New EPoC Burst Markers with Data Field

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Burst Markers Update

- Modifications in Burst Marker
  - Motivation
  - Updated BM Sequences and Modulated Waveforms
- Burst Marker with Burst Noise Impairment
- FEC Coding for Burst Markers
- Burst Marker Data for End of Data Burst Pointer
- Burst Marker Detection
  - Burst Marker Processing Example
  - Performance Analysis
  - Comparison to Objective
- Conclusions

Why new Burst Markers (BM)?

- No intermixing of data payload within BM for simplicity
  - Significantly reduces complexity of the Symbol Mapper
- Each Stop BM has a data field
  - Stop BM data indicates the last payload RE in the last RB and the last bit location in the last RE
  - Start BM does not need data but inserts a fixed pad value
- Data is sent in D-QPSK modulation with 3 dB boosting

  First data symbol of RB (in time direction) is reference symbol

  (00) → 0^0 phase shift, (01) → $+90^0$ phase shift

  (11) → 180^0 phase shift, (10) → -90^0 phase shift
- Demodulation without channel estimation
- Demodulation with imperfect pre-equalization
- Allows BM detection and demodulation with frequency exclusions in a BM or a BM spanning two OFDM frames

Burst Marker Sequences (1 of 3)

- Resource Block = 1 subcarrier by 16 symbols
  - BM uses two RBs
- Resource Block = 1 subcarrier by 8 symbols
  - BM uses four RBs
- D-QPSK data on “B” and Nulls on “N” within the BM pattern
- 2-D sequences have good auto-correlation and cross-correlation properties
- Start and Stop BM have low cross-correlation property to reduce false detection

Burst Marker Sequences (2 of 3)

- BM 2x16 (2 subcarriers by 16 symbols)

  Start = [B N B N B N N N N N B N B B B B
  N B N B N B B B B B N B N N N N];

  Stop = [B B B B N B N N N N N B N B N B
  N N N N B N B B B B B N B N B N];

- BM 4x8 (4 subcarriers by 8 symbols)

  Start = [B N B B N N B N
  B N N N B B N B
  N B N N B N B B
  N B B B N B N N];

  Stop = [N B B N B B N N
  N B N B N N B B
  B N N B B N N B
  B N B N N B B N];

First “B” on a subcarrier is a reference symbol

“B” → D-QPSK
“N” → Null

Burst Marker Sequences (3 of 3)

- Example of Data in a Stop BM 2x16 (2 subcarriers by 16 symbols)

  BM = [(+1+1) (+1+1) (-1-1) (+1-1) N (+1+1) N N N N N (+1-1) N (-1+1) N (-1+1)
  N N N N (+1+1) N (-1+1) (-1-1) (-1-1) (-1+1) (+1-1) N (+1+1) N (+1+1) N];

  Data = [* (00) (11) (01) * (01) * * * * * (10) * (11) * (00)
  * * * * * * (01) (01) (00) (10) (11) * (01) * (00) *];

- Example of Data in a Stop BM 4x8 (4 subcarriers by 8 symbols)

  BM = [N (+1+1) (-1+1) N (+1+1) (-1-1) N N
  N (+1+1) N (+1+1) N N (-1-1) (+1-1)
  (+1+1) N N (+1-1) (+1+1) N N (-1-1)
  (+1+1) N (-1+1) N N (-1-1) (+1-1) N];

  Data = [* * (01) * (10) (11) * *
  * * * (00) * * (11) (01)
  * * * (10) (01) * * (11)
  * * (01) * * (01) (01) *];

First QPSK (+1+1) on a subcarrier is a reference symbol

* denotes a null or a reference symbol

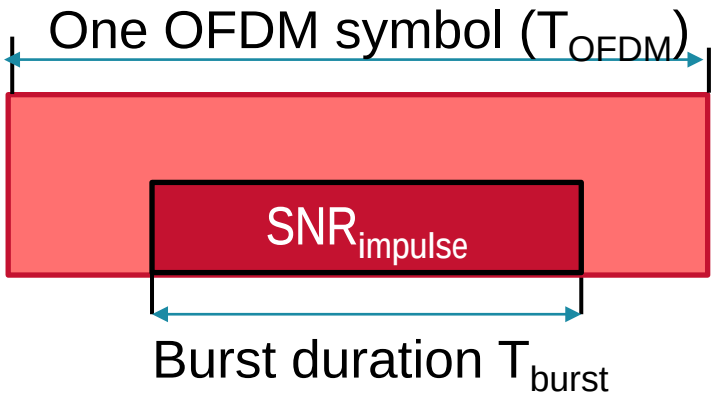
Phase Shift	Data
0^0	00
$+90^0$	01
180^0	11
-90^0	10

