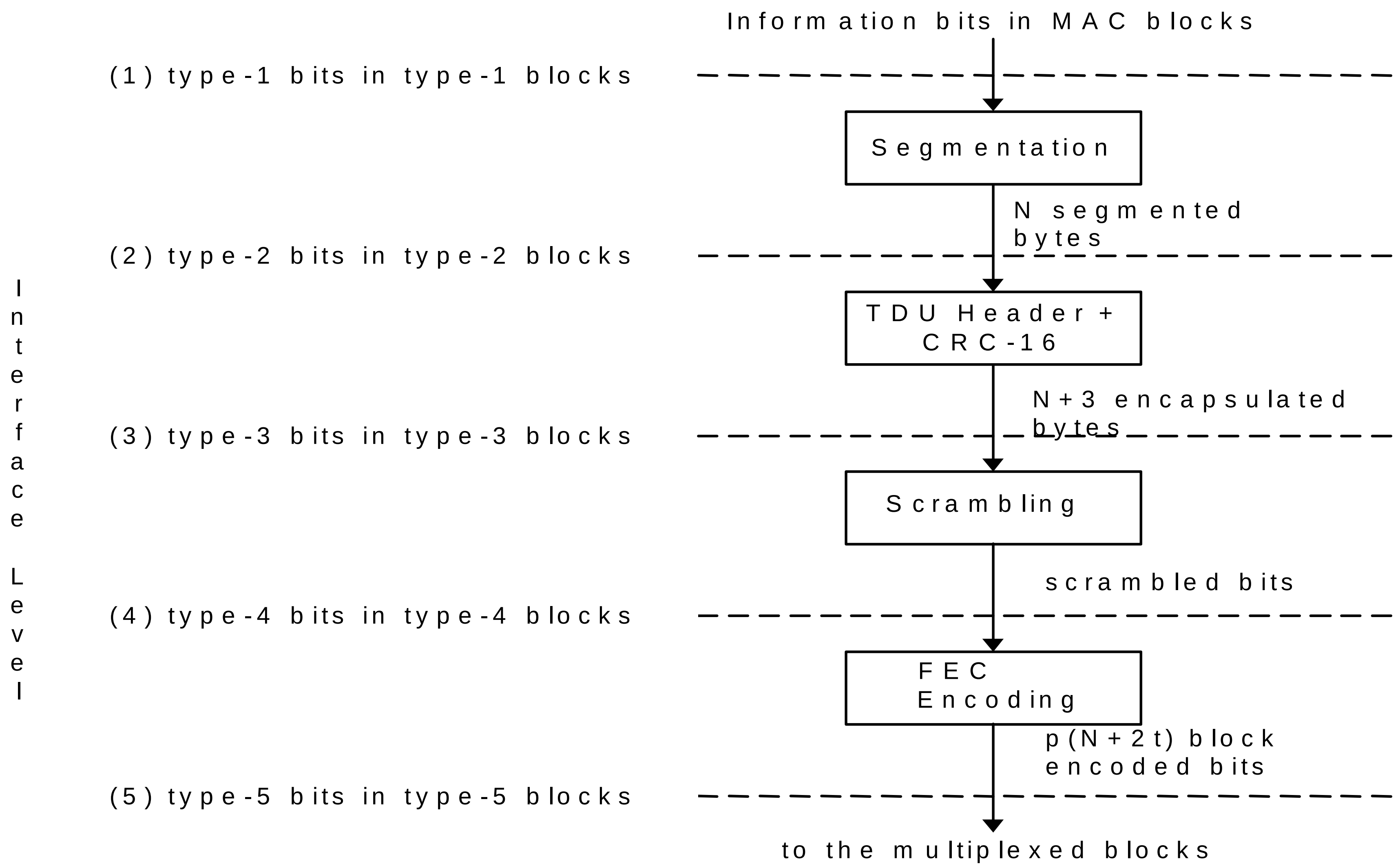
# Allocation maps for H/FDD

- The allocation map is needed to notify the terminal where to expect its downlink segment
- The map is similar to a uplink/TDMA map
- Allows for tight timing control of downlink vs. uplink bursts per terminal
  - Higher utilization of frame among terminals
- A preamble approach (no map, terminal needs to “run” over data) requires the terminal to be in a receive mode (no transmissions)
  - Large “dead zone” for allocation
  - Large preambles lead to larger overhead

