Proposal for IEEE 802.16m Downlink Feedforward Transmission Based on Hierarchical Modulation

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*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Re: IEEE 802.16m-08/024 – Call for Contributions on Project 802.16m System Description Document (SDD), on the topics of "HARQ (PHY aspects) and link adaptation"

Purpose: Adopt the proposal into the IEEE 802.16m System Description Document

Scope

- This contribution proposes feedforward transmission scheme for IEEE 802.16m.

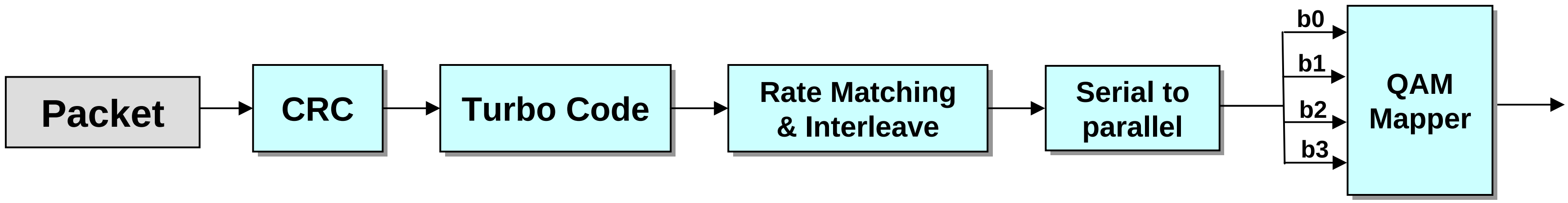
IEEE 802.16m System Requirements

- The TGm SRD (IEEE 802.16m-07/002r4) specifies the following requirements:
  - Section 6.2 Latency
    - “Latency should be further reduced as compared to the WirelessMAN-OFDMA Reference System for all aspects of the system including the air link, state transition delay, access delay, and handover.”
  - Section 6.3 QoS
    - “IEEE 802.16m shall support QoS classes, enabling an optimal matching of service, application and protocol requirements (including higher layer signaling) to radio access network (RAN) resources and radio characteristics. This includes enabling new applications such as interactive gaming .”
- The proposed design targets the above requirements.

Outline

- Regular modulation vs. hierarchical modulation
- Issues with existing link adaptation scheme
- Feedforward transmission based on hierarchical modulation
- HARQ for feedforward transmission
- MIMO feedforward transmission
- Simulation results

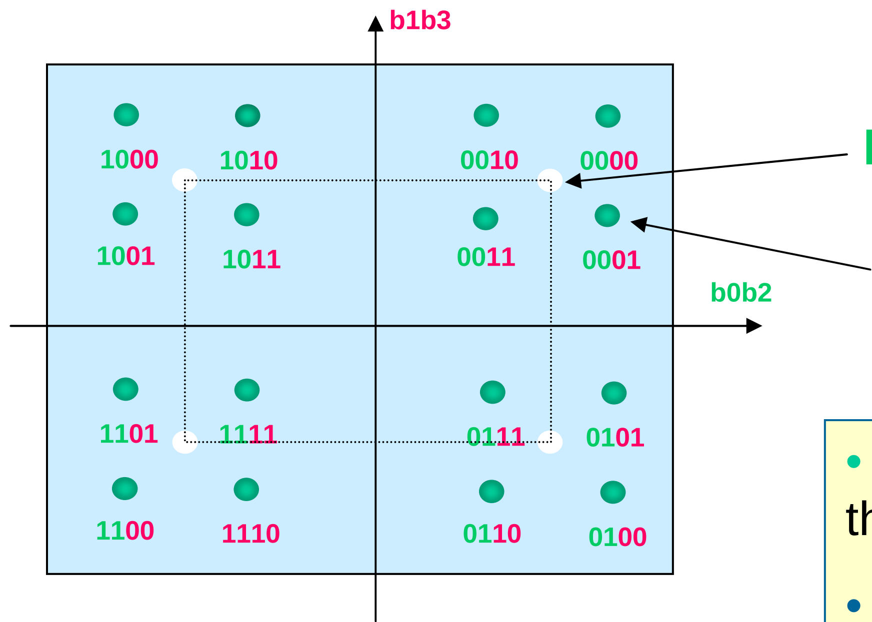
Regular Modulation



- Bits of one packet (e.g. b0b1b2b3) are mapped into one QAM symbol.

QAM Constellation: Multilayer Interpretation

- 16-QAM constellation (as an example) could be interpreted as a combination of two QPSK constellations with different average powers.



