

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

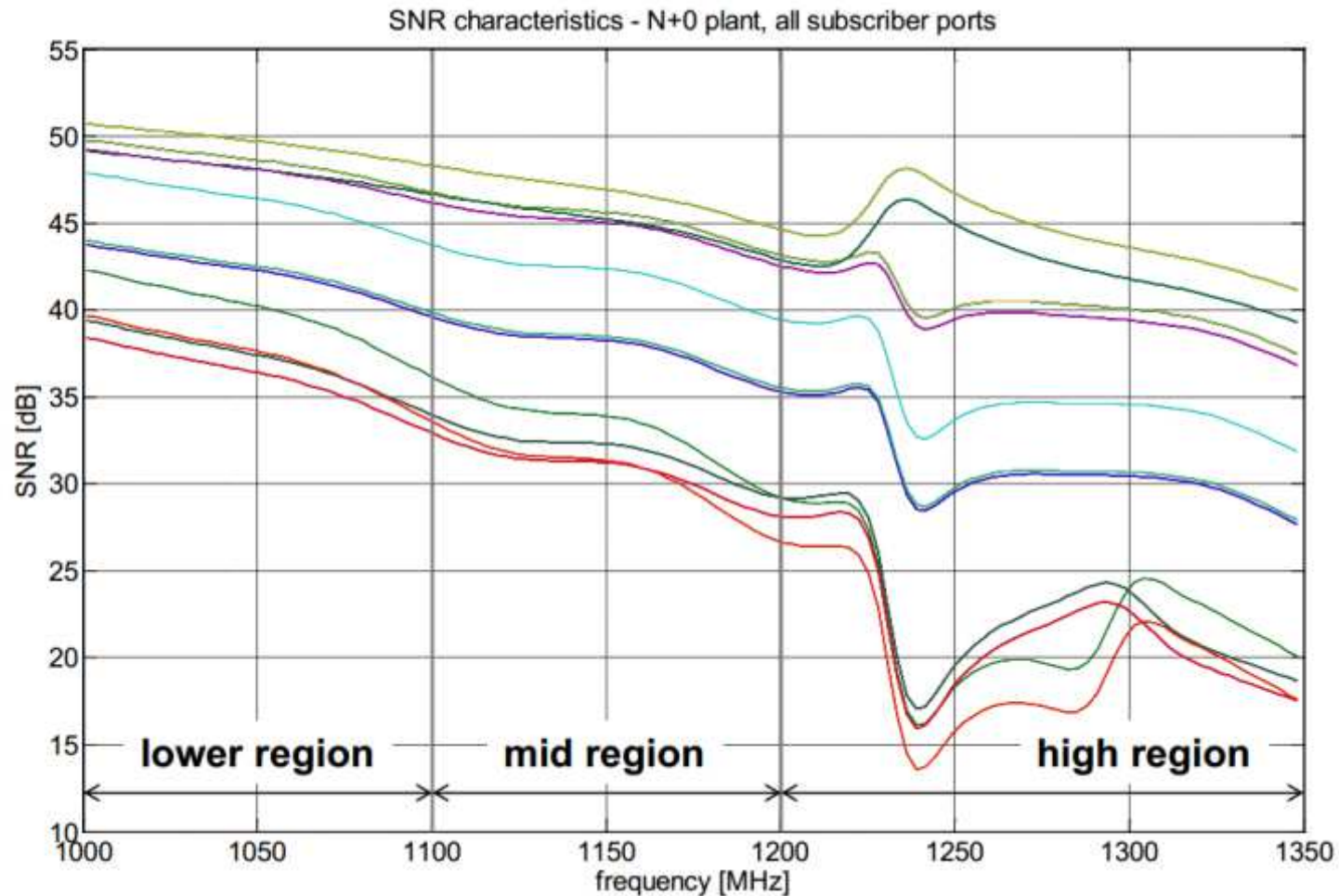
- How to achieve maximum efficiency/throughput in EPoC US under the given constraints
 1. significant coax channel variability
 2. scheduling constraints: constant MAC data rate desirable, no frequency awareness
- Modulation adaptation options:

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

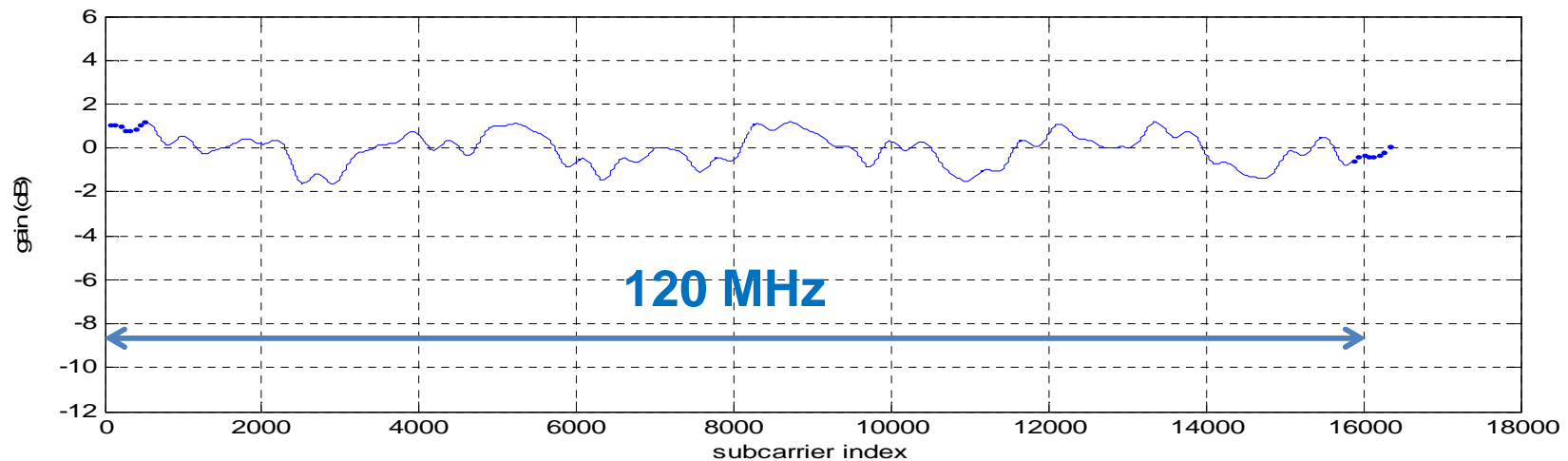
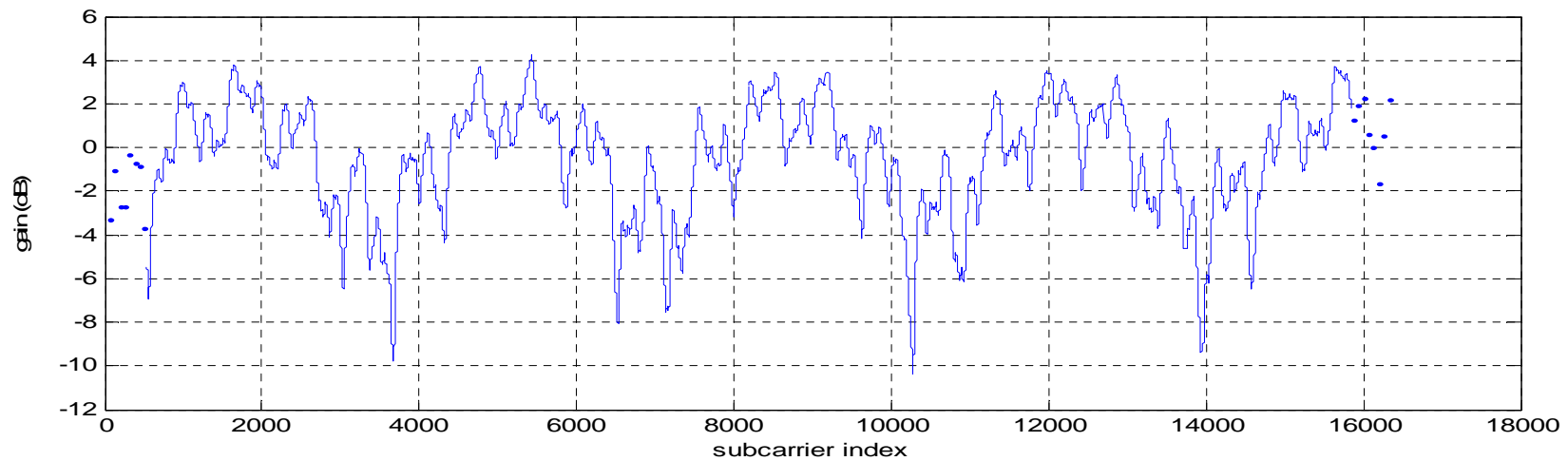


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N.B. Result was derived for DS, but for N+0 should be equivalent to US

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
 $20 \text{ dB (slope)} + 3 \text{ dB (res. FSC)} + 15 \text{ dB (per-CNU attenuation)} - 28 \text{ dB (PC)} = \mathbf{10 \text{ dB}}$
- 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