Qualcomm Research

Modulation Profiles in EPoC US

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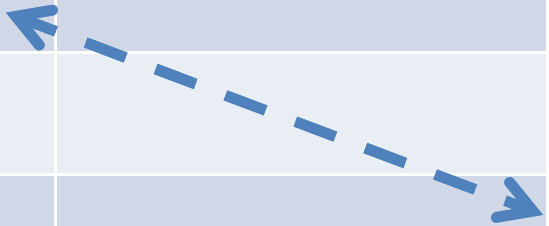
Outline

- Problem motivation
- Frequency variability of coax channels
- Countermeasures against SNR variations
- Modulation profile considerations
- Conclusions

Motivation

- How to achieve maximum efficiency/throughput in EPoC US under the given constraints
  1. significant coax channel variability
  2. scheduling constraints: constant MAC data rate desirable, no frequency awareness
- Modulation adaptation options:

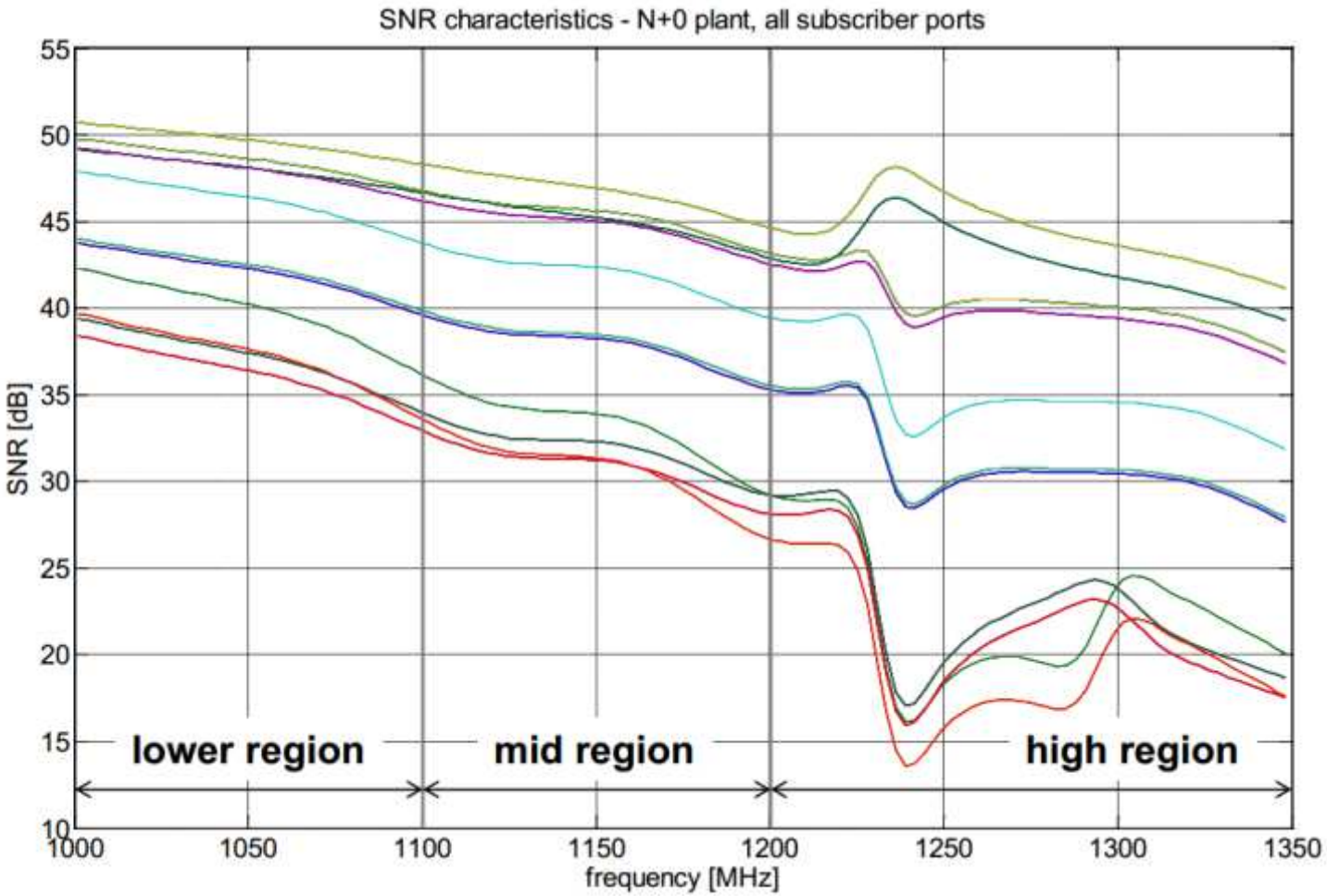
Adaptation: **per CNU →** **↓ over frequency**	**Single Modulation Profile (SMP)**	**Multiple Modulation Profiles (MMP), constant offset between CNUs**	**MMP independent for each CNU**
Constant modulation for all SCs	low complexity low efficiency no adaptation		
Constant modulation per PHY resource block (PRB)			
Per-SC Bitloading			high complexity high efficiency full adaptation