Burst Marker with Burst Noise Impairment

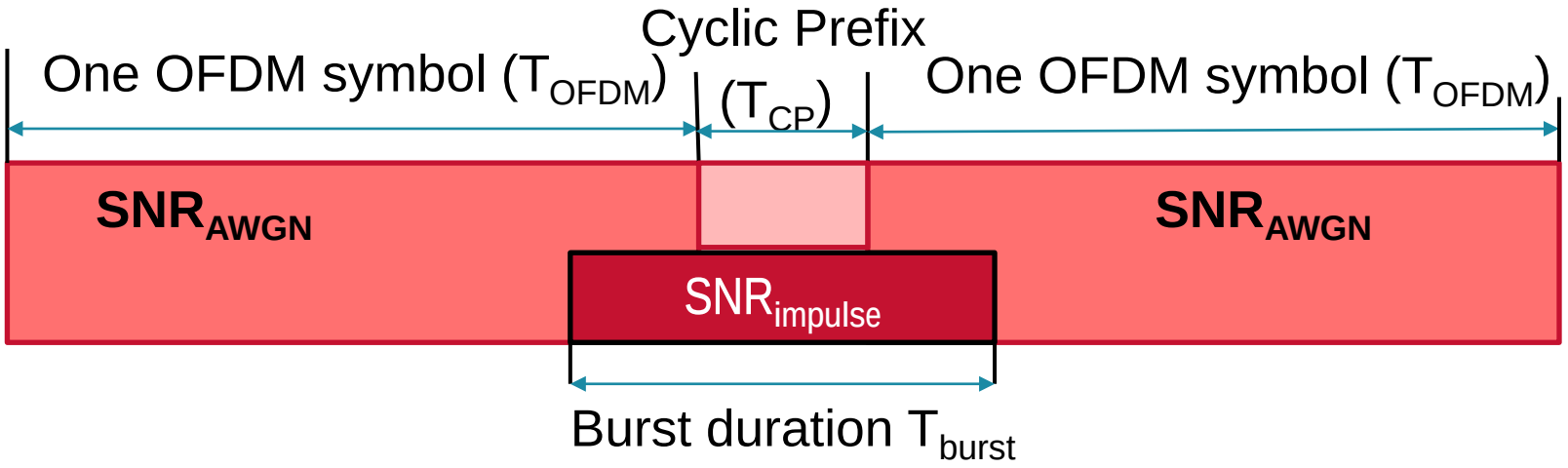
- Impulse noise causing a burst error event is the predominant impairment in the upstream
- Typical impairment statistics[1]:
  - Less than 1 µs in 94% of burst error events
  - 1 µs to 10 µs in 5% of burst error events
  - Longer than 10 µs in 1% of burst error events
- Almost all (over 99%) of burst error events will impair one or two adjacent OFDMA symbols

[1]*Characterization of Upstream Transient Impairments on Cable Television Systems,* CableLabs 1997

Burst Marker with Burst Noise Impairment



Burst hits one OFDM symbol



Burst hits two OFDM symbols

Reed-Solomon (RS) FEC Code for Data Field

- Reed-Solomon code over GF(2^4) with t = 2
  - 4 bits per code symbol
  - 4 parity symbols per codeword
  - Can correct two symbol errors in a codeword
- Reed-Solomon generator polynomial

  $g(x) = (x+\alpha^0)(x+\alpha^1)(x+\alpha^2)(x+\alpha^3)$

  where the primitive element alpha is 0x2
- Reed-Solomon primitive polynomial

  $p(x) = x^4 + x + 1$
- Reed-Solomon(15,11) code shortened to length 6 or 7
  - 8 information bits ≡ $(0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ I_2\ I_1\ P_4\ P_3\ P_2\ P_1)$
  - 12 information bits ≡ $(0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ I_3\ I_2\ I_1\ P_4\ P_3\ P_2\ P_1)$

FEC for 2x16 Burst Marker

- RS symbol uses two QPSK data Resource Elements
- QPSK info data pair of 2 MSBs I_{jH} and 2 LSBs I_{jL}, j=1,2,3
- QPSK parity pair of 2 MSBs P_{kH} and 2 LSBs P_{kL}, k=1,2,3,4
- RS(15,11) 2 error-correcting code shortened to length 7
- Corrects burst error over two consecutive OFDMA symbols
- 12 information bits per shortened codeword (8 used, I_3=0)

Stop BM:

I_{ref} I_{3H} I_{3L} I_{2H} 0 I_{2L} 0 0 0 0 0 P_{3L} 0 P_{2L} 0 P_{1L}

0 0 0 0 I_{ref} 0 I_{1H} I_{1L} P_{4H} P_{4L} P_{3H} 0 P_{2H} 0 P_{1H} 0

FEC for 4x8 Burst Marker

- RS symbol uses two QPSK data Resource Elements
- QPSK info data pair of 2 MSBs I_{jH} and 2 LSBs I_{jL}, j=1,2
- QPSK parity pair of 2 MSBs P_{kH} and 2 LSBs P_{kL}, k=1,2,3,4
- RS(15,11) 2 error-correcting code shortened to length 6
- Corrects burst error over two consecutive OFDMA symbols
- 8 information bits per shortened codeword

Stop BM:

0	I_{ref}	I_{2H}	0	P_{4H}	P_{3H}	0	0
0	I_{ref}	0	I_{1H}	0	0	P_{2H}	P_{1H}
I_{ref}	0	0	I_{1L}	P_{4L}	0	0	P_{1L}
I_{ref}	0	I_{2L}	0	0	P_{3L}	P_{2L}	0