# Uplink Sub-frame



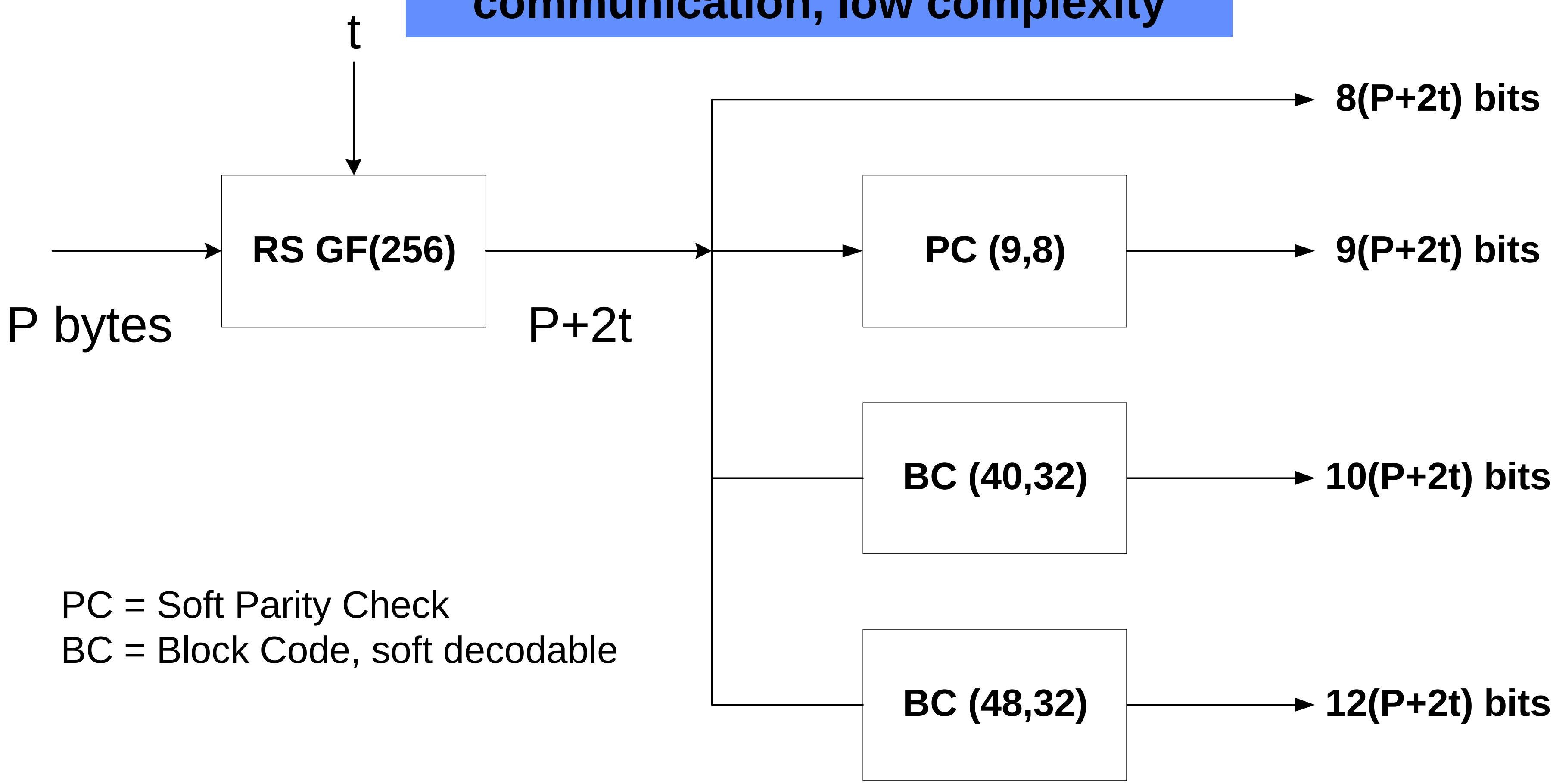
# FEC Process




Error_Control_IF.vsd