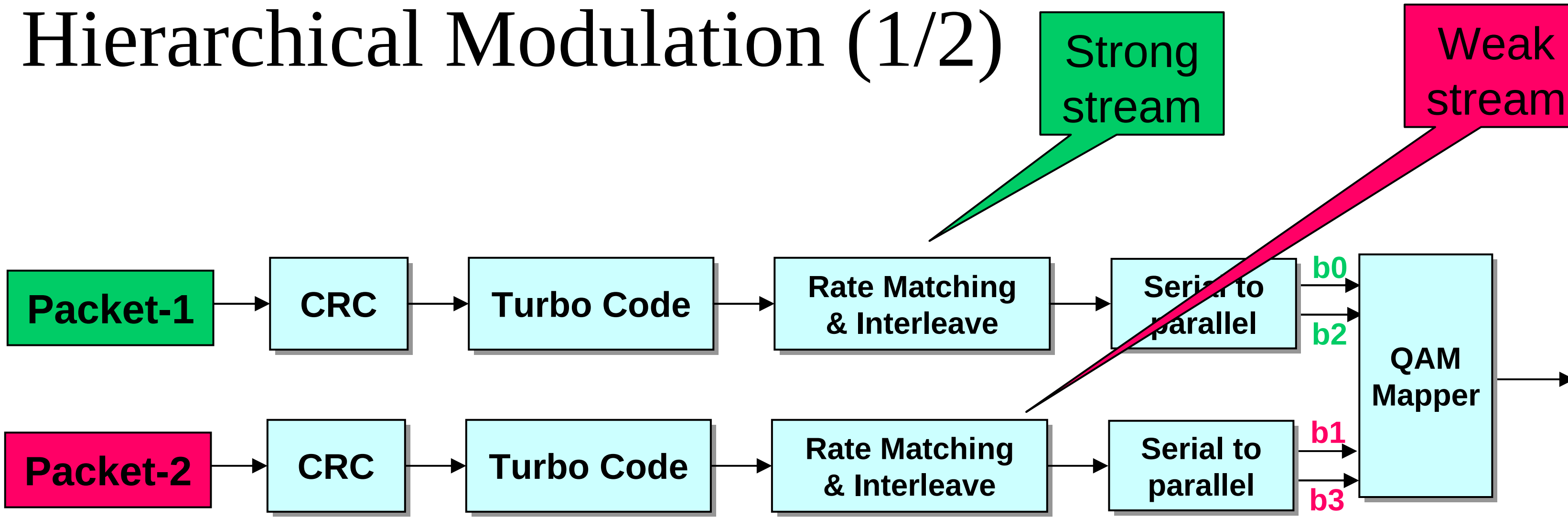
high SNR, d^2_{min}=1.6

low SNR, 6 dB less, d^2_{min}=0.4

- Raw BER of b0 and b2 is less than b1 and b3.
- Two layers with different quality.

QAM = map(b0b1) + j map(b2b3)

Hierarchical Modulation (1/2)



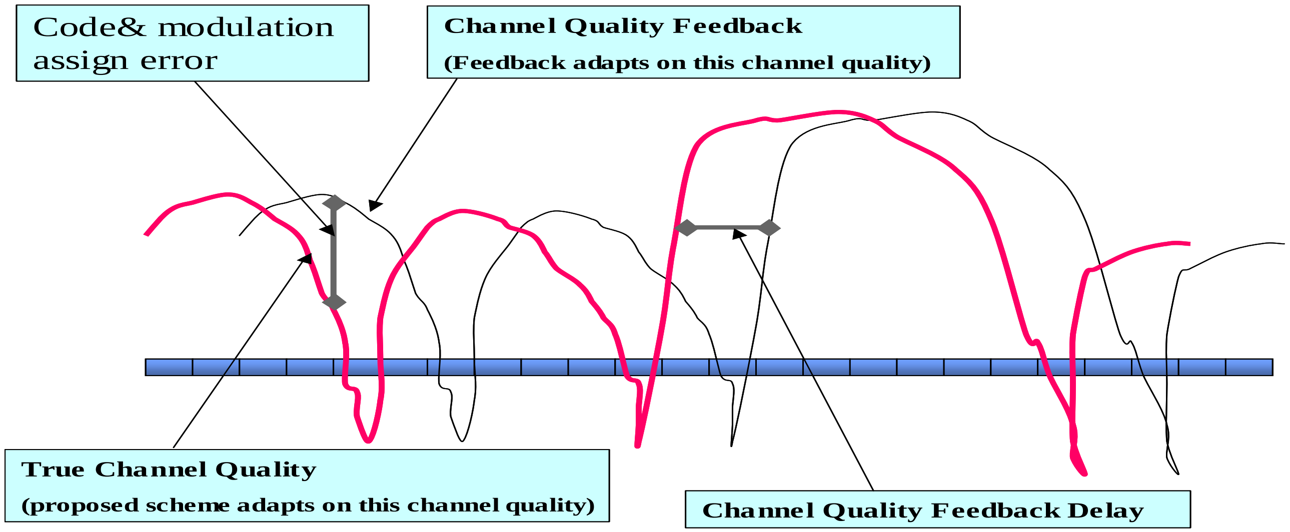
- In hierarchical modulation, several separate data streams are modulated onto a single QAM stream.
- Packets may have different length
  - Each stream can have different coding rate
- Each stream carries a different level of energy
- In this 16-QAM example, strong stream utilizes 80% energy of 16-QAM and weak stream utilizes 20% energy of the 16-QAM constellation.
- 64-QAM constellation could support 3 QPSK streams or two streams one QPSK and the other 16-QAM.
  - <u>3 QPSK</u>: 1st QPSK contains 57.1% energy, 2nd QPSK contains 28.6% energy, and the 3rd QPSK contains 14.3 energy.
  - <u>QPSK/16-QAM</u>: QPSK conations 57.1% and 16-QAM contains 42.9% energy of 64-QAM constellation. Note that, the rate of 16-QAM is two times more that QPSK.