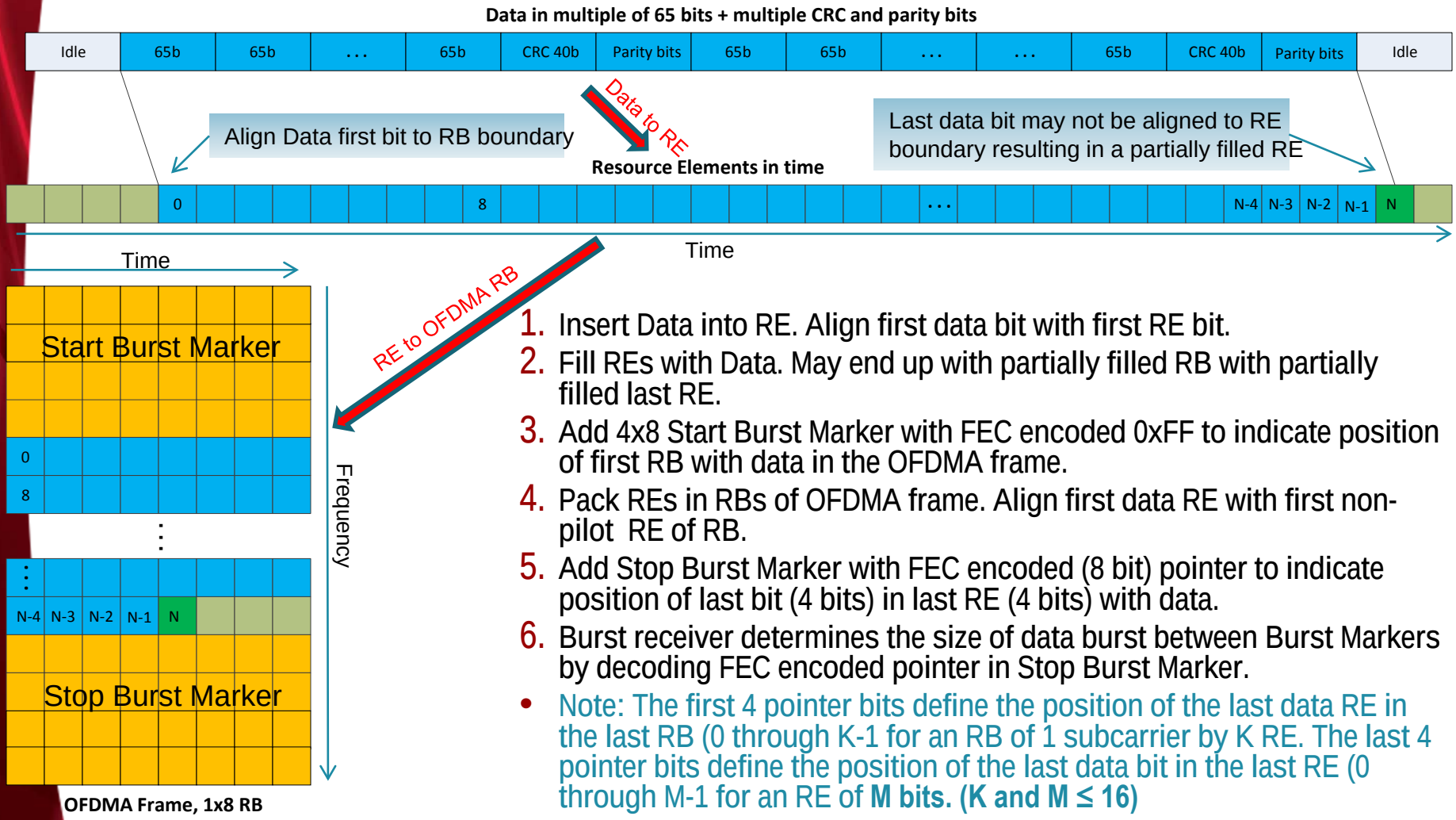
Burst Marker Data for End of Data Burst Pointer

Last RE Position in Last RB	MSB Pointer Bits (I_{2H} I_{2L})
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Last Bit Position in Last RE	LSB Pointer Bits (I_{1H} I_{1L})
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Note: 0xFF or 0xFFF used for 4x8 or 2x16 Start BM RS information symbols respectively.

Packing of Data into 1 by 8 RB example
Stop BM marks last bit in last RE with Data