# FEC Scheme

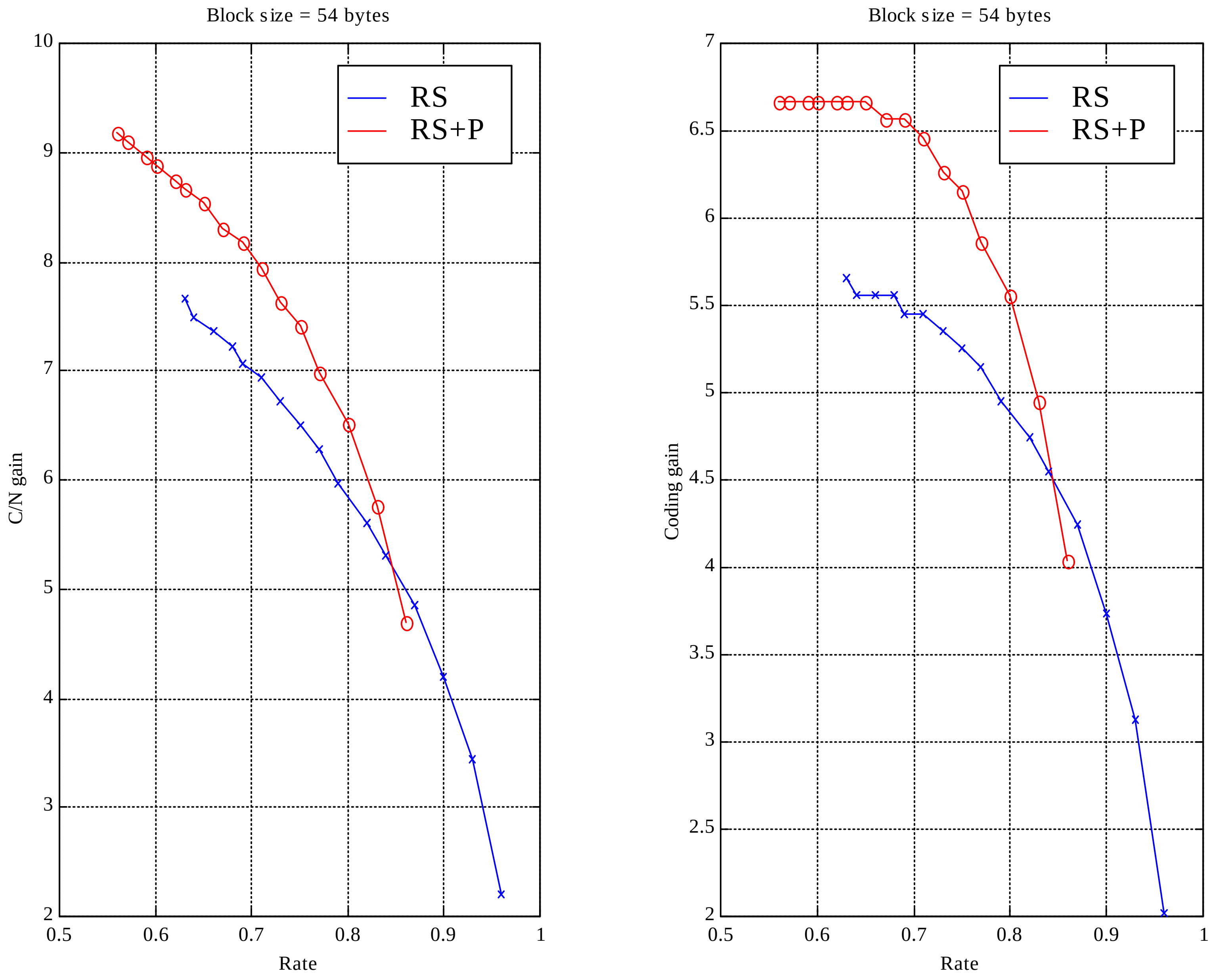
**Codes are designed for burst communication, low complexity**




