A Baseline Proposal for 1000BASE-T1 Mapping and FEC

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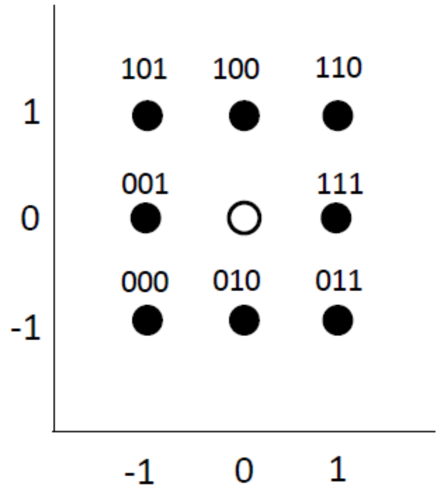
Selecting FEC and mapping candidates

- **RS FEC protection capability is not the only factor**
  - External noises are present at the input of the receiver, not at the input of FEC decoder
  - Simulated data including both DFE and FEC are critical in making sound decision

- **RS FEC and mapping criterion**
  - Baud rate = 750MHz
  - Works well with 8n/(8n+1) PCS encoding
  - Overall RS encoder and decoder buffer latency ≤ 4usec
  - RS block error rate ≤ 1e-6 under noises
  - Supports OA&M bits per FEC block

3-bit to 2-ternary (3B2T) geometric structured mapping

- **Constellation and bit-mapping**:
  - Similar to 1 Twisted Pair 100 Mb/s solution
    - 2-D QAM-like constellation
    - 3-bit to one 2-D PAM3 symbol
  - Gray code mapping
    - Best suited for block code FEC
- **Advantages:**
  - Mitigating DFE error propagation
    - 3B2T FEC with 2-D DFE slicer becomes a coded modulation scheme
    - Euclidean distance helps
  - Low complexity but high performance
    - See performance pages
- **Proposed at** IEEE 802 Plenary Beijing meeting in March 2014 (Shen_3bp_01_0314.pdf)
- **Other proposals:**
  - 11B7T mapping (liu_3bp_01a_0314.pdf)
  - PAM2 and two 3B2T mapping (xiaofeng_3bp_02_0314.pdf)



3B2T (3bit to 2 ternary)

FEC codes

- **FEC structure**: algebraic block code
- **Decoding algorithms**
  - Erasure decoding: must know erasure locations
    - Unreliable due to uncertain erasure location estimation
  - Error correction: finding both error locations and error values
    - Reliable
  - **Conclusion**: choose error correction decoding algorithm
- **Code symbol sizes**
  - Choices for 3B2T: binary BCH, 9-bits RS, 12-bit RS,15-bit RS,…
    - Usually, the smaller of the size the better of the performance for AWGN
    - However, BCH is not MDS the property that RS codes enjoy
  - **Conclusion:** 9-bit RS code is chosen
- Other proposed FEC for 11B7T: 11bit RS code (liu_3bp_01a_0314.pdf)
- The complexity of 9-bit RS code is much lower than that of 11-bit RS code

FEC and mapping candidates

Candidate	Mapping	8n	8n+1	RS m	RS N	RS K	FEC rate	OAM bits	RS N-K	FEC Block ns	Correction ns	FEC latency ns	OAM Mbps
A	3B2T	80	81	9	450	406	0.902	9	44	3600	176.00	3952.00	2.50
B	11B7T	120	121	11	360	309	0.858	11	51	3360	233.33	3836.00	3.27

- Use one RS redundancy symbol for OAM bits.

