Multiple Profiles for EPoC

IEEE 802.3bn – Multiple Profile ad-hoc

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Why adaptive modulation and coding scheme?

- Two very important benefits are achievable by adapting the downstream transmission to the user channel conditions:

  A. Increase of overall performance of the cable plant

  B. Reduction of SNR margins and easier operations – the plant is automatically adjusted to the user condition

- These two benefits directly translates into CAPEX and OPEX savings/benefits for operators:
  - more data can be delivered in the plant due to optimized matching of channel conditions for groups of users and reduced SNR margins
  - automatic adjustments to slowly varying channel conditions achieved by assessing and grouping users, without human intervention

Observations

Measurements and estimates show a **gain of ~17% to 43% in spectral efficiency and of 20% to 50% in peak data rate** can be achieved vs. single fixed profile

- SNR variations among users in a plant are present in all frequency regions and they tend to be larger for higher portion of the spectrum
- Mitigation could be done via plant upgrade to certain extent, but could be costly or not always possible in all locations – thus implying reduction of service penetration

Bit Loading does not seem to offer a significant gain over single MCS

- Single MCS should be combined with frequency interleaving for better performance
- Good selection of MCS set enables an efficient adaptation to the channel quality
  - MCS granularity can be obtained by modulation and/or code rate variation

Considering tradeoffs of performance gains, easier operations and lower SNR margins, complexity and specification impact, the solution with <u>MCS per user group</u> is the best for EPoC downstream

Design Overview

- The downstream channel conditions are assessed and reported by each user during the PHY negotiation procedure, for the EPoC channel in use
  - The collected information is provided to upper layers via MDIO
- The CLT maintain a table in which users are grouped according to their supported Modulation and Coding Scheme (MCS), which is used by MAC Control to determine the supported rate and regulate idle insertion
- The PHY at the CLT processes the transmit packets on a per-group base, so that packets belonging to the same group can be encoded together
  - Stream based FEC applied to each group with large code words
  - MCS transitions optimized FEC efficiency by filling up the last code word as possible and eventually shortening it to free resources for the next group
  - A mapping of the OFDM symbol is included in the first part of the symbol (fixed robust MCS and reserved sub-carriers) to inform the receiver PHY in the CNU about how to decode incoming OFDM symbol and de-jitter packets
- The PHY at each CNU decodes the mapping of the incoming OFDM symbol and uses the information to process the related part in the PHY

MAC-Control Operations

- For each packet to be transmitted, the MAC Control extracts from the MCS table the corresponding entry for the involved CNU
  - Depending on the MAC client which provides the packet, the CNU group is identified and the related MCS is read
  - Once the MCS is known, the corresponding data rate is calculated, which allows for the correct idle insertion after the packet (rate match)

