Burst Markers in EPoC

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Introduction

- Burst markers are used to indicate the start and end of each burst in EPoC burst mode
  - The same marker delimits the start and the end of a burst
- A burst marker is a sequence of known modulated symbols (in the frequency domain).
- To indicate the profile of a burst, a different marker can be used for each profile.
  - E.g., assuming the use of a ternary alphabet for the markers

Profile	Marker (8 symbols)
0	{+1, 0,-1,-1, 0, 0,+1,+1}
1	{ 0,-1, 0, 0,+1,+1, 0, 0}

Upstream Transmission

Upstream Burst Markers

Features specific to Upstream transmission:

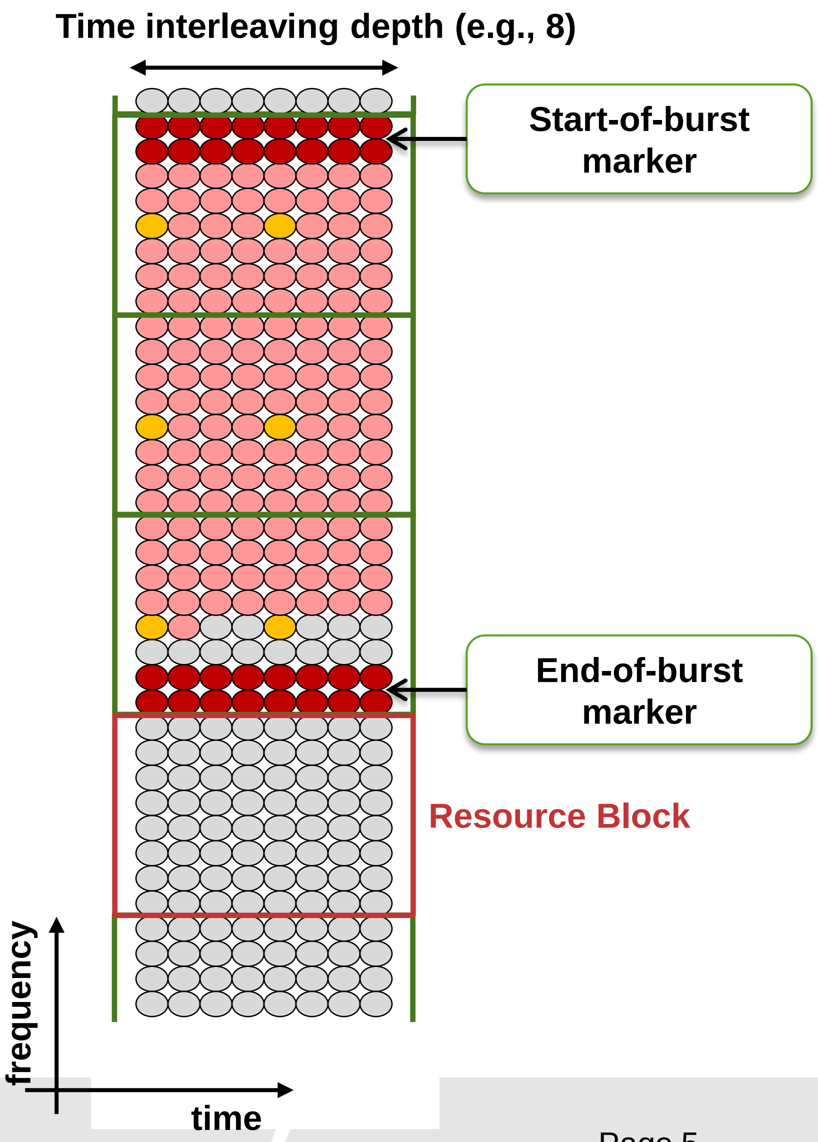
- **Each CNU performs pre-equalization**
  - Channel is pre-compensated at transmitter's side (to some extent)
- **Each burst is interleaved in Time and Frequency independently**
  - Different bursts correspond to independent grants
- **Time/Frequency resources are divided into Resource Blocks (RB)**
  - A particular grant spans an integer number of RBs
- **Association of pilot tones to a specific burst is unknown until the burst start/end have been detected**
- **Transmissions from different CNUs do not follow back-to-back**

→ **Need for markers:**

1) At the start of each burst
2) At the end of each burst

Upstream Receiver Processing

- The output of the FFT is buffered in blocks equal to the time interleaving depth
- Each burst occupies an integer number of RBs
- The marker for the specific burst profile is placed at the start of the first RB and at the end of the last occupied RB. In this example:
  - – 🔴 is a marker symbol (e.g., {-1, 0,+1})
  - – ● is a data symbol (e.g., 1024QAM)
  - – 🟡 is a pilot symbol (e.g., QPSK)
  - – ⚪ is an unused resource element
- Markers and pilots are independent and are located at predictable locations