Pros and cons of the two candidates

Candidate	Mapping	PCS 8n/(8n+1)	RS FEC	Without DFE	With DFE
A	3B2T	80/81	(450,406,m=9)		Better 1. Advantage of 2D coded modulation 2. Smaller RS symbol size 3. See details in following slides
B	11B7T	120/121	(360,309,m=11)	Better Stronger RS correction capability	* 2D slicing might be doable

Two critical channel noises

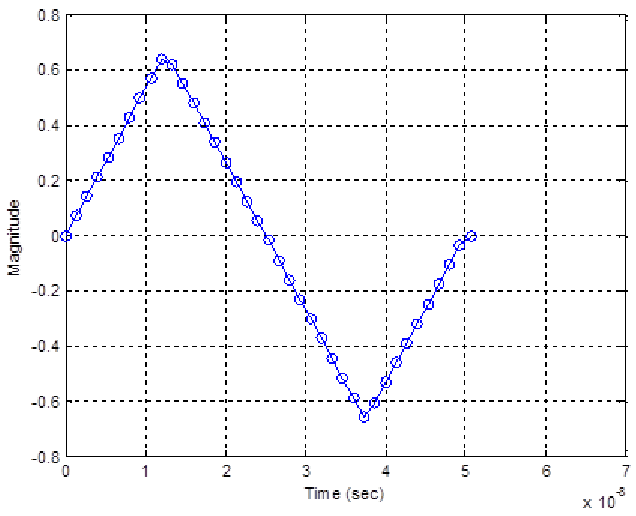
- **Narrowbband interference**
  At time k with an amplitude A: $n_I(A,k) = A\cos\left(\phi + \left[2\pi\left(\frac{f_c}{f_s}\right)k\right]\right)$,

  $A = \sqrt{2P_{NBI}}$, P_{NBI}: average power of NBI

  f_s: sampling frequency,

  f_c: carrier frequency,

  Random phase carrier: $\phi \in [-\pi, \pi]$
- **Impulse noise**
  - Occurs every 1,000 coded blocks
  - Duration: 50nsec
  - Burst noise source considered:
    - AWGN
    - Triangular



Triangular impulse noise

- **Simulation model:** $rx(k) = s(k) + n_{AWGN}(SNR_{AWGN}, k) + n_{NBI}(A,k) + n_{burst}(SNR_{burst}, k = 1000m);$

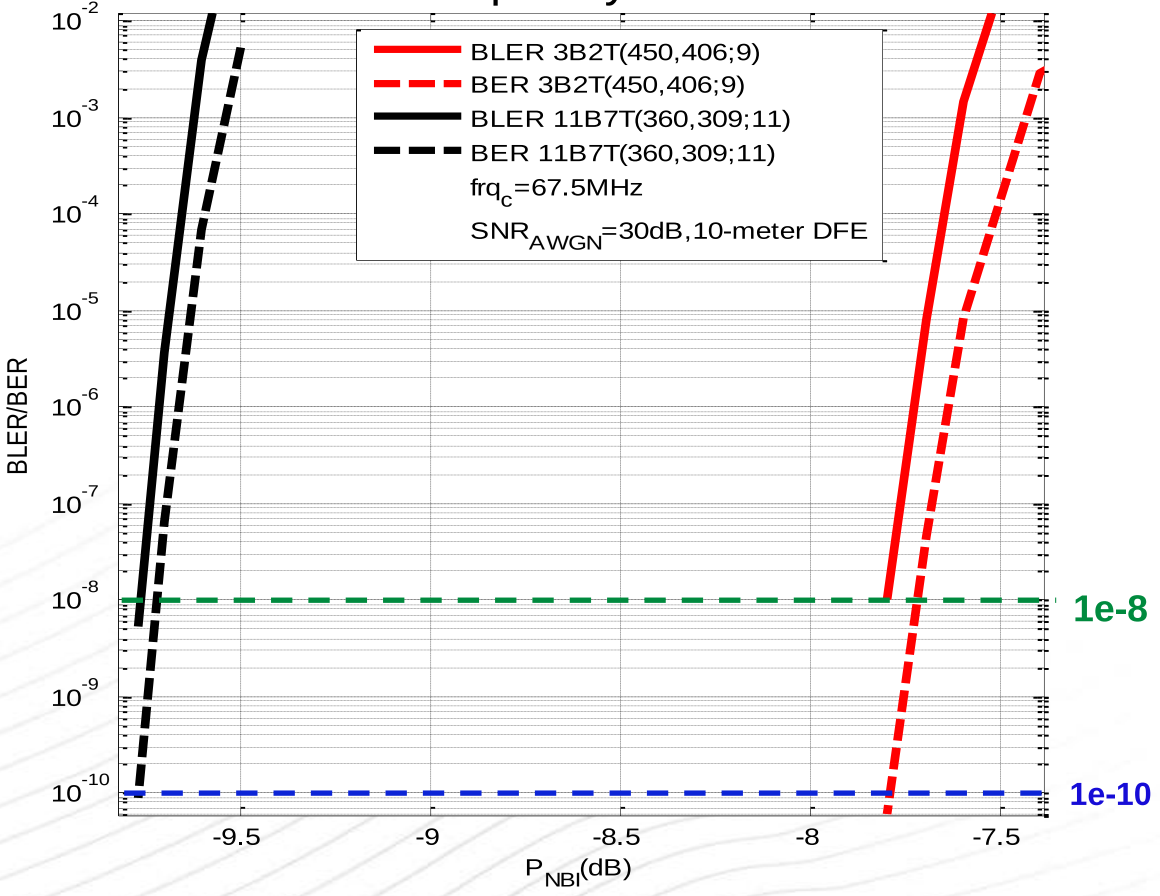
*assume the background AWGN noise is low (dpSNR≥30dB))