Frequency Variability of Coax Channel

- The US SNR can exhibit a large frequency variability, e.g. due to
  - Frequency slope/roll-off (esp. high split scenario),
  - Ingress noise
- Despite noise funneling, there is also a per-CNU variability, due to
  - individual attenuation levels
  - differences in effective frequency selective channels
- The following figures provide examples of this channel variability
  - Channel variations can easily exceed 30 dB

Frequency Variability: SNR Distribution



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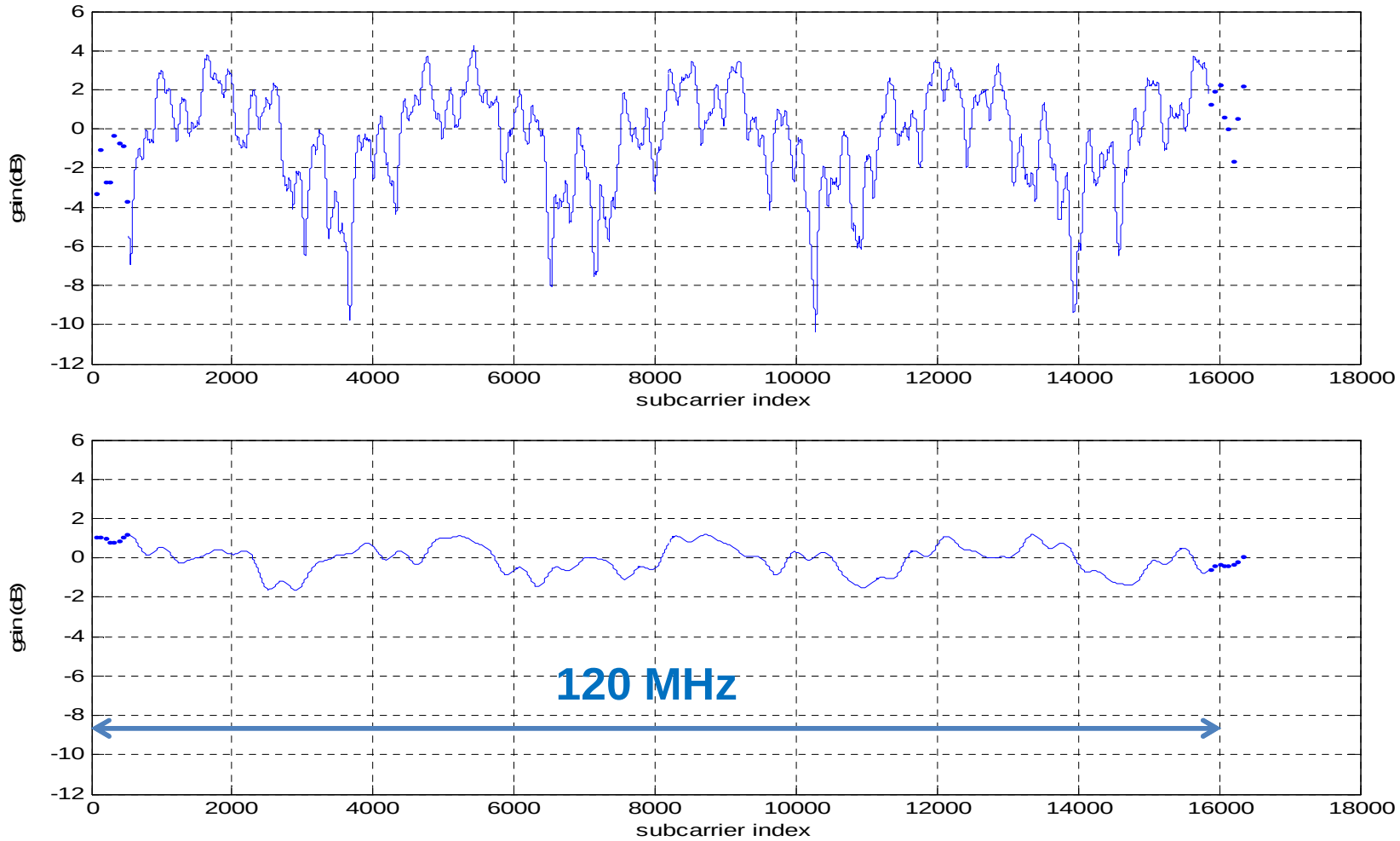
N.B. Result was derived for DS, but for N+0 should be equivalent to US