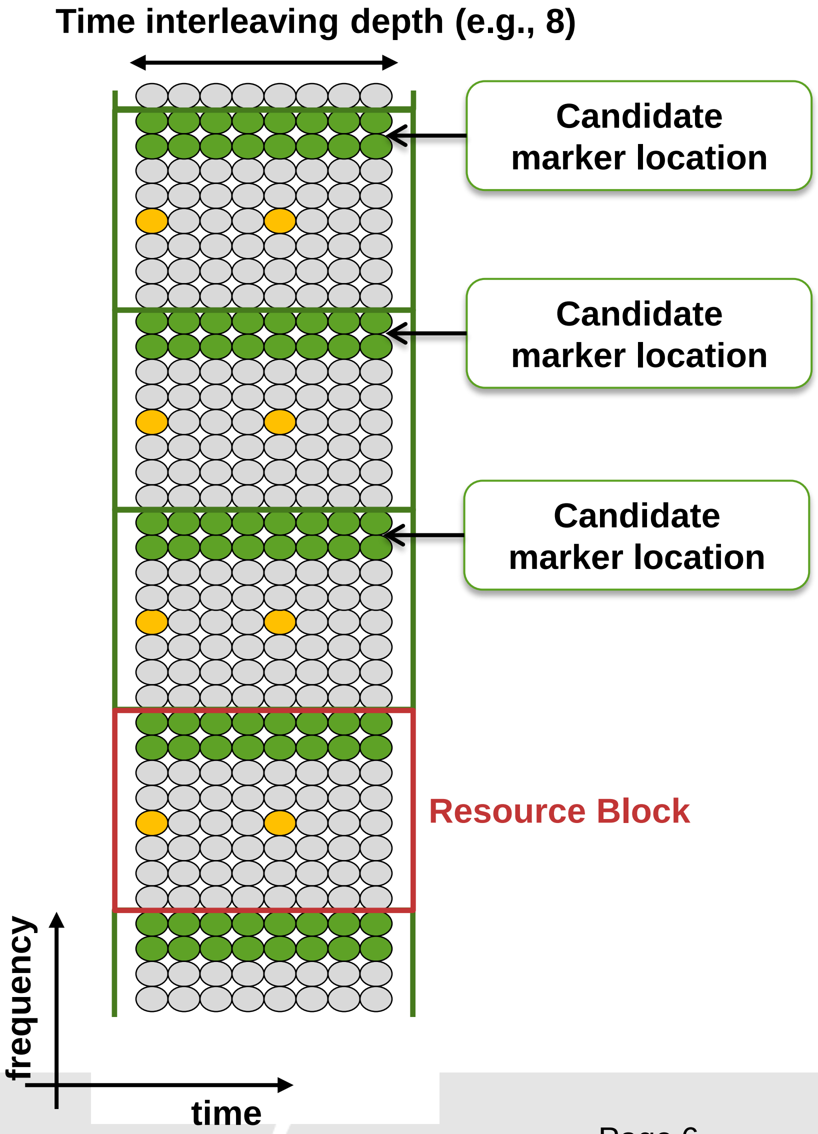


Upstream Receiver Processing

- **Marker detection follows FFT and buffering**

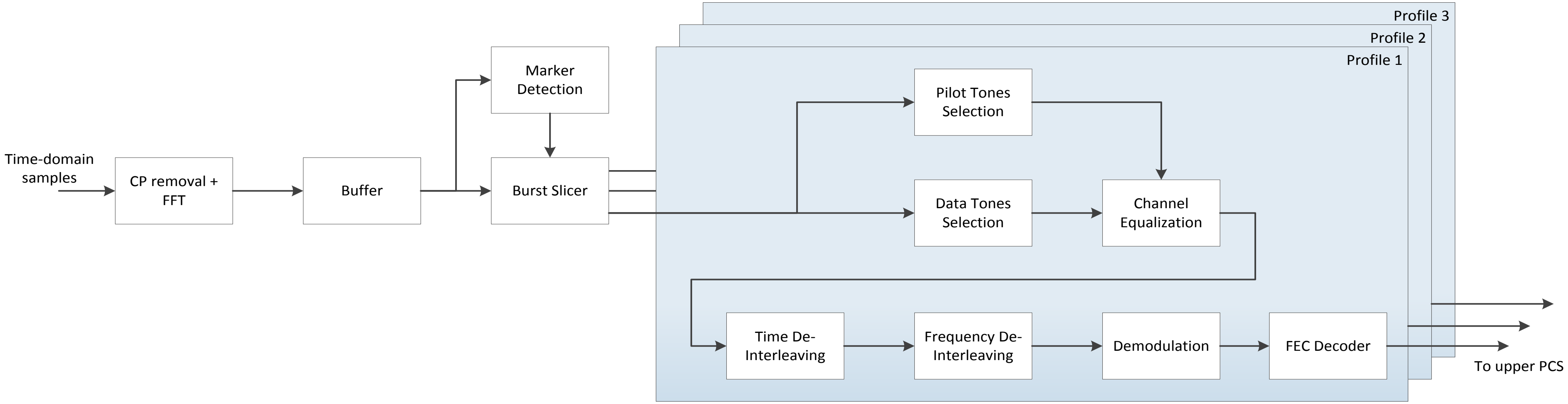
- **Marker searcher scans all candidate marker locations**

- **Marker detection needs to be resilient to residual channel distortion (not pre-equalized)**
  - Phase may change in time (CNU LO instability)
  - Channel response may change in frequency (e.g., RF front-end response varies with temperature)



Overall Upstream Receiver Processing

- **Marker search is performed right after FFT (possibly jointly with buffering of incoming samples)**
- **Channel estimation and equalization, Frequency and Time de-interleaving are performed separately for each burst, after burst slicing has occurred**



Downstream Transmission

Downstream Burst Markers

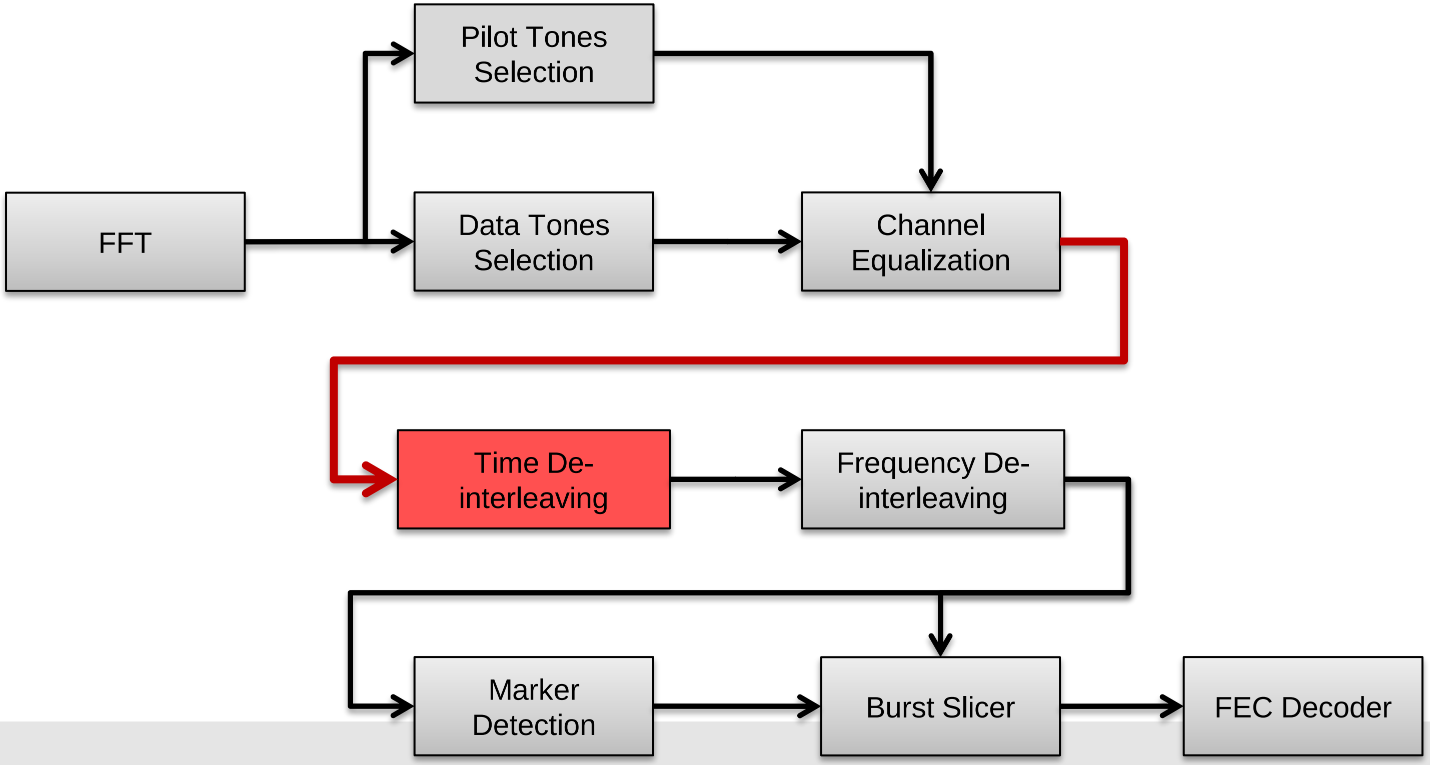
- **In the DS case, transmission is continuous.**
  - One profile follows the previous back-to-back (no notion of Resource Block)
  - Only a single start marker for each profile is strictly needed