Simulation model for performances

- **Baud rate**
  - 750MHz
- **DFE**
  - 10m measured UTP
- **Slicer**
  - 2-D slicer for 3B2T
  - 1-D slicer for 11B7T
    - 7-D slicer geometric structure is not obvious
    - Also simulated 2-D slicer for 11B7T per Xiaofeng’s suggestions
- **Noises**
  - Background: 30dB SNR of AWGN
  - NBI frequencies
    - 67.5MHz (f_c/f_s= 0.09)
    - 337.5MHz (f_c/f_s= 0.45)
  - Impulse noise
    - Noise duration: 50ns
    - Appear once in every 1,000 FEC blocks

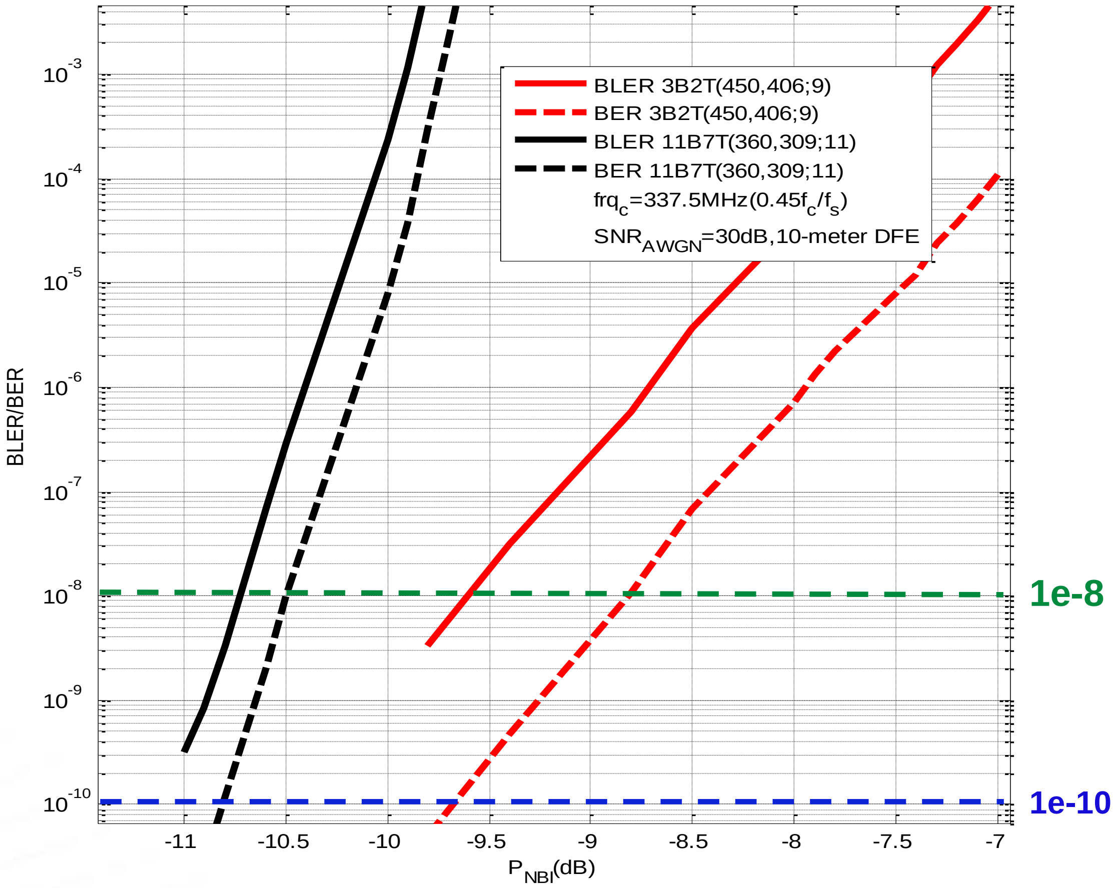
NBI only with DFE

NBI frequency: 67.5MHz



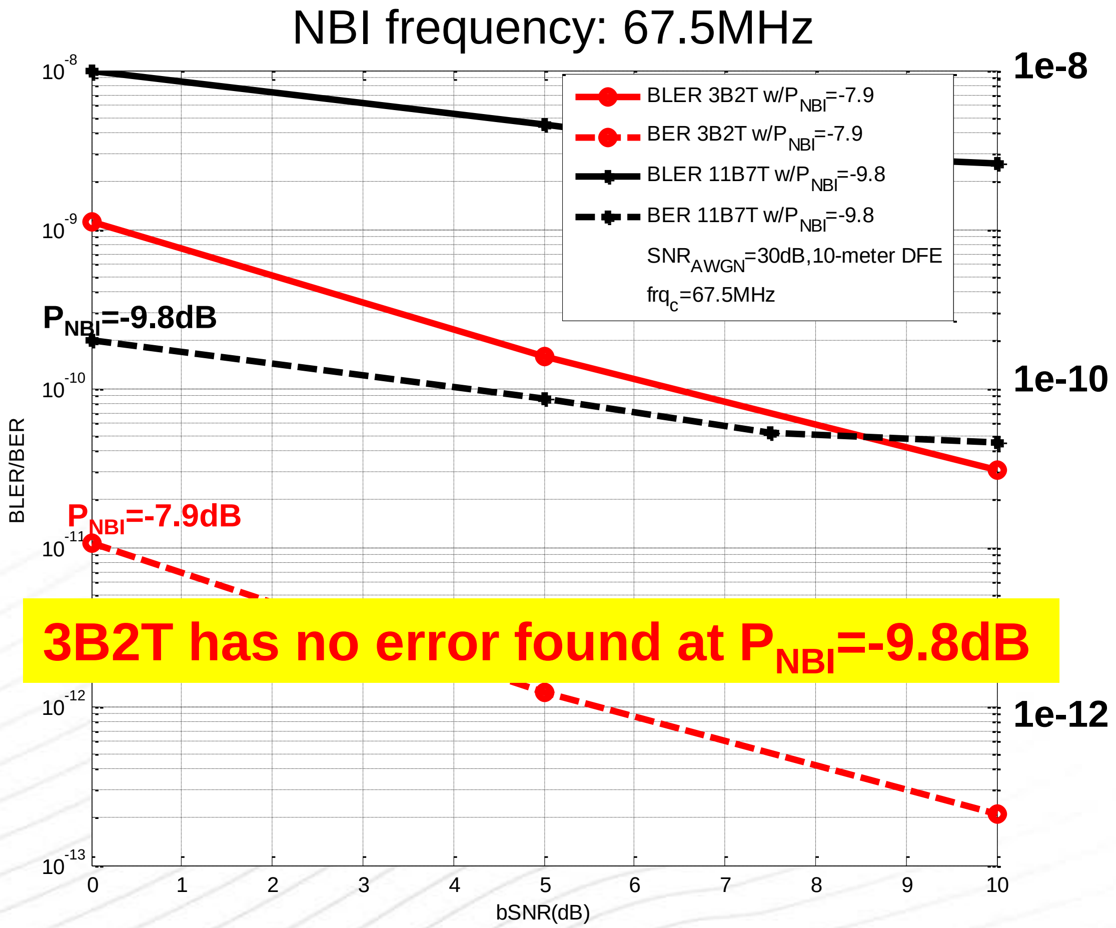
3B2T outperform 11B7T
~2dB @BLER=1e-8
~2dB @BER=1e-10