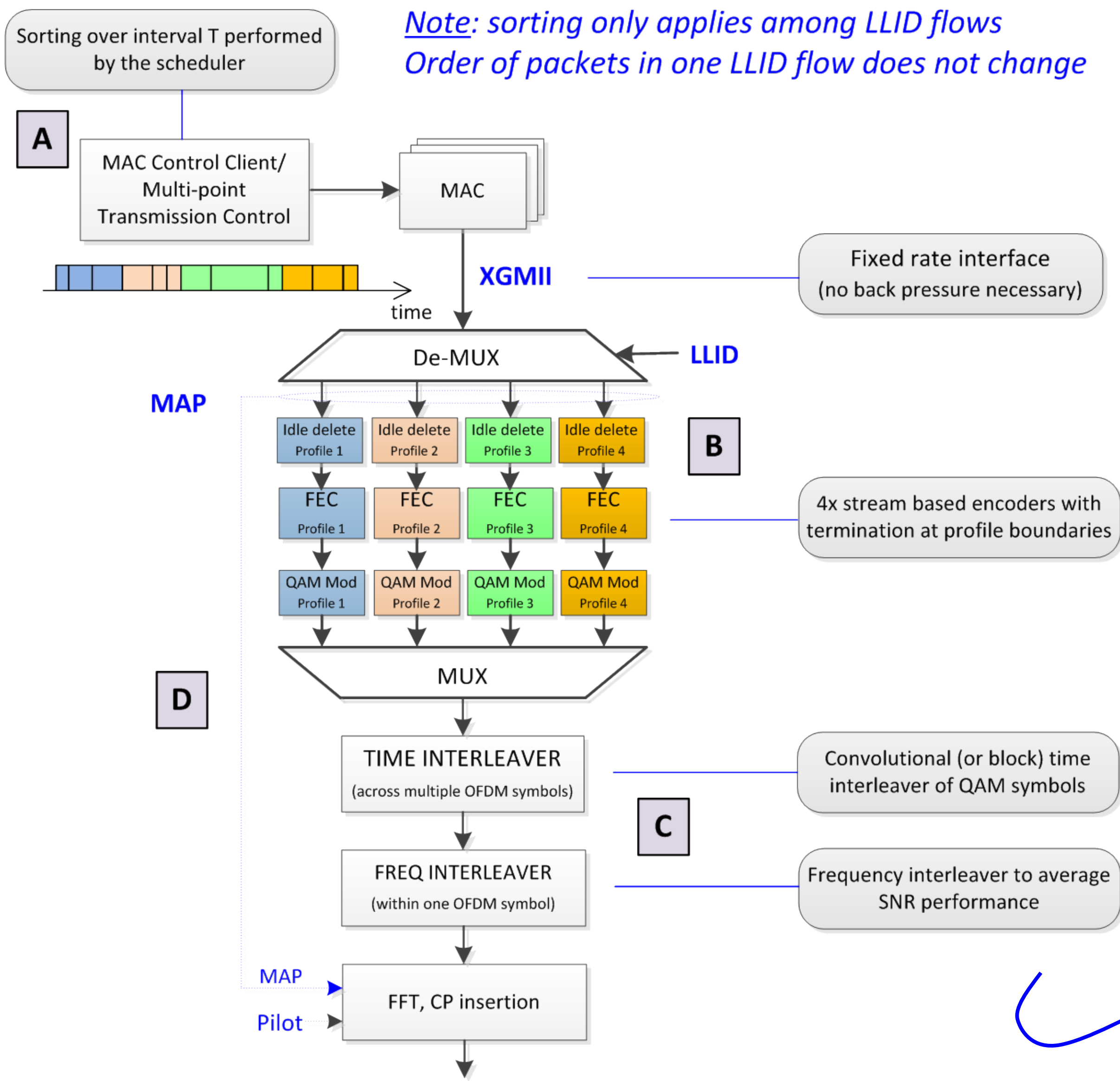
- Note: This operation is the same if a single MCS is used in the plant, whereby here a table with more values is used (no complexity added)
  - Single MCS can still be supported as possible use case

- Number of MCS per plant: in practical deployments, a small number of groups (MCS) is sufficient to cover the range of typical SNRs
  - A range of e.g. 6-8 values can be included in the specification
  - In each plant, up to e.g. 4 groups can be configured at the time, choosing among those standardized values and a index/table is used to identify them