Frequency Selective Coax Channels

- 10 dB / 3 dB spread



Countermeasures against SNR Variations

- Possible mitigation techniques
  - Power control: addresses overall per-CNU attenuation
  - Pre-equalization: addresses frequency selective channel, and parts of slope, ingress
- Limitations:
  - Overall maximum Tx power is limited to 65 dBmV (16 dBm on 75 Ω)
  - Total Tx dynamic range should not exceed e.g. 40 dB (for fixed PA gain)
    - increasing dynamic range increases PA distortions, makes it difficult to maintain high required Tx SNR (e.g. 47 dB)
  - Total dynamic range has to consider OFDM PAPR (approx. 12 dB)
  - Leaves only approx. 28 dB for power control
  - However, channel variations can exceed 35 dB

- → Power control and equalization cannot address channel variability in all scenarios
  - Instead, capacity would be determined by worst case CNU

Modulation Profile Considerations

- Worst case CNU:
  - High individual attenuation
  - Scheduled at upper end of frequency slope (high split)
  - in bad part of frequency selective channel (FSC)

- Potential SNR loss example

  20 dB (slope) + 3 dB (res. FSC) + 15 dB (per-CNU attenuation) – 28 dB (PC) = **10 dB**

- There is no suitable single MCS for CNUs that can be 10 dB apart in received SNR
  - Would lead to significant capacity loss

- → EPoC US should employ frequency-adaptive Modulation Profile(s)
  - MP should coexist with pre-equalization and power control

MP Examples

- MP could consist of 4K QAM, 1K QAM, 256QAM, 64QAM
  - can cover a 24 dB SNR range
  - Finer granularity: non-square constellations, mixed constellations, coding
- MPs are assigned depending on the frequency range that a user's transmission is scheduled
- Per-CNU variations (attenuation) can be addressed by
  - Individual constant modulation offsets per CNU (MMP)
  - or, exclusively by power control (SMP)

Adaptation: per CNU → ↓ over frequency	SMP	MMP, const. offset between CNUs	MMP independent for each CNU
Constant modulation for all SCs	no adaptation		
Constant modulation per PRB	✓	✓	
Per-SC Bitloading			full adaptation

MP and Scheduler Frequency Awareness

- Does the scheduler need to be frequency aware to allow a frequency-adaptive MP scheme?
  - We believe there are solutions to avoid this requirement
  - e.g. [boyd_01_1112.pdf]

Constant Modulation per PRB, or Bitloading?

- PRBs should be large enough to allow per-CNU frequency interleaving
  - reducing residual FCS variability effects on decoding performance
    - (FCS is largely mitigated by pre-equalization)

- Frequency interleaving across each CNU's subcarriers will effectively remove the need for subcarrier-level bitloading
  - MCS of each PRB will be chosen according to individual average SNR
  - see our Docsis 3.1 DS contributions on bitloading vs. constant MCS

- Bitloading has higher complexity and signaling overhead which is probably not justified by higher efficiency

Conclusions

- How to achieve maximum efficiency/throughput in EPoC US under the given constraints
  - significant frequency & per-CNU channel variability, can exceed 35 dB
  - scheduling constraints regarding frequency awareness
- Power control and equalization cannot address channel variability in all scenarios
  - capacity would be determined by residual worst case CNU
- MPs allow to address a large residual Rx SNR range
  - should coexist with equalization and power control for maximum efficiency
  - Per-CNU variations (attenuation) can be addressed by
    - Individual constant modulation offsets per CNU (MMP)
    - or, exclusively by power control (SMP)
- Scheduler frequency awareness can probably be avoided

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thank you