NBI frequency: 337.5MHz

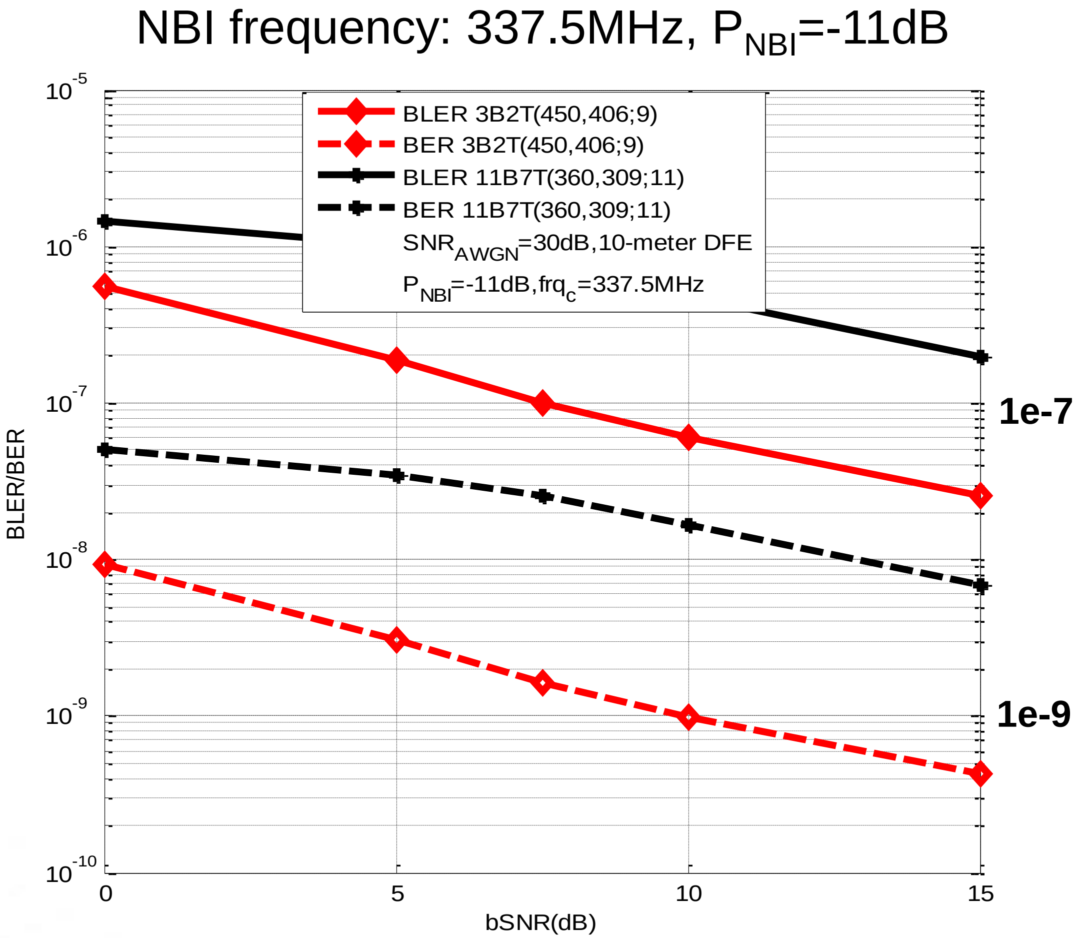


3B2T outperform 11B7T
>1dB @BLER=1e-8
>1dB @BER=1e-10

AWGN impulse noise + NBI with DFE