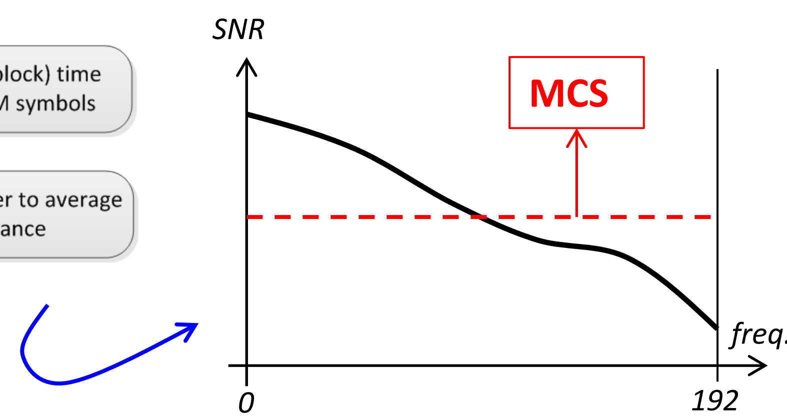
PHY Operations – Grouping and Encoding

- To minimize FEC overhead, packets that are using the same MCS (i.e. for LLID pointing at CNU in the same group) are sent contiguously
  - Stream based FEC applied to each group, enable possible large code words
  - Group-to-group transition with optimized FEC efficiency by filling up the last code word as possible and eventually shortening it to free resources for the next group
    - MAC Control is aware of FEC formats to insert correct number of idles
  - The number of transitions is small (as the number of group in the plant is small)
- The grouping of packets can be performed
  - at MAC Control (e.g. via semi-static split of resources within a symbol, slowly adapting over time as traffic and groups change)
  - at PHY layer (e.g. distributing packets to the correct PHY processing chain based on their LLID – LLID maps uniquely into a MCS)
  - Both alternatives allows for single XGMII between MAC and PHY
- Broadcast traffic can be map into the group with smallest MCS, so that everybody can decode – similar concept could be used for multicast

Downstream operations – Grouping at MAC Control



- Support of multiple groups via capability exchange
- Each group has fixed data rate (MCS), no backpressure needed
- Sorting applied at MAC Control over configurable interval – no impact on EPoC PHY delay budget



Downstream operations overview

A. Concurrent downstream transmission requests from different MAC Client are coordinated by the Multi-Point Transmission Control entity in the CLT
   - packets are sorted by the scheduler based on their destination and grouped per profile, so they appear in a convenient order to be processed in PHY
   - idles are inserted after each packet for de-rating, upon need

B. Within the baseband processing of each channel, packets are divided into N parallel flows (N is configurable, e.g. N = 1…4), one for each configured profile, and processed accordingly (idle deletion + FEC+ QAM modulation)
   - due to scheduler operations in A, packets are already grouped on a per profile base, so that the FEC encoder can be performed efficiently

C. Processed data from each profile are multiplexed again together (same order is maintained to minimize possible time jitter) and the interleaving operations are performed (time and frequency) for each channel

D. A MAP is created during PHY processing and inserted into the symbol to be conveyed to the receiver using a fixed and robust modulation and coding scheme and reserving a small fixed number of OFDM subcarriers in a precise position