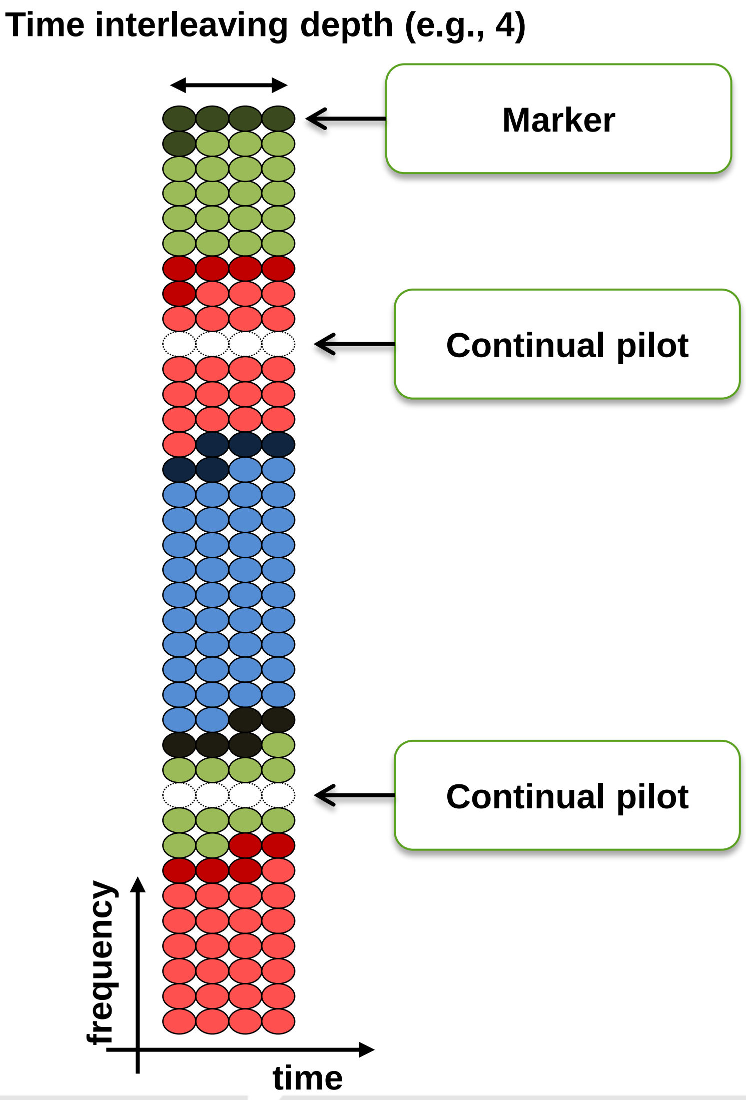
- **EPoC DS is a system with a single transmitter**
  - Pilot positions are known to CNUs
  - The channel response is estimated over the full bandwidth by each CNU using all available pilots in order to achieve the largest possible processing gain
  - This implies that channel equalization is performed before marker detection

- **Marker detection comes after frequency and time de-interleaving (see following slides)**
  - Time and frequency interleaving are common for all profiles

Downstream Receiver Processing

- Time and Frequency de-interleaving is a reordering operation applied to modulated symbols (in this figure frequency interleaving is neglected for simplicity)
- Channel estimation and equalization, Frequency and Time de-interleaving are performed after the FFT and are burst-agnostic
- Marker search is performed last, before demodulation and FEC decoding