Hierarchical Modulation (2/2)

- Advantages of multiple data streams
  - With down-fades, strong streams can still survive the transmission, the majority of the energy is not wasted (80% for 16-QAM)
    - If regular 16-QAM modulation is used, the whole transmission energy is wasted in down-fade condition of the channel
  - With up-fades, weak streams can catch up-fades and survive the transmission and fully utilize channel condition

Issues with Existing Link Adaptation Scheme (1/2)

- For the feedback based link adaptation scheme, in mobility environment (>30km/h), system capacity based on tracking of short-term fading is significantly reduced due to the following factors:
  - feedback delay
  - instantaneous C/I measurement error



Issues with Existing Link Adaptation Scheme (2/2)

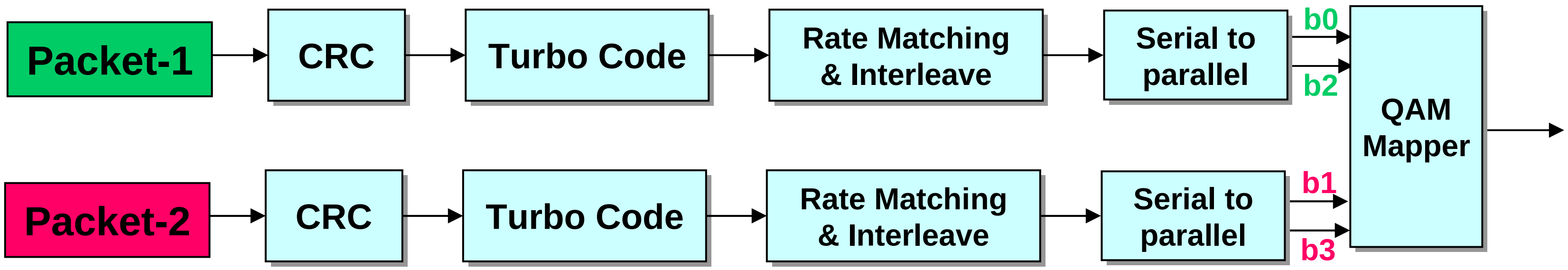
- In order to compensate for the inaccurate C/I feedback from the MS, BS selects MCS based on long-term behavior of the channel. System can not utilize the full capacity of the channel due to lack of instantaneous short-term fading information. In this approach, system can not catch the up-fades. MCS selection is based on average behavior of the channel, therefore, MCS is conservative and consequently throughput is low.

- In this contribution, we propose feedforward transmission scheme based on hierarchical modulation to fully utilize the instantaneous channel capacity. Long-term information is still required to set the coding rate. MCS is selected aggressively to make the channel overloaded. If channel is in up-fade condition, the whole packet is passed. If channel is in down-fade condition, most likely the strong stream of the hierarchical modulation can pass. Therefore, even with aggressive MCS level, at least a portion of transmitted energy is not wasted. HARQ can be used to retrieve information of weak stream of the hierarchical modulation.