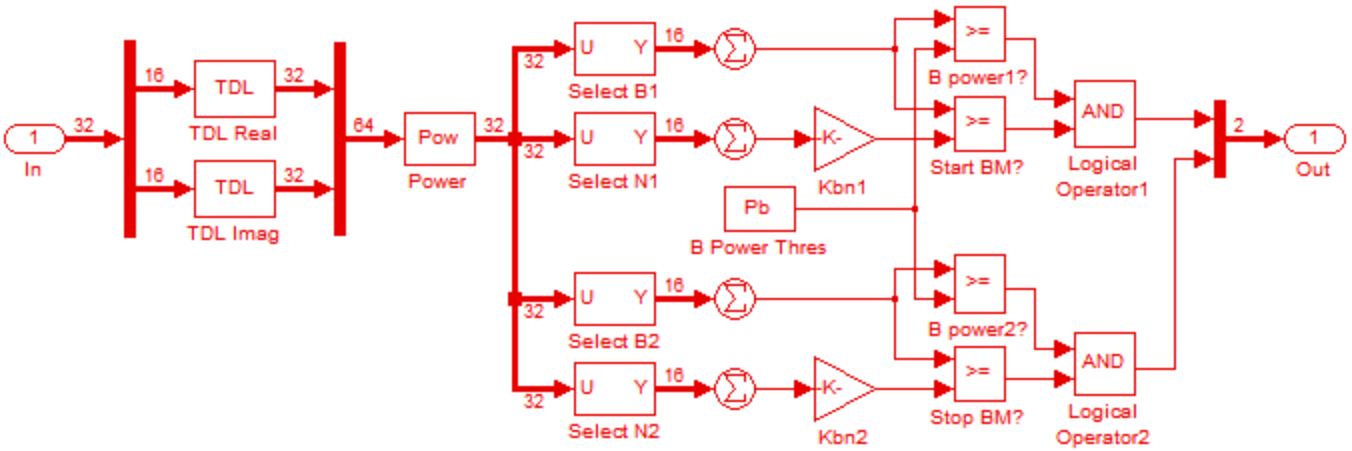
1. Insert Data into RE. Align first data bit with first RE bit.
2. Fill REs with Data. May end up with partially filled RB with partially filled last RE.
3. Add 4x8 Start Burst Marker with FEC encoded 0xFF to indicate position of first RB with data in the OFDMA frame.
4. Pack REs in RBs of OFDMA frame. Align first data RE with first non-pilot RE of RB.
5. Add Stop Burst Marker with FEC encoded (8 bit) pointer to indicate position of last bit (4 bits) in last RE (4 bits) with data.
6. Burst receiver determines the size of data burst between Burst Markers by decoding FEC encoded pointer in Stop Burst Marker.

- Note: The first 4 pointer bits define the position of the last data RE in the last RB (0 through K-1 for an RB of 1 subcarrier by K RE. The last 4 pointer bits define the position of the last data bit in the last RE (0 through M-1 for an RE of **M bits. (K and M ≤ 16)**

BURST MARKER DETECTION

Example of “B” & “N” Sequence Detector

- Kbn set the B vs. N power ratio threshold
  - Smaller gain allow detection at lower SNR
  - Higher gain prevent false trigger from payload data or noise
- Pb set the min power for trigger
  - Prevent false trigger from background noise