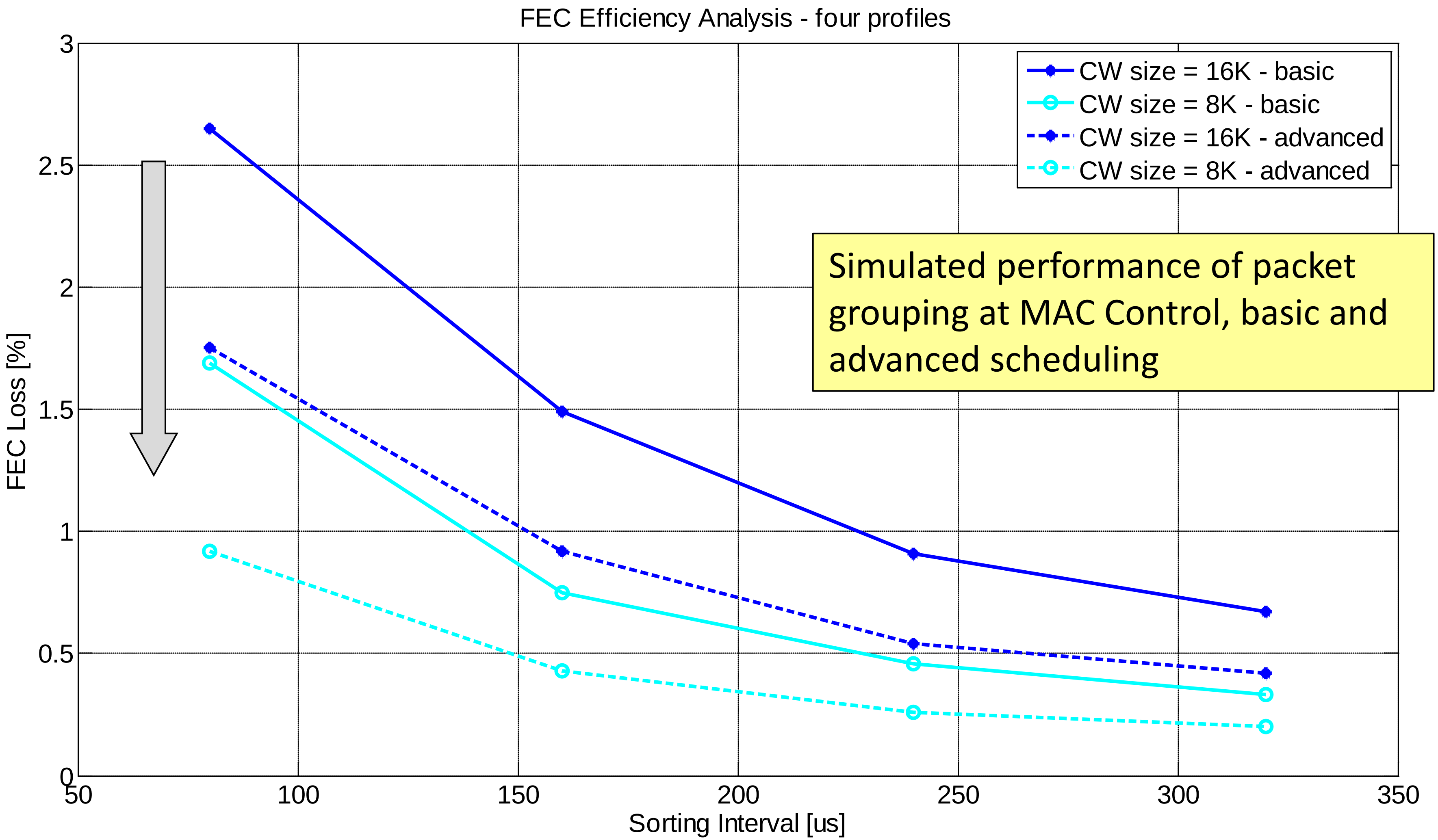
CNU Reception

- The PHY at the CNU receiver first decode the symbol map part in order to get instructions about what part of the OFDM symbol is of interest and where the corresponding code words are located

- All the code words for that group are decoded and all packets retrieved
  - PCS provides idle insertion (also) for packets which are not decoded
  - LLID is then used as usual to filter at RS what packets are for the CNU
  - No reordering of packet necessary within the same group

- Jitter handling:
  - In case the packet grouping is done at MAC Control, jitter is avoided

PHY Operations – FEC Efficiency



- The potential FEC losses are limited to less than 3% and can be further optimized and tuned via sorting interval and code word size configuration

Conclusions

- A design proposal for multiple profiles in EPoC downstream has been illustrated, based on MCS
- Preliminary analysis of performance shows low overhead and no added EPoC PHY delay or jitter is achieved via grouping packets at MAC Control level
- The proposal adds very limited complexity in comparison to single profile per plant, while achieving important benefits in terms of easier plant operations, automatic adjustment to (slowly varying) channel conditions and higher deliverable system throughput