Overview of Feedforward Transmission Scheme (1/3)

- Feedforward transmission provides the following benefit:
  - Mitigate the loss due to lack of instantaneous channel information
  - Reduce the CQI feedback rate, hence, increase the UL user data rate and simplify UL design
  - Reduce MS complexity by removing the fast accurate C/I estimation
  - Use HARQ to maximize utilizing the instantaneous channel capacity (catch up-fades)
  - Reduce delay of HARQ retransmission
    - useful for delay-sensitive services
    - reduce the buffer size in both BS and MS side

Overview of Feedforward Transmission Scheme (2/3)



- DL feedforward is an open-loop scheme
- Packets belong to one DL user
  - Packets may have different sizes ➔ different coding rate
  - Packet size (coding rate) is chosen based on long-term CQI feedback
    - One CQI per user
- QAM mapper
  - 16-QAM (2 QPSK streams)
  - 64-QAM
    - three QPSK streams
    - one QPSK stream and one 16-QAM stream

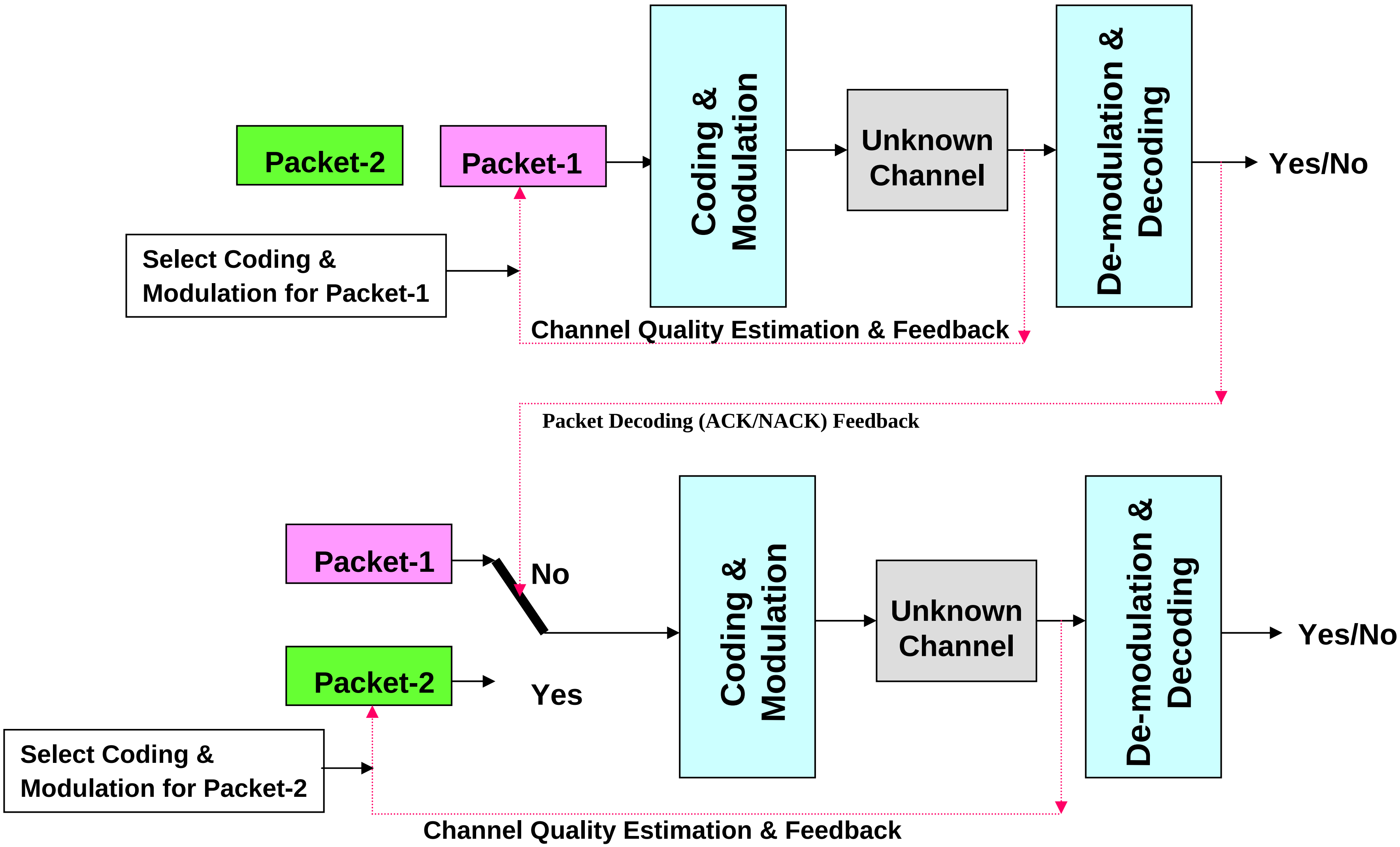
Overview of Feedforward Transmission Scheme (3/3)