Marker Sequence Design

Proposed burst marker scheme

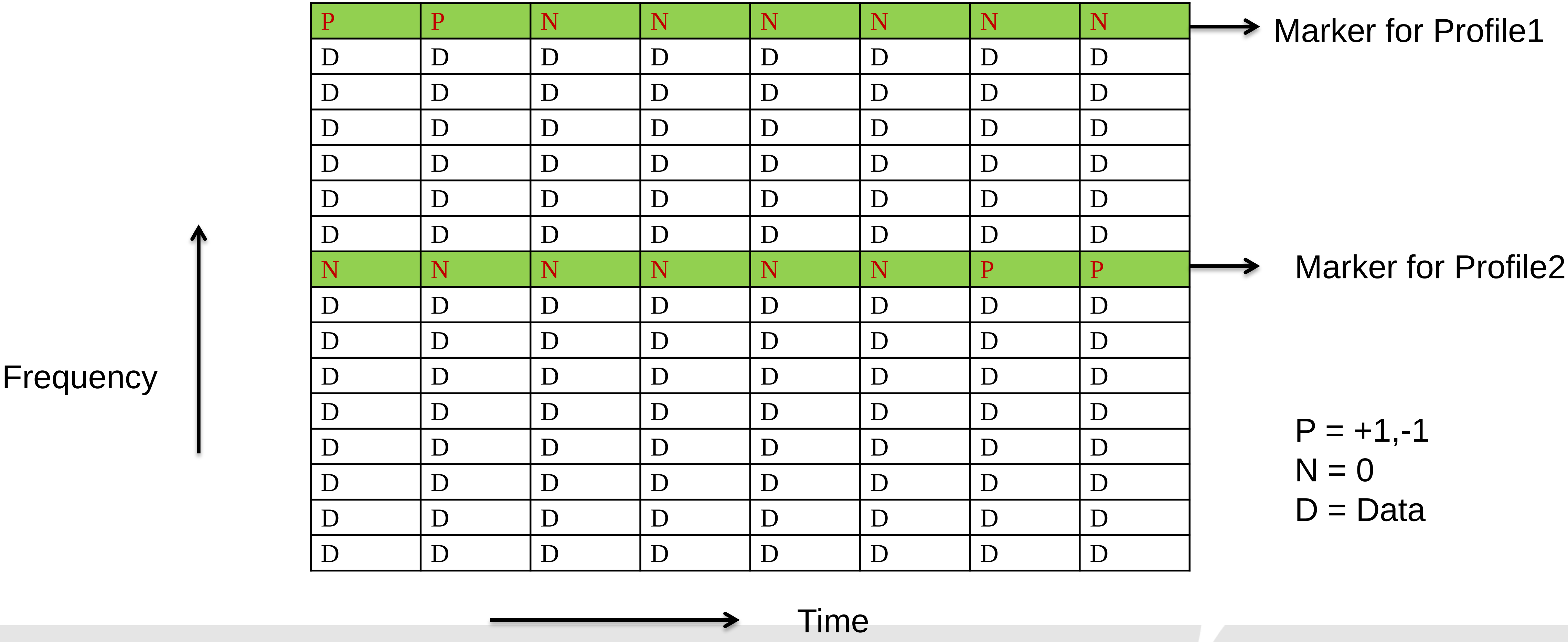
- In the proposed scheme, a burst marker is a sequence from a ternary alphabet {-1, 0,+1}
- In particular, a burst marker is formed by combining a fixed pattern of non-zero symbols P=+1,-1, and null (silent) symbols, N=0, interlaced with each other.
- Locations of P are mutually orthogonal in all burst marker sequences.
- Example of 4 burst marker sequence to represent 4 profiles:

Burst marker sequence #1 = P, P, N, N, N, N, N, N
Burst marker sequence #2 = N, N, P, P, N, N, N, N
Burst marker sequence #3 = N, N, N, N, P, P, N, N
Burst marker sequence #4 = N, N, N, N, N, N, P, P

Proposed burst marker scheme example

Horizontal marker placement

- Minimizes distortion due to channel response changes (not pre-equalized)



P	P	N	N	N	N	N	N
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
N	N	N	N	N	N	P	P
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D

P = +1,-1
N = 0
D = Data

Burst marker detector

- In case of ‘x’ dB signal to noise ratio, the power of a non-zero symbol is ‘x’ dB higher than the power of a null symbol.
- This difference in power levels between the non-zero symbols and the null symbols is exploited by the receiver for detection of the correct burst marker sequence in a non-coherent fashion (energy-based), therefore inherently robust to phase distortion due to, e.g., residual carrier frequency offset.

Burst marker detector

- For the case of 4 profiles, the detector computes 4 power ratios, one for each hypothesis.
- The numerator of the power ratio is the sum of powers of two symbols at the locations of the pilots.
- The denominator of the power ratio is the sum of powers of the 4 symbols, at the location of the nulls.
- This non-coherent detector is compared to a correlation-based detection method.

Performance Target

- Packet loss in EPoC will be due to two factors:
    1. Packet loss due to 1E-8 BER requirement
    2. Packet loss due to burst detection error.
- Two sources of burst detection error.
    1. Missed detection of a burst.
    2. False detection of burst. This causes dropping of the existing burst.
- Burst loss rate should include both the false detection and missing detection.
- EPoC target packet loss rate is 1E-5 for US and 1E-6 for DS.
- Cable labs have similar requirements.
- Since a burst has multiple packets, the burst loss rate should be much smaller than packet loss rate.

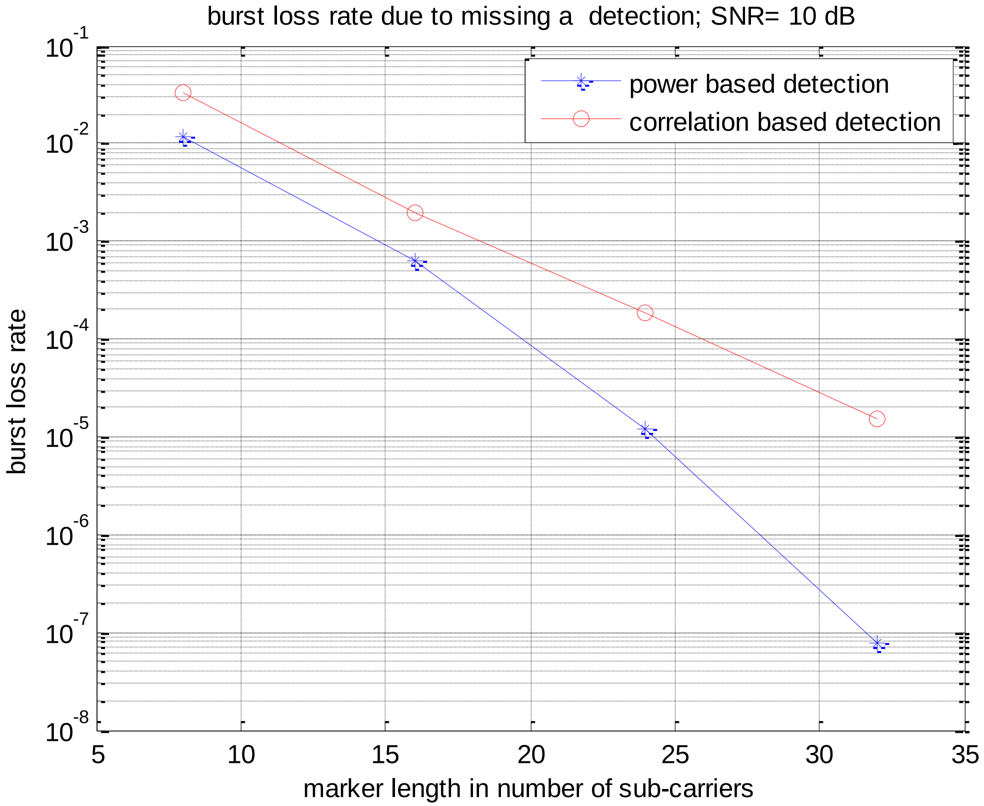
Simulation Results:

- Upstream transmission
- AWGN
- DOCSIS Multipath profile (Valid 97% of the time):

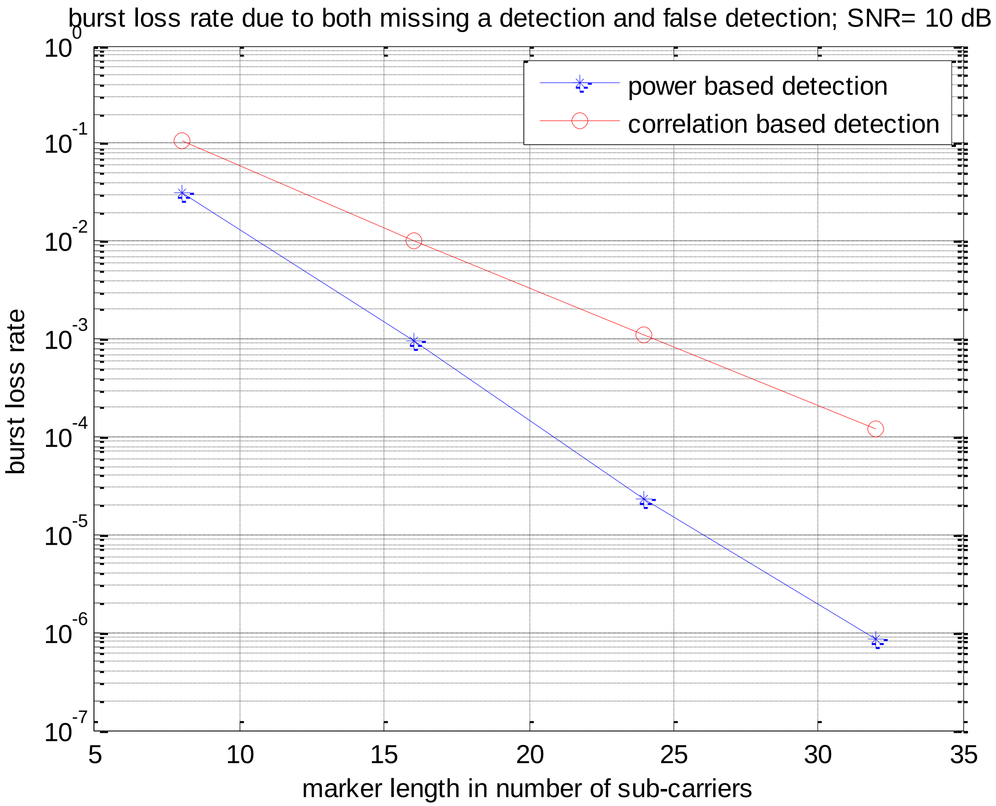
  delay = [0.5 1 1.5 2 3 4.5]*1e-6;

  pwr_db = [-16   -22 -29 -35 -42 -51];
- Residual carrier frequency offset = 25 Hz
- Data modulation order: 1024QAM
- In the plots a missing data point indicates 100% detection.