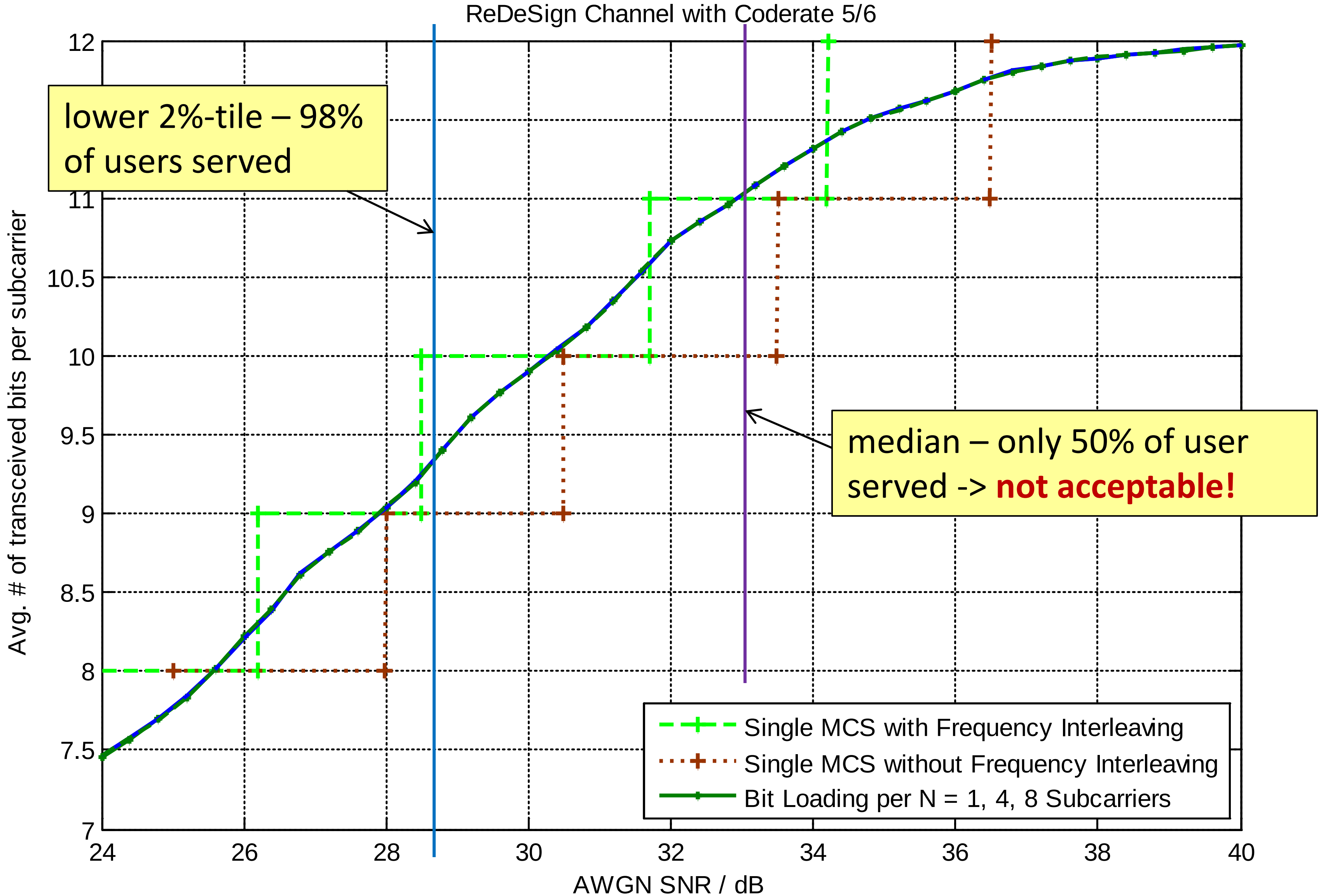
➢ **Multiple profiles for EPoC downstream is feasible**

SNR Analysis - Summary

SNR Estimates	Broadcast per plant		Broadcast per user group	
	Common MCS (reference)	**Bit loading**	**Single MCS per user group**	**Bit loading per user group**
Average spectral efficiency	7.2 bps/Hz	9.4 bps/Hz	9.5 bps/Hz	10.3 bps/Hz
Gain	--	30%	32%	43%
Peak User Spectral efficiency	7.2 bps/Hz	9.4 bps/Hz	10.8 bps/Hz	10.8 bps/Hz
Gain	--	30%	50%	50%

SNR Measurements	Broadcast per plant – Common MCS	Broadcast per user group – single MCS per user group
Average spectral efficiency	9.0 bps/Hz	10.5 bps/Hz
Gain	--	17%
Peak User Spectral efficiency	9.0 bps/Hz	10.8 bps/Hz
Gain	--	20%

Throughput Comparison – Bit Loading vs. MCS



Note: SNR distribution example with normal distribution with 33 dB average and 2 dB deviation