- Feedforward transmission is suitable for multi-QoS service
  - Packets with different delay requirements
  - Packets with different PER requirement (e.g. video application)
  - Packet with high QoS requirements is sent over strong stream
  - Packet with low QoS requirements is sent over weak stream

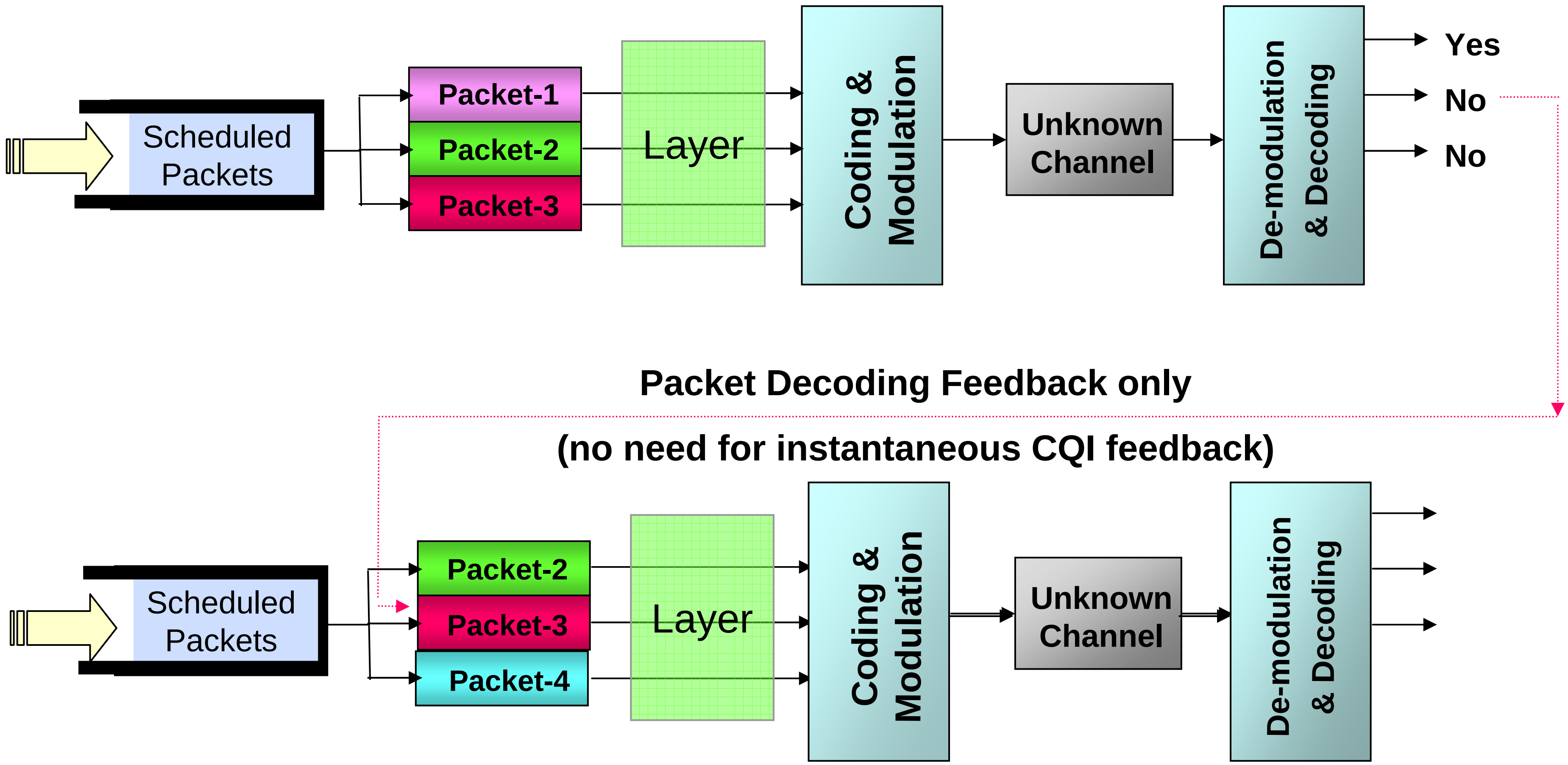
Feedforward Transmission with HARQ

- Traditionally, to maintain PER=1%, for fading channel, a significant margin (6-8dB) has to be budget to ensure that 99% of the time the received signal can be correctly decoded
  - conservative MCS level is selected based long-term CQI
- This implies the system operating point is rather conservative and channel up-fades are not utilized
- With HARQ, the operating point is shifted more aggressively to increase the system throughput
- When channel is in down-fade condition, the strong stream can most likely get through, if the weak stream fails, HARQ is used to retrieve the information of weak stream.
- **Use multi-data-stream transmission to maximize the benefit of catch-the-up-fades and use HARQ to compensate the loss of down-fades**