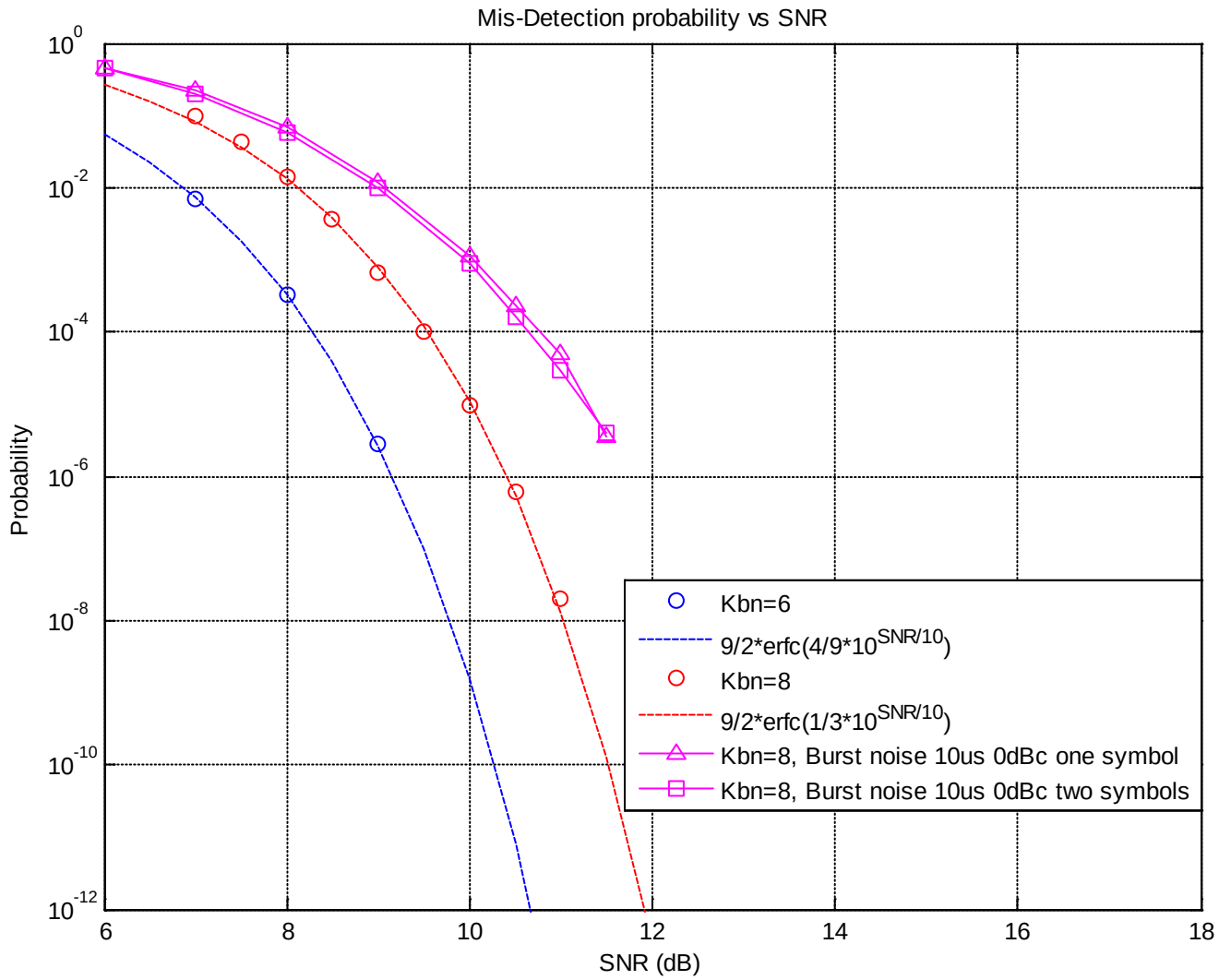
Simulation Methodology

- Frame base simulation
  - 2x16: 2 RB start, 94 RB 64-QAM payload, 2 RB stop, 2 RB quiet. 100 RB total
  - 4x8: 4 RB start, 88 RB 64-QAM payload, 4 RB stop, 4 RB quiet. 100 RB total
- 1 Burst Noise event corrupt a whole column of subcarriers
  - 2x16: Corruption of 2 RE in start BM, 2 RE in stop BM, 94 RB in payload and 2 in quiet time.
  - 4x8: Corruption of 4 RE in start BM, 4 RE in stop BM, 88 RB in payload and 4 in quiet time.

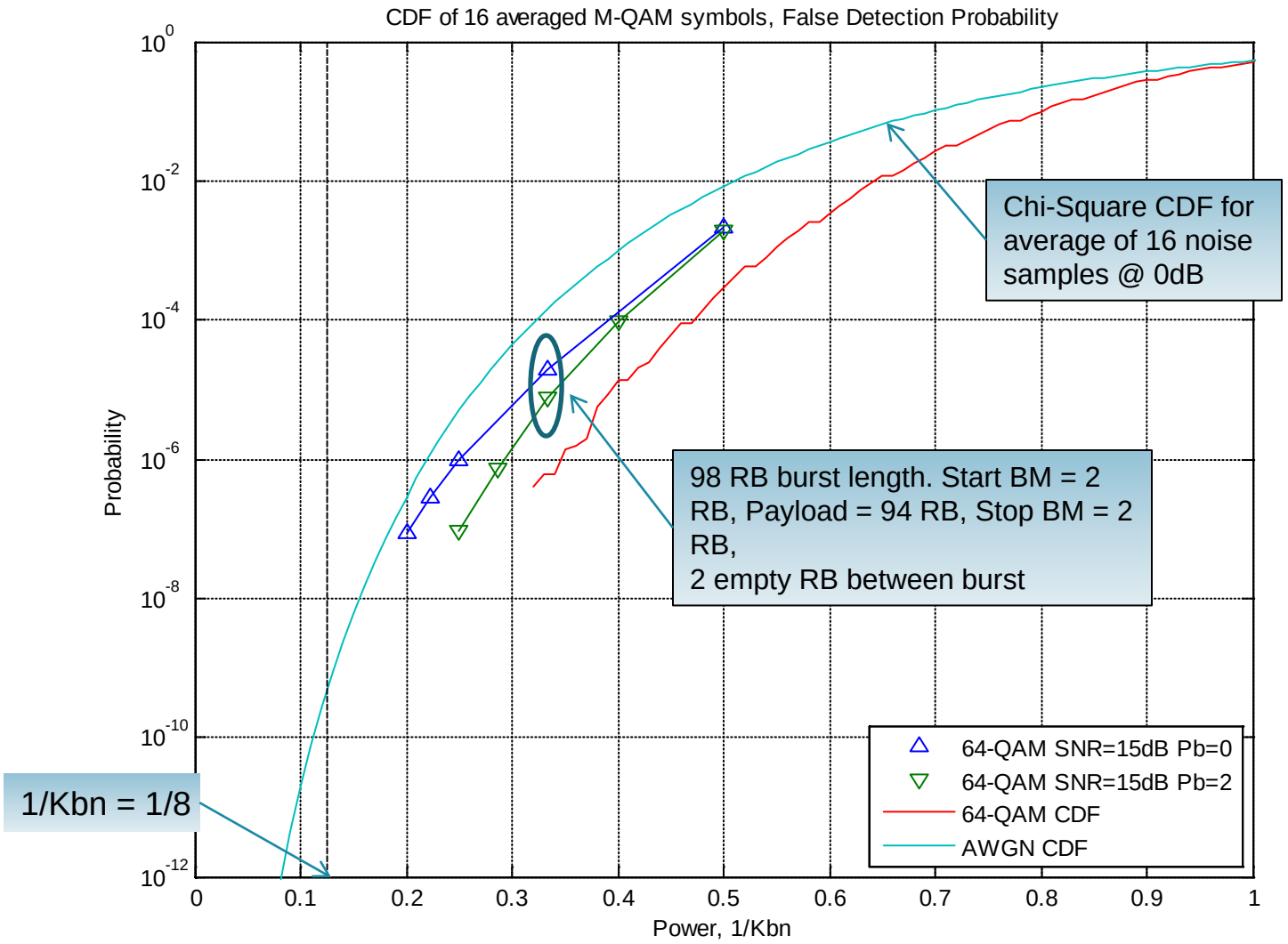
Burst Marker Simulations

- 2x16 and 4x8 BM have virtually the same Mis-Detection probability. Depend on:
  - Additive Noise on “B” and “N”
- False Detection probability is more complex. Depend on:
  - Auto-Correlation of Start and Stop BM sequence, i.e. the spurious peaks
  - Cross-Correlation of Start and Stop BM
  - False detection of a Start BM on a Stop BM and Stop BM on a Start BM
  - False detection of BM on QAM payload
  - False detection of BM on a quiet time