3B2T has no error found at P_{NBI}=-9.8dB

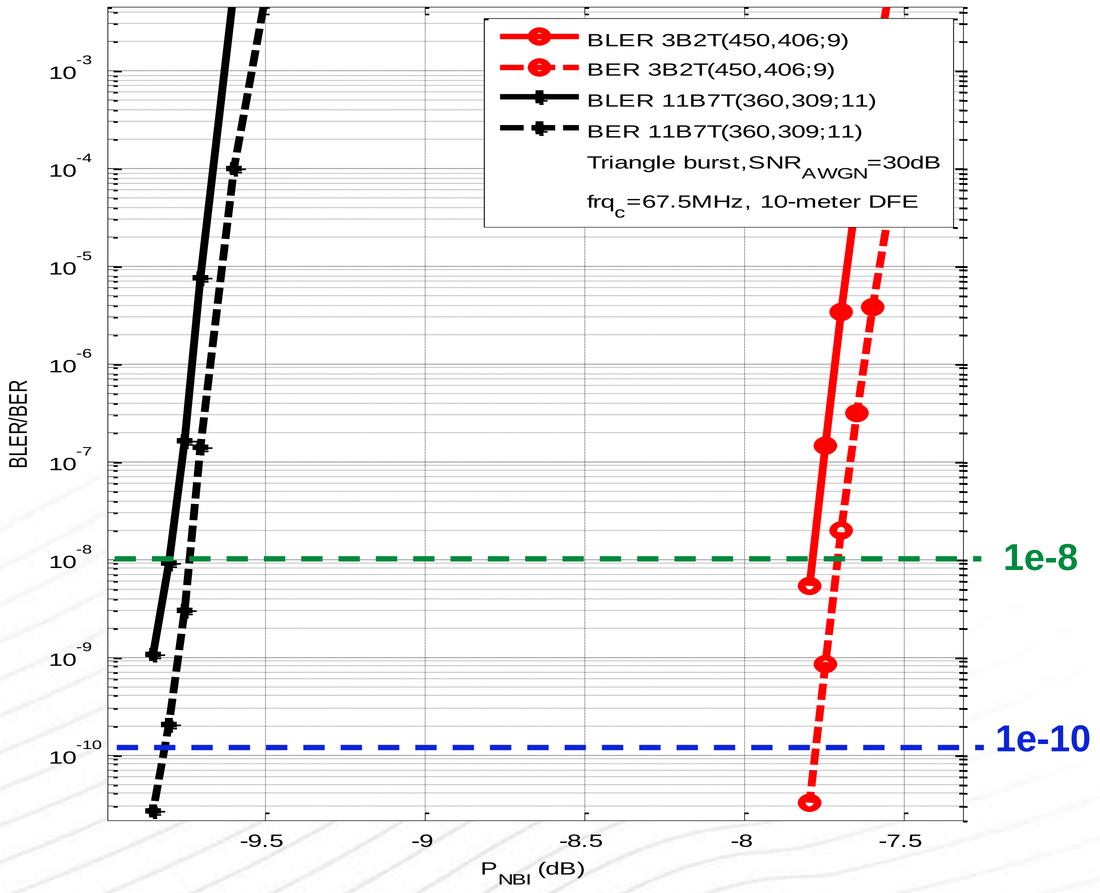


3B2T w/ P_{NBI}=-7.9dB outperform 11B7T w/ P_{NBI}=-9.8dB
>5dB @BLER=1e-8
>5dB @BER=1e-10