Traditional Feedback Based Re-transmission Scheme



Feedforward Re-transmission Scheme (1/2)



Feedforward Re-transmission Scheme (2/2)

- MS feeds back the layer index for the highest layer that passed (1 or 2 bits)
- BS retransmits the layers that fail.
- The method that packets are mapped to streams can be determined by scheduler and link-adaptation scheme
  - fixed mapping of packets to streams
  - dynamic mapping over HARQ retransmissions
  - the retransmission packets may be shifted to stronger layers to increase robustness (as shown in previous slide)

Feedforward Transmission with MIMO

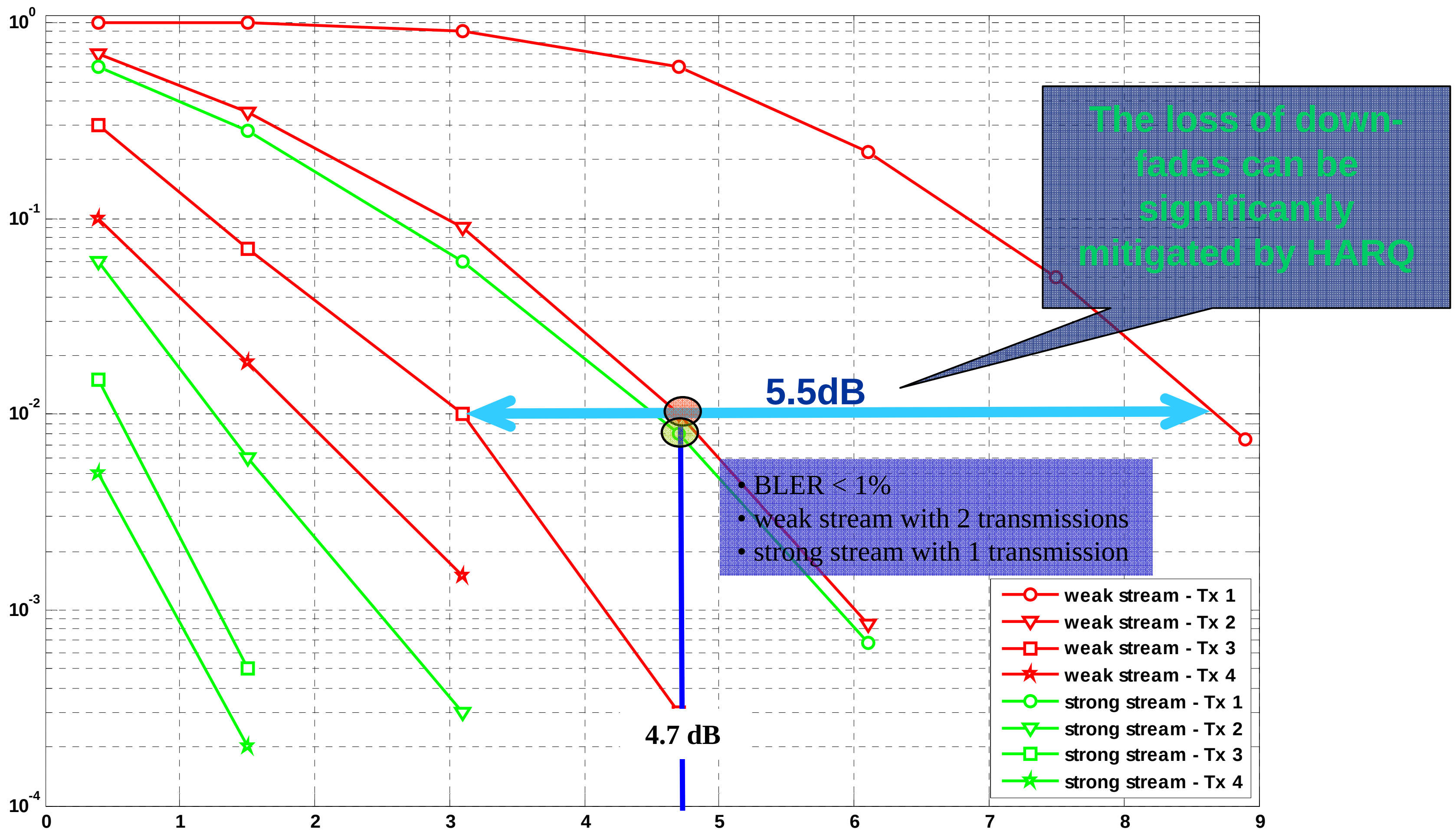
- Output of QAM mapper is passed through MIMO encoder
- MIMO encoder can have multiple layers
  - STC (rank 1)
  - SM (rank 2, 3, or 4)
- One feedforward QAM stream is mapped into all MIMO layers
- MS sends one long-term CQI for all MIMO layers
  - Modulation level of hierarchical modulation and coding rate of layers is selected according to the reported long-term CQI