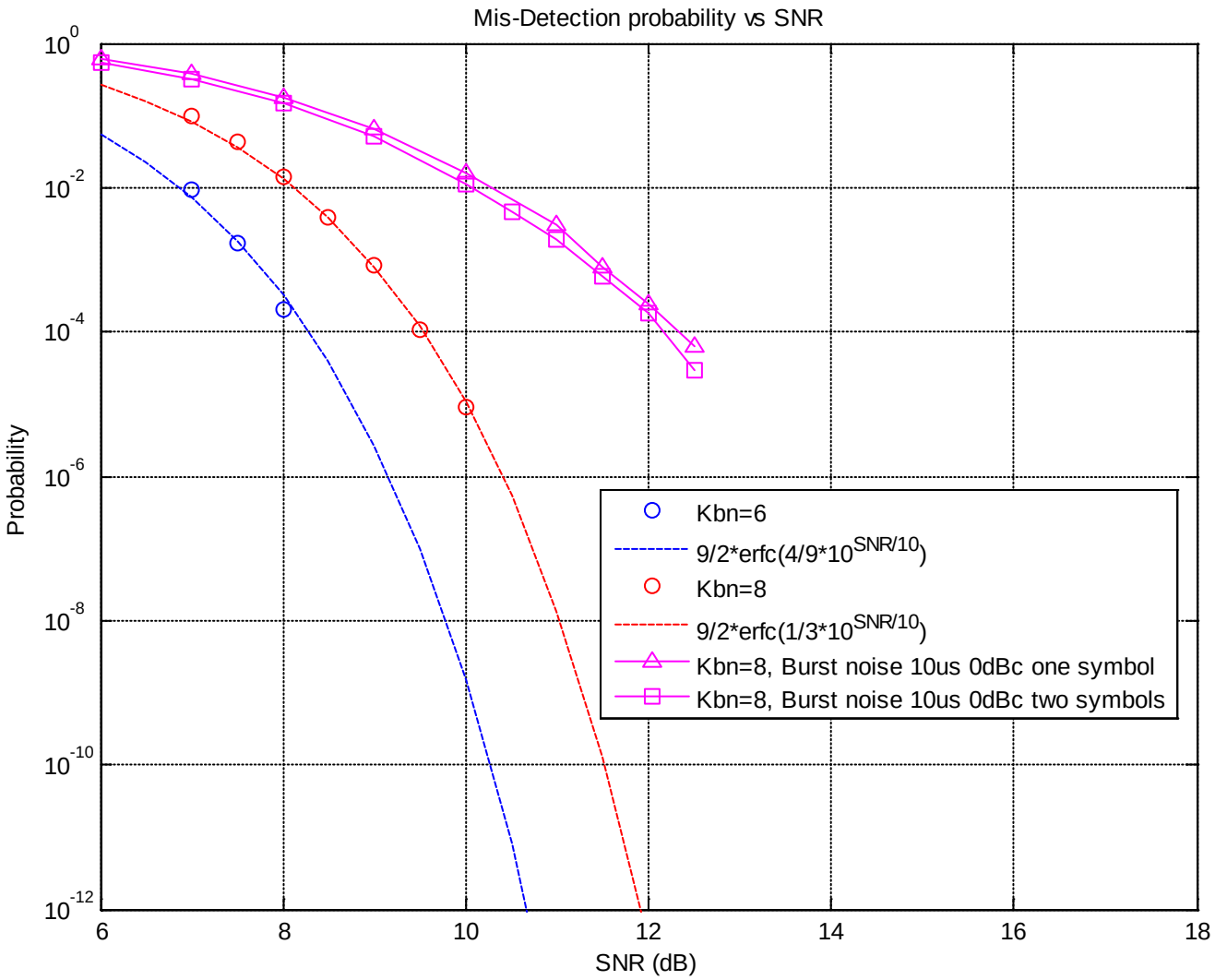
2x16 Mis-Detection Probability with Burst Noise



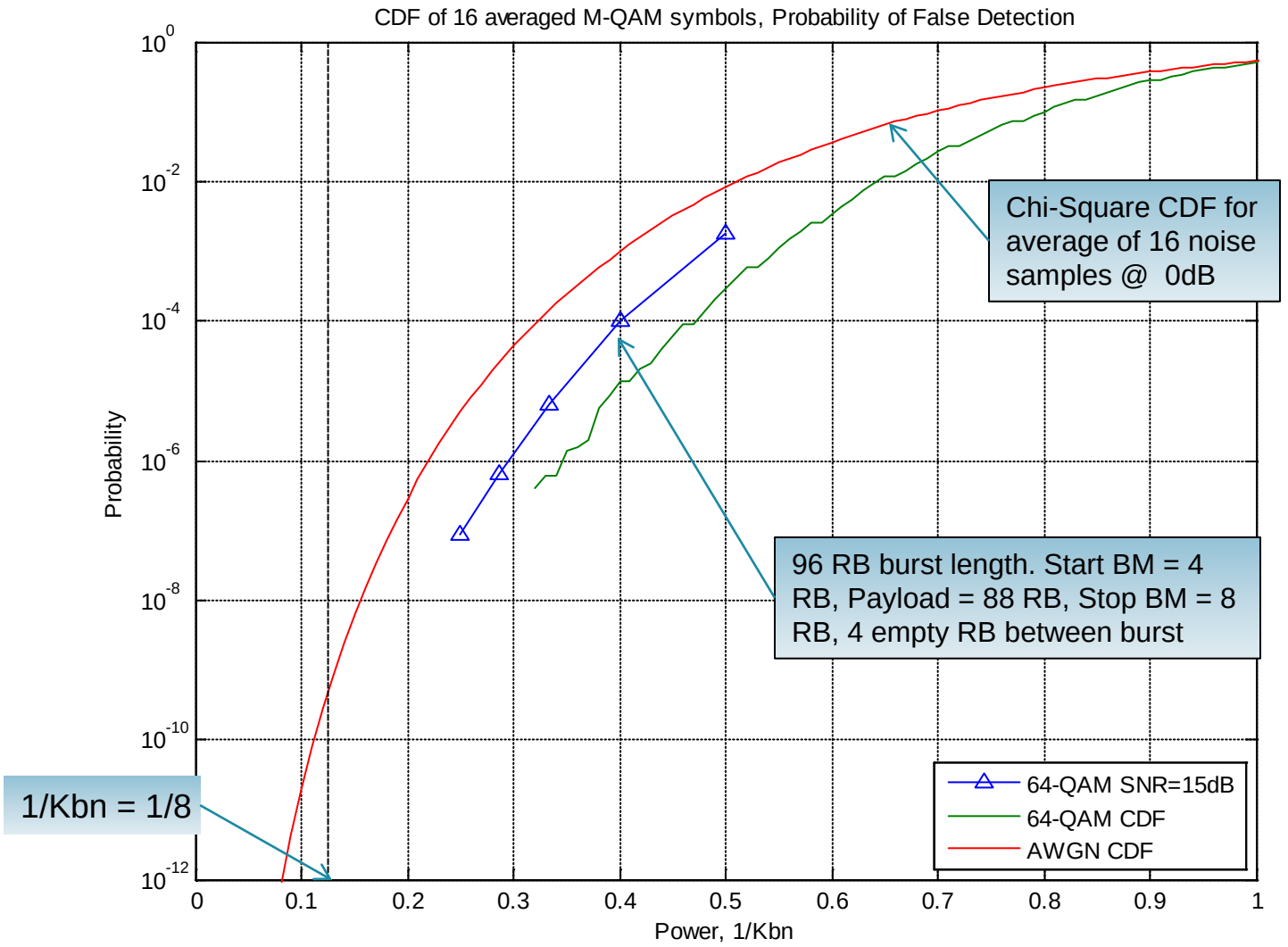
2x16 False-Detection Probability and QAM Cumulative Distribution Function



4x8 Mis-Detection Probability



4x8 False-Detection Probability and QAM Cumulative Distribution Function



Data Burst Error Rate Example

- Assumptions:
  - SNR = 15 dB (≈ 2.5 dB above 16-QAM error threshold)
  - FEC code rate ≈ 0.865
  - Pilots overhead = 1/8
  - Resource Block = 16 Resource Elements (1 subcarrier by 16 symbols)
  - 1500 Byte data burst payload
  - K_{bn} = 1/8, P_b = 2
- Burst size:
  - Payload = 3468 Resource Elements before pilots
    = 244 Resource Blocks after pilots insertion
- Probability of missing a data burst:
  - Data Burst Error Rate = Pm + Pm + 244*Pf
    = 0 + 0 + $244*10^{-12} = 2.44*10^{-10}$
    << $5*10^{-5}$ upstream Frame Loss Ratio objective

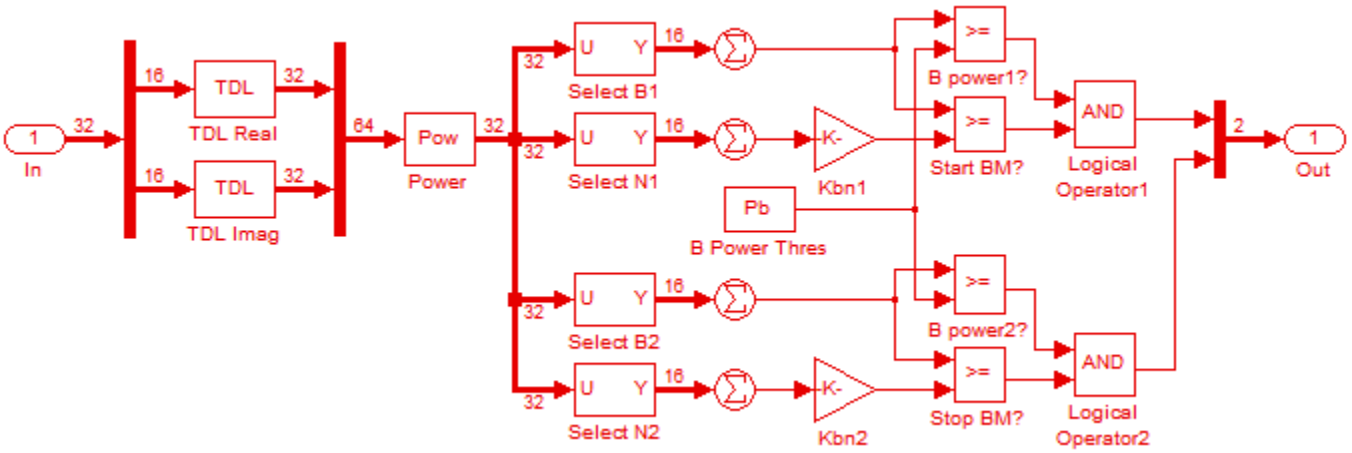
Pm: Probability of missing Start or Stop Burst Marker (≈ 10^{-49} @ SNR=15 dB)
Pf: Probability of false detecting a Start or Stop Burst Marker (≈ 10^{-12} @ SNR=15 dB)