3B2T outperform 11B7T
>8dB @BLER=1e-7
>8dB @BER=1e-9

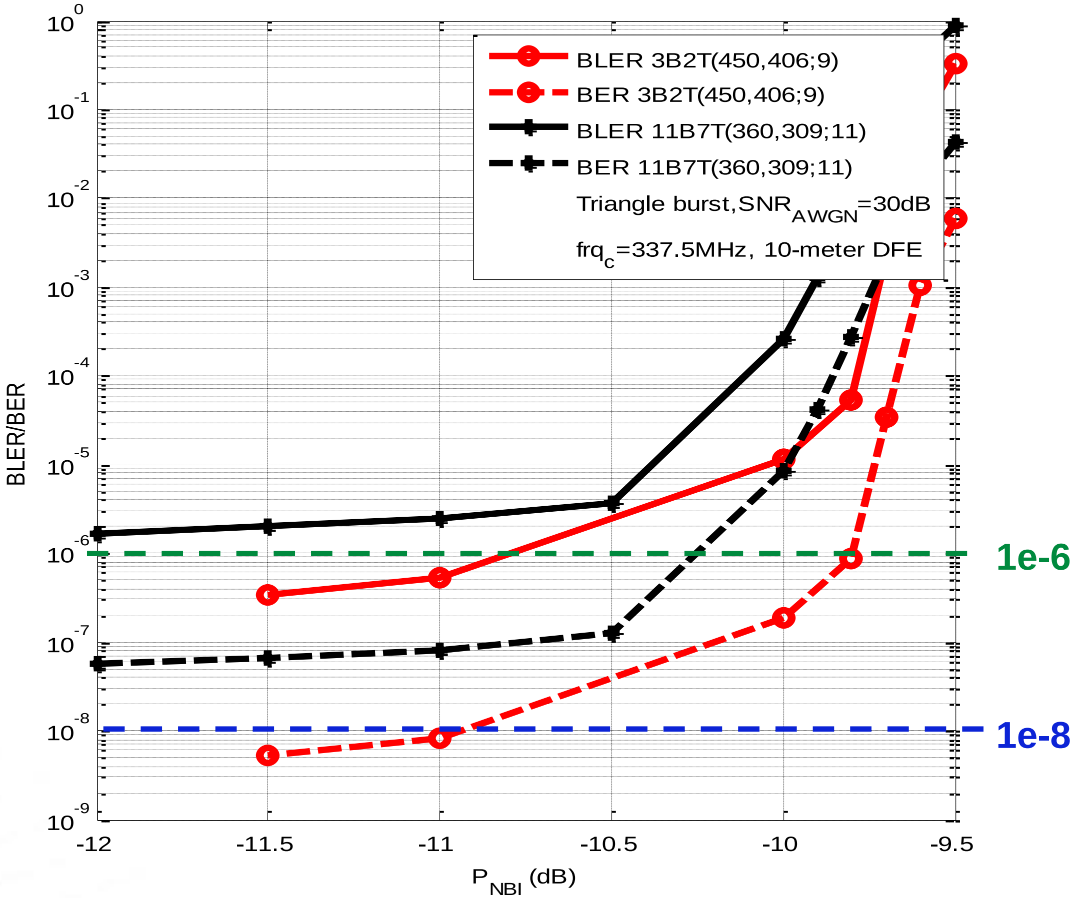
Triangular impulse noise + NBI with DFE

NBI frequency: 67.5MHz



3B2T outperforms 11B7T
>2dB @BLER=1e-8
>2dB @BER=1e-10