Performance Evaluation of Feedforward Transmission with HARQ

Simulation Parameters

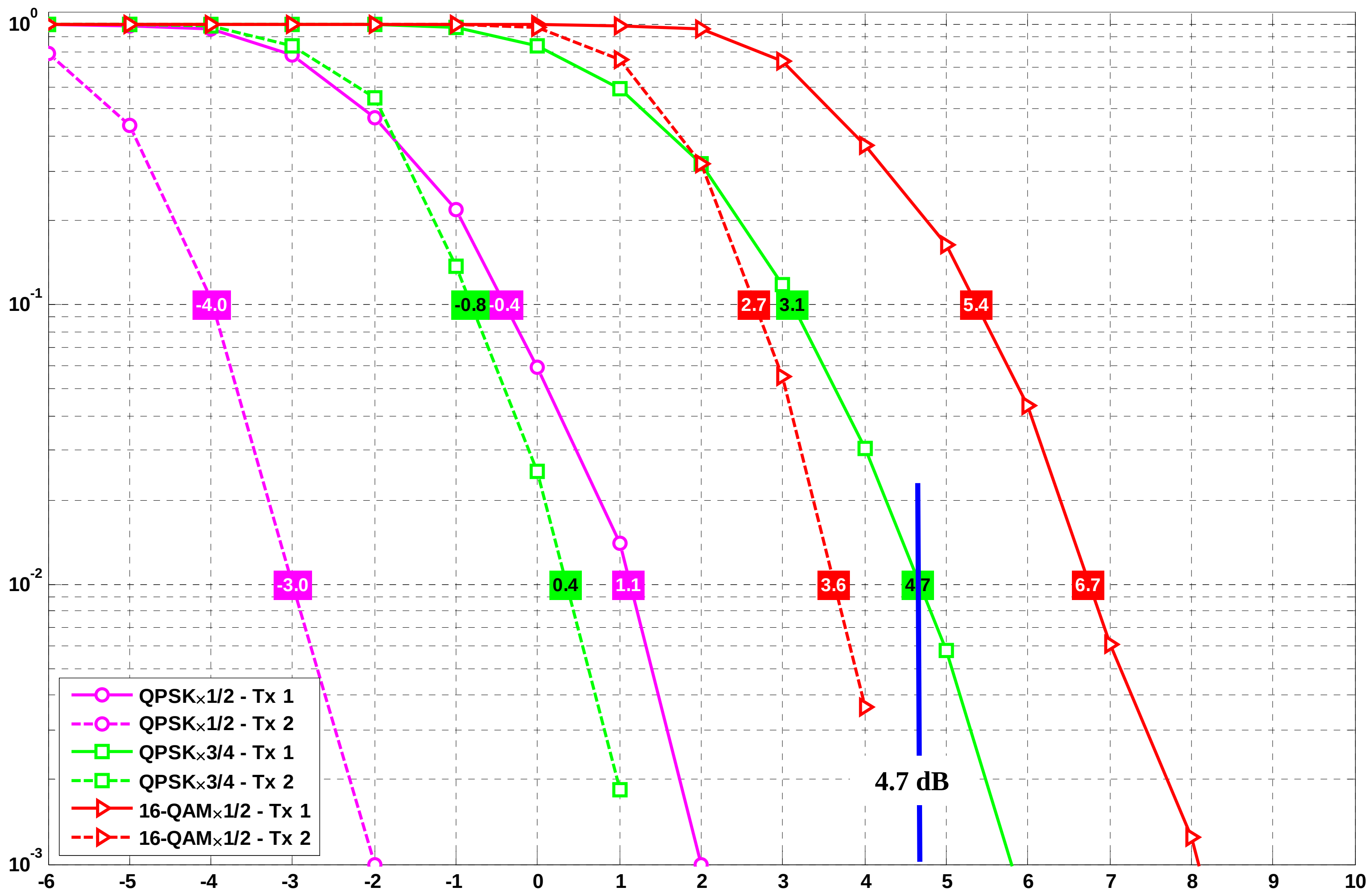
- **Channelization**
  - 2 RUs (18 × 6)
  - tone-based distributed
- **Antenna**
  - 2 Tx, 2 Rx
  - uncorrelated
  - 0 dB receive power imbalance
- **Fading channel**
  - VA 30 km/h
  - Carrier frequency 2.5 GHz
  - Ideal channel estimation
- **Detector**
  - Alamouti receiver
- **Coding**
  - Duo-binary turbo code
- **MIMO**
  - Downlink (DL) open loop (OL) matrix A (MA) for rank 1 transmission over 2 Tx antennas
- **HARQ**
  - Chase combining
  - Random mapping of packets to hierarchical streams