PC = Soft Parity Check
BC = Block Code, soft decodable

# FEC Scheme – *cont.*

- Input to encoder: P bytes
- Output of decoder: k(P+2t) bytes
- Outer code: Reed Solomon, GF(256)
  - Shortened, Error correction capability t
- Inner code alternatives:
  - k=8, no inner code
  - k=9, inner code is a block code (9,8)
  - k=10, inner code is a block code (40,32)
  - k=12, inner code is a block code (48,32)
- Block code
  - (9,8) Parity check
  - (40,32) and (48,32) Conv. Code $(7,5)_8$, 32 bit input termination, tail-biting used
  - (40,32) and (48,32) are optional


Block size = 54 bytes
C/N gain
Rate
RS
RS+P
Block size = 54 bytes
Coding gain
Rate
RS
RS+P

| **Block Size** | **Inner Code rate** | **RS correction t** | **Overall Code Rate** | **Coding Gain (In dB) at BER $10^{-9}$** |
|---|---|---|---|---|
| 56 | 1/2 | 8 | 0.38 | 7.50 |
| 56 | 2/3 | 8 | 0.51 | 6.90 |
| 56 | 4/5 | 8 | 0.62 | 6.00 |
| 56 | 8/9 (parity) | 6 | 0.73 | 6.10 |
| 56 | 8/9 (parity) | 3 | 0.80 | 5.30 |
| 212 | 1/2 | 8 | 0.46 | 8.00 |
| 212 | 1/2 | 16 | 0.43 | 8.50 |
| 212 | 2/3 | 8 | 0.62 | 7.25 |
| 212 | 2/3 | 16 | 0.58 | 7.95 |
| 212 | 4/5 | 16 | 0.70 | 7.10 |

# FEC parameters

- PHY and MAC control portions & data transport for Downlink/TDM use P=128, t=5
- PHY and MAC control portions & data transport for TDMA use P=64, t=5
- Registration portion uses P=14, t=2
- Contention based access portion uses P=5, t=3
- Other options - TBD