Multipath, SNR=10dB

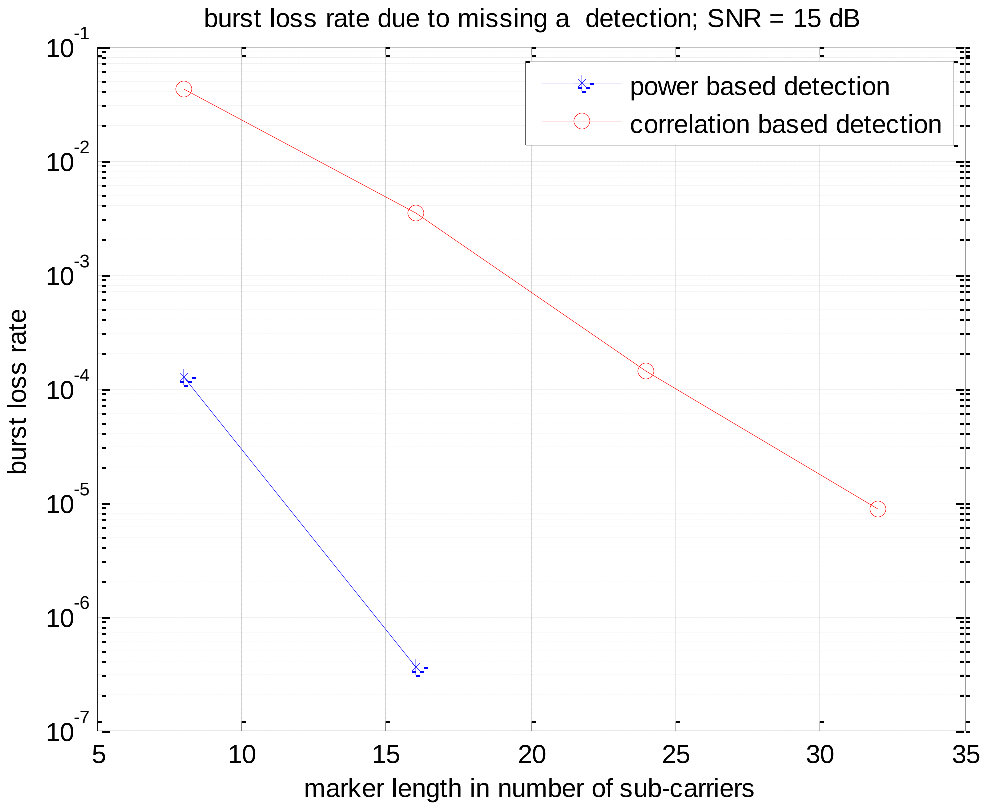


Plot 1A

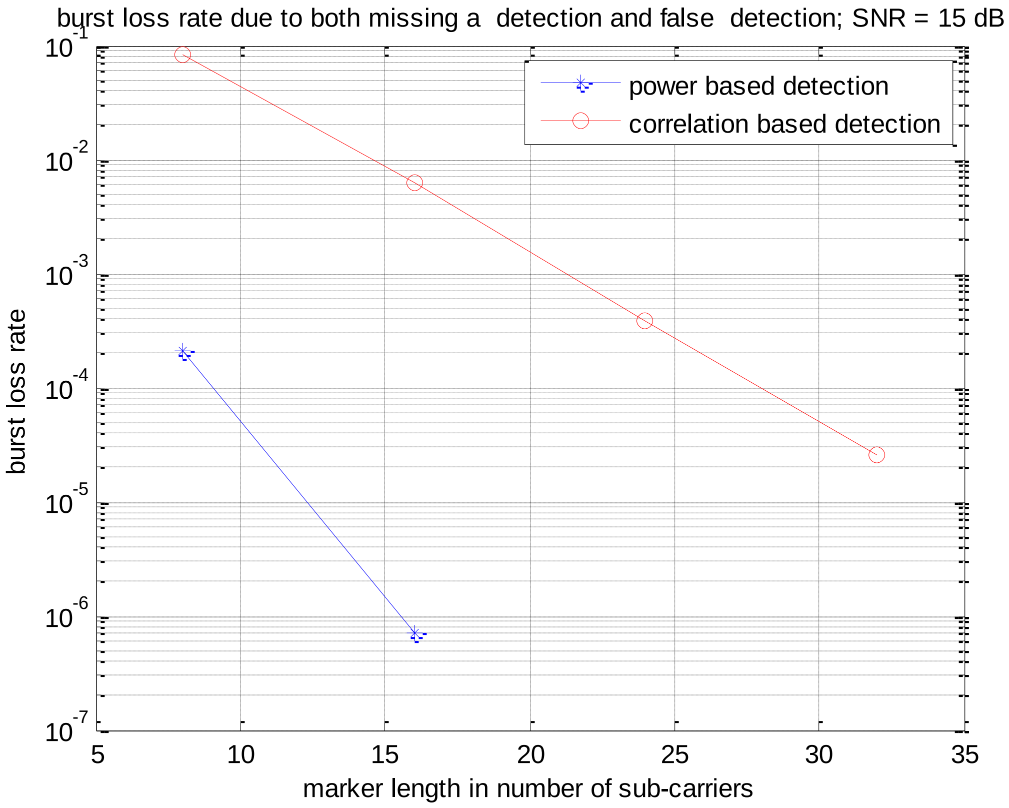


Plot 1B

Multipath, SNR=15dB

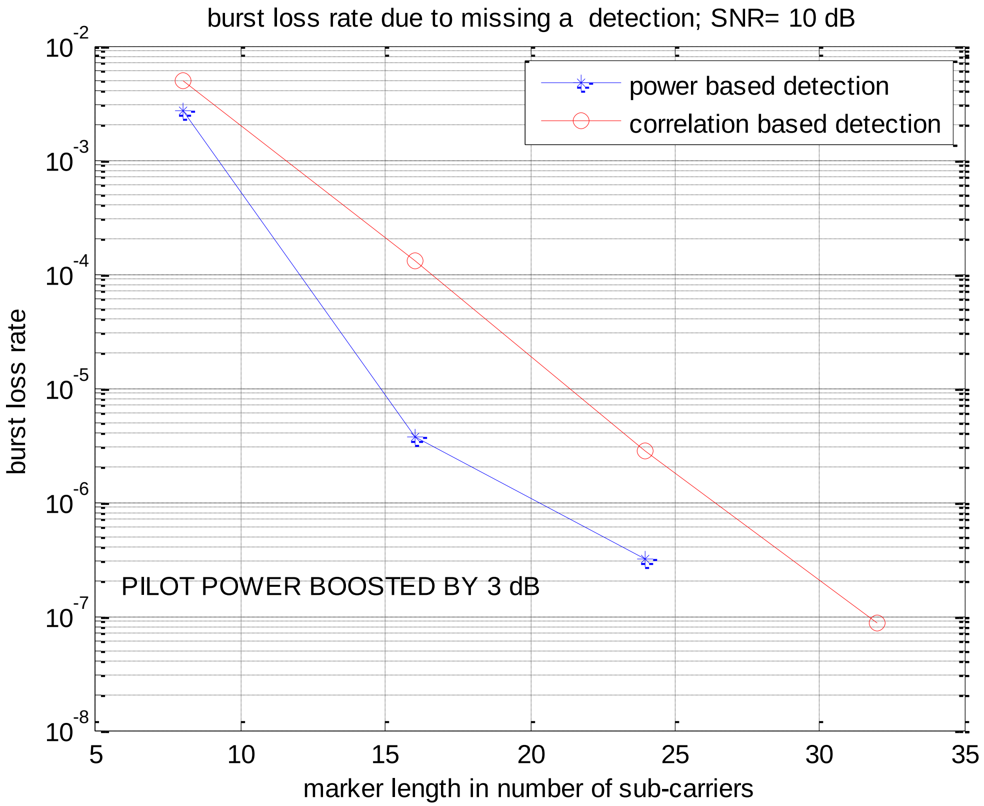


Plot 2A

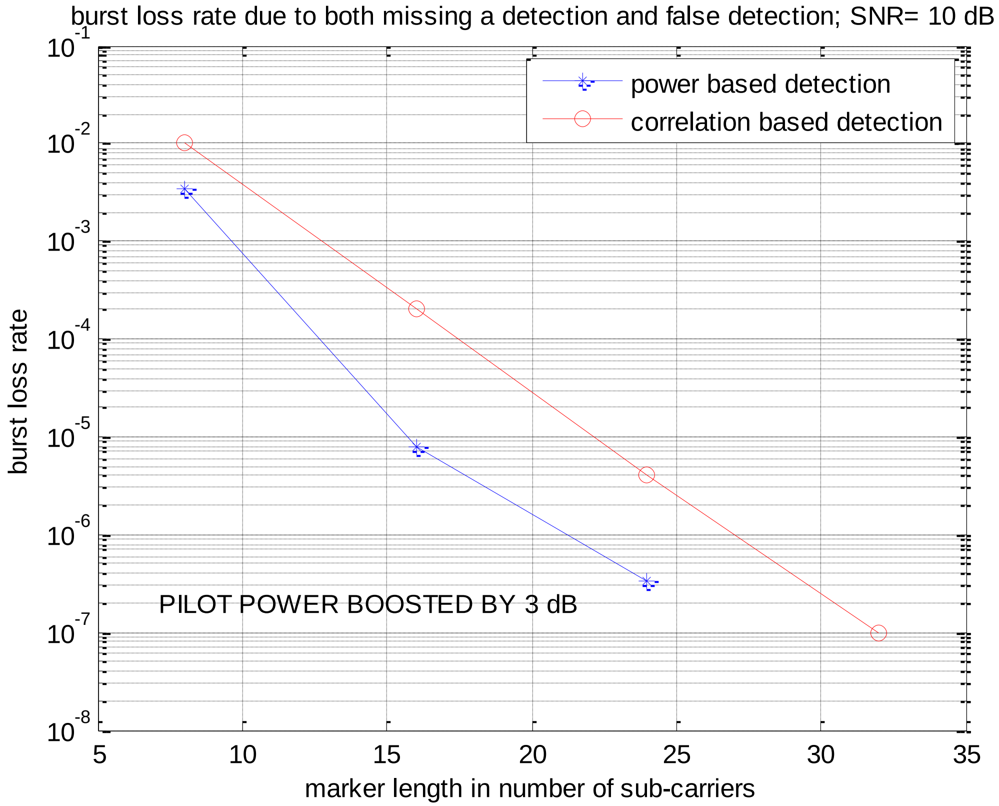


Plot 2B

Multipath, SNR=10dB, 3dB power boost

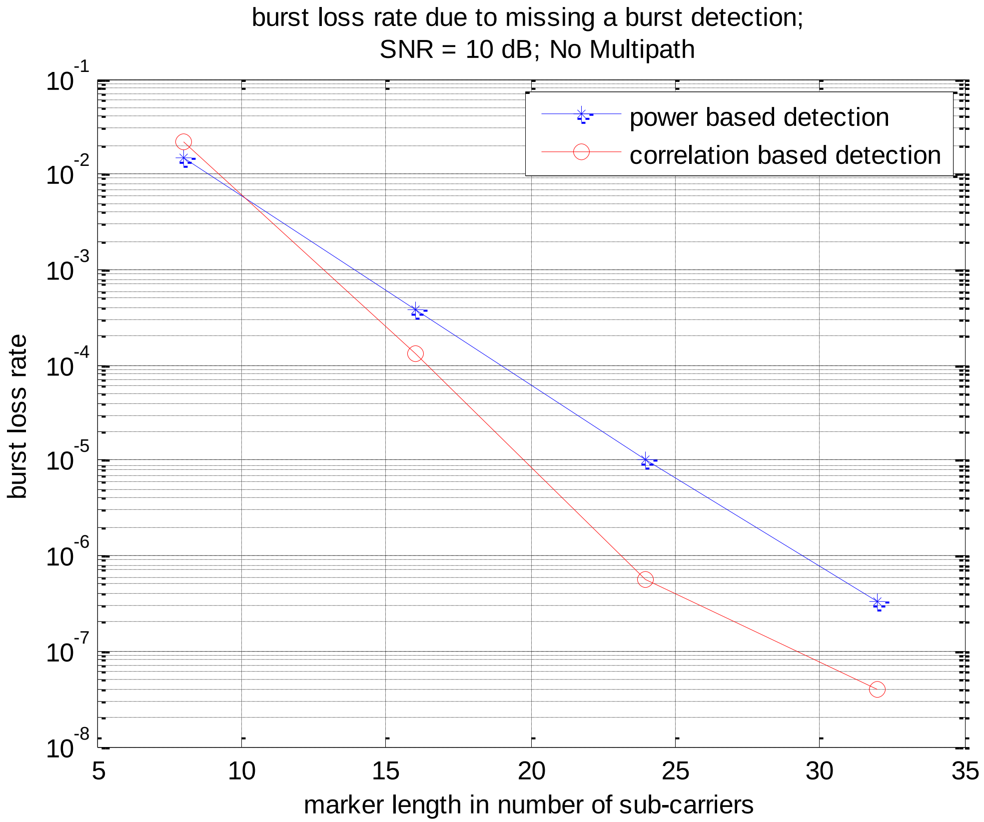


Plot 3A

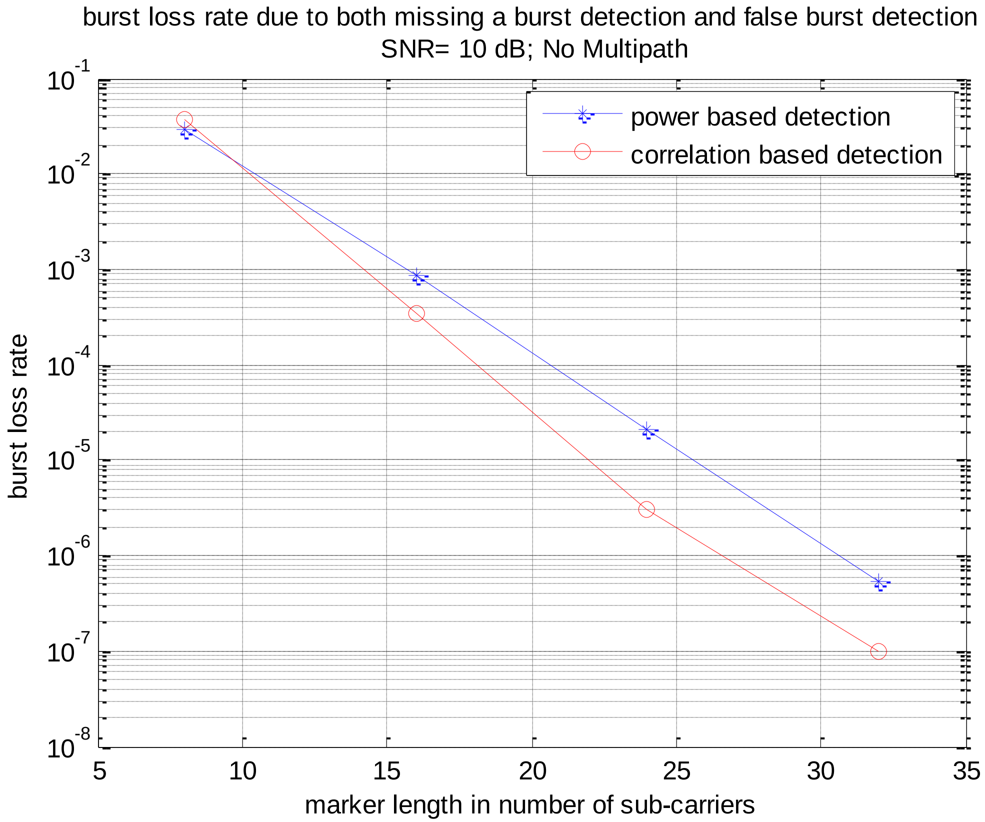


Plot 3B

No Multipath, SNR=10dB

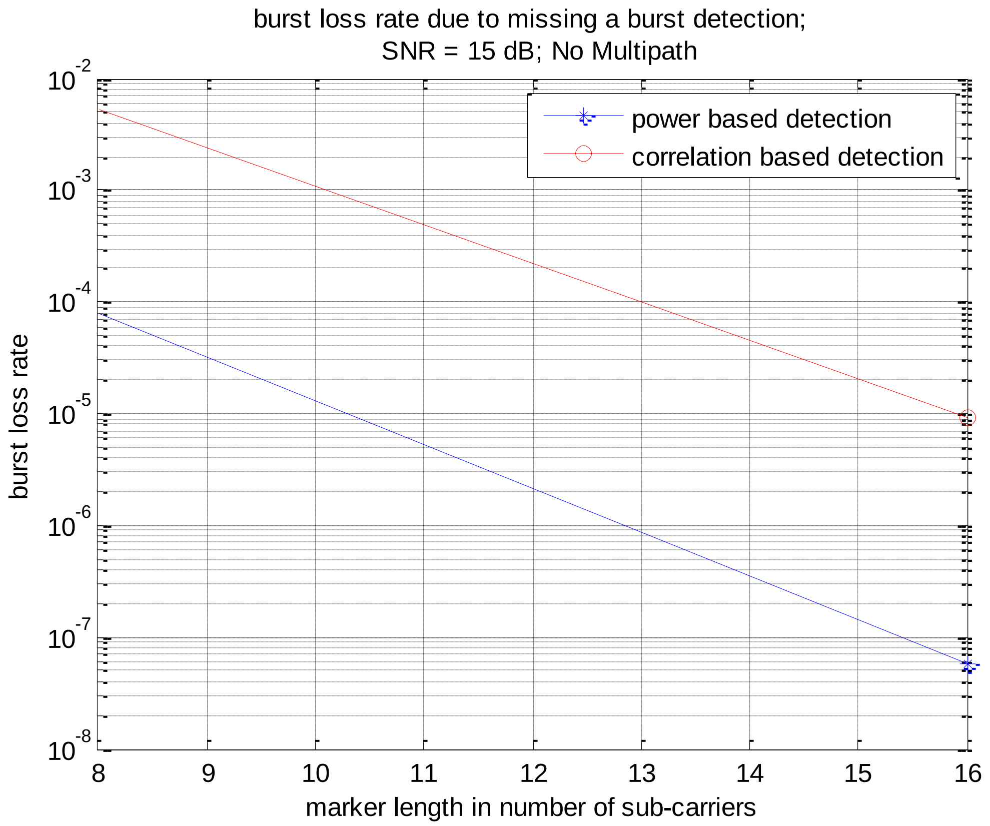


Plot 4A

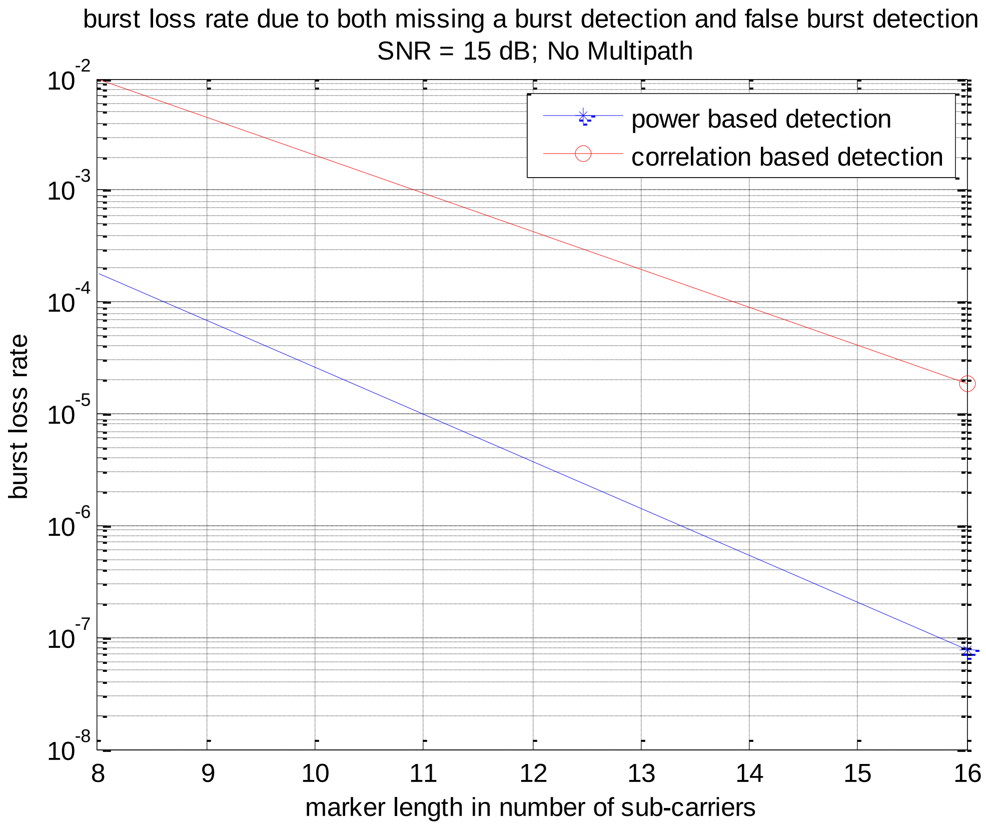


Plot 4B

No Multipath, SNR=15dB



Plot 5A



Plot 5B

Conclusions

- The energy based detection scheme is superior to the correlation based scheme in the following cases:
  - If pre-equalization is not performed (multipath), it is superior in all simulated cases.
  - If pre-equalization is performed (no multipath), it is superior for higher SNR values (> 10 dB).
- The correlation based detection scheme is superior to the energy based scheme in following cases:
  - If pre-equalization is performed (no multipath) and for low SNR values (10 dB).
- Boosting the power of marker symbols by 3 dB, improves the performance by an order of magnitude.

Conclusions

- More simulations are needed with inclusion of pre-equalization. Which will eliminate the multipath effect to a large extent, but not completely.
- More research is needed to explore the possibility of combining both the schemes to improve performance.
- The following parameters need to be specified
  - Targeted total burst loss rate (due to both missed detection and false detection), for both Upstream and Downstream.
  - Lowest supported QAM modulation order for data (Upstream and Downstream). This sets the minimum SNR for evaluating the burst marker detection schemes.

Thank You