Link Level Performance for 16-QAM with HARQ



* 2 packets with CTC code rate ½, re-transmit packet is randomly mapped onto data streams

Regular Modulation with HARQ



A Case Study Comparing Regular and Feedforward Transmission

- Requirements:
  - Residual BLER of HARQ < 1%
  - Maximum number of transmission for service 1 = 1 (higher QoS)
  - Maximum number of transmission for service 2 = 2 (lower QoS)

- Operating point for feedforward scheme with 16-QAM, rate ½ for both streams is : ~4.7 dB (see slide 21)
- Overall spectral efficiency: 1.5 bits/tone/transmission (see appendix)

- With regular transmission, to meet requirements (see slide 22)
  - service 1 at 4.7 dB: modulation must be QPSK, rate ¾ (spectral efficiency = 1.5 bits/tone)
  - service 2 at 4.7 dB: modulation must be 16-QAM, rate 1/2 (spectral efficiency = 2.0 bits/tone)
- Overall spectral efficiency: 1.28 bits/tone/transmission (see appendix)

Feedforward scheme with HARQ improves throughput of delay sensitive services

Single (Regular Modulation) and Multiple Data Streams (Feedforward) Comparison with HARQ

- Multi-data-stream scheme is better than single-data-stream for delay limited services
  - the strong stream will pass with high probability without HARQ
  - reduction of buffer size at both BS and MS side
- To mitigate delay-sensitivity by single stream transmission, the MCS must be set to lower level to reduce number of HARQ retransmissions ➔throughput loss due to lower MCS level
- Throughput of feedforward is more than regular modulation for delay-sensitive transmissions.

Proposed Text for SDD

- Section 11.x.1: DL Feedforward Transmission
  - [*copy content of slides 11,12,13 here*]
- Section 11.x.2: HARQ for Feedforward Transmission
  - [*copy content of slides 16,17 here*]
- Section 11.x.3: MIMO and Feedforward
  - [*copy content of slide 18 here*]

Appendix: Spectral Efficiency Calculation (1/2)

- Overall spectral efficiency of feedforward transmission
  - size of packet 1 and 2 : b bits
  - spectral efficiency of every stream of hierarchical modulation 16-QAM with coding rate ½: 1 bit/tone
  - total number of shared tones required to transmit packet 1 and 2: b [bits]/1[bit/tone]= b tones
  - overall spectral efficiency over 2 transmissions = b (bits, packet 1 Tx 1) + b (bits, packet 1 Tx 2) + b (bits, packet 2 over Tx 1 and 2) / b [tones] / 2 [transmissions] = 1.5 bits/tone/transmission

Appendix: Spectral Efficiency Calculation (2/2)

- Overall spectral efficiency of regular transmission
  - size of packet 1 and 2 : b bits
  - spectral efficiency of QPSKx3/4 for packet 1: 3/2 bits/tone
  - spectral efficiency od 16-QAMx1/2 for packet 2: 2 bits/tone
  - total number of tones required to transmit packet 1: b [bits] /(3/2) [bits/tone] = 2b/3 tones
  - total number of tones required to transmit packet 2: b [bits] / 2 [bits/tone]= b/2 tones
  - total number of tones required to send packet 1 and 2: 2b/3+b/2=7b/6
  - overall spectral efficiency over 2 transmissions = b (bits, packet 1 Tx 1) + b (bits, packet 1 Tx 2) + b (bits, packet 2 over Tx 1 and 2) / (7b/6) [tones] / 2[transmissions] = 9/7 bits/tone/transmission