# 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.

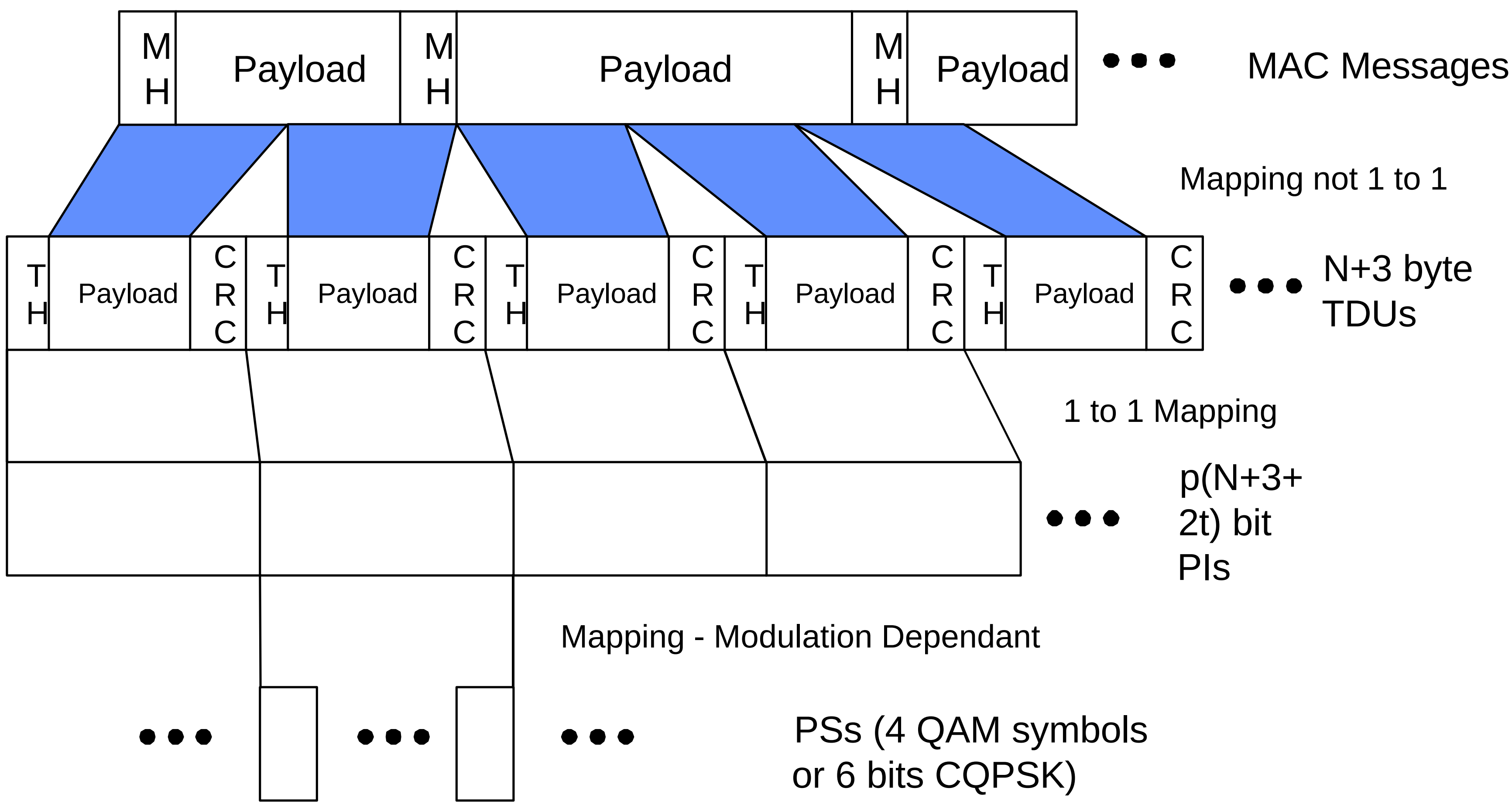
# Variable Length Coding

- 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.

# Distance/Capacity Trade-off

- C/N threshold could be decreased either by increasing the coding gain or reducing the coding rate or both
- Threshold decrease would lead to increased cell range
  - Larger cell $\Rightarrow$More customers $\Rightarrow$ More bandwidth sharing $\Rightarrow$less capacity per user
- We need to carefully balance between system gain and capacity by revisiting traffic requirements and available spectrum

# PHY/TC Interaction (both Uplink/Downlink)



# TDU Allocation by Modulation

| Modulation | PSs required |
|---|---|
| **QPSK** | N+3+2t |
| CQPSK | Ceil[4(N+3+2t)/3] |
| QAM-16 | Ceil[(N+3+2t)/2] |
| QAM-64 | Ceil[(N+3+2t)/3] |

**RS Only**

| Modulation | PSs required |
|---|---|
| **QPSK** | Ceil[9(N+3+2t)/8] |
| CQPSK | Ceil[3(N+3+2t)/2] |
| QAM-16 | Ceil[9(N+3+2t)/16] |
| QAM-64 | Ceil[3(N+3+2t)/8] |

**RS+Parity**

| | | |
|---|---|---|
| 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
  - Silicon is not the main system cost driver it is the RF (ODU)
- Supports efficiently **ALL** duplex scheme variants
- This is the best TDD/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