Conclusions

- 4x8 and 2x16 are more robust than 4x6 Burst Markers
  - BM Detector relies only on data and null pattern
  - No need for “S” correlators
- Stop BM contains Reed-Solomon FEC protected data
  - 4x8 BM carries 8 info data bits in 24 encoded bits
  - 2x16 BM carries 8 info data bits plus 4 zero pad bits in 28 encoded bits
- Stop BM data points to the last payload data bit in the last subcarrier of the resource block before the stop BM
- RS FEC protects against burst errors in 1 or 2 consecutive OFDMA symbols (99% of burst errors)
- BM and payload data do not share Resource Blocks
- BM construction with an equal number of “B” and “N” per symbol provides immunity to a false trigger from burst noise events
- Data burst error rate well below upstream Frame Loss Ratio objective

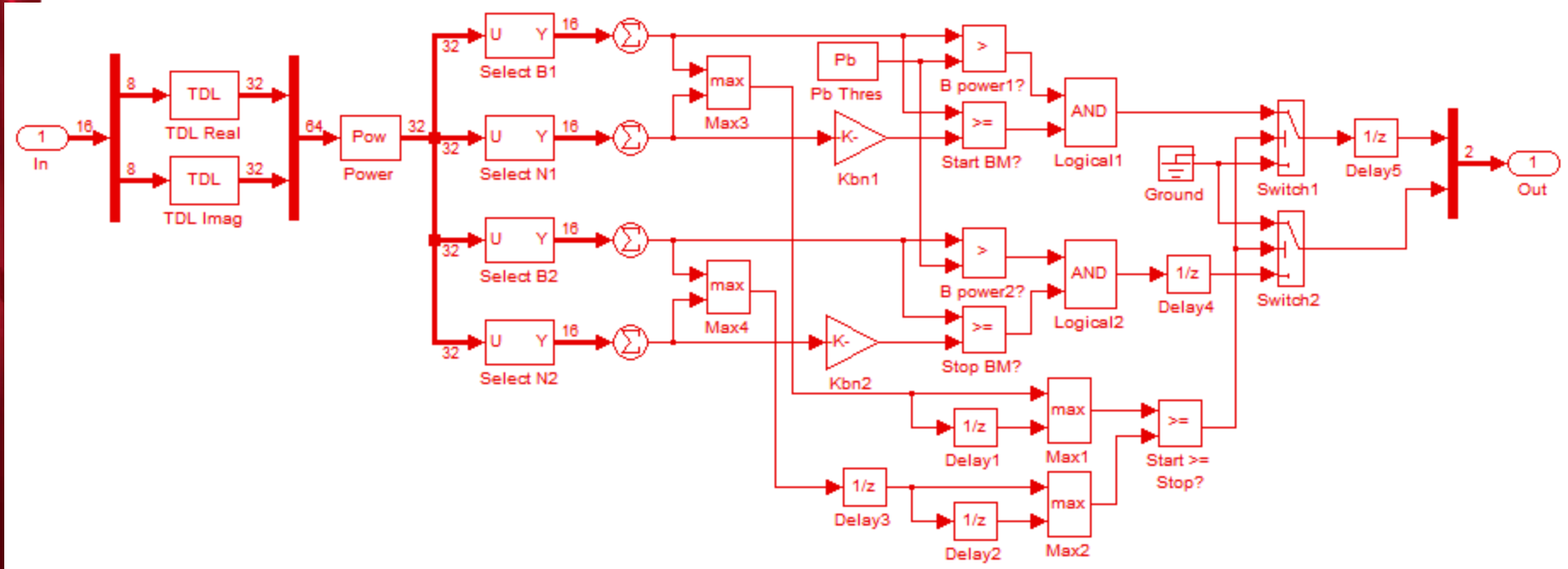
BACKUP SLIDES

2x16 BM Detector block diagram



2x16 Start and Stop BM detectors (yellow: “B”, magenta: “N”)

4x8 BM Detector block diagram with circuit to prevent simultaneous Start and Stop BM trigger



Improved Burst Marker Detector with low False Detection rate

4x8 Start and Stop BM detectors (yellow: “B”, magenta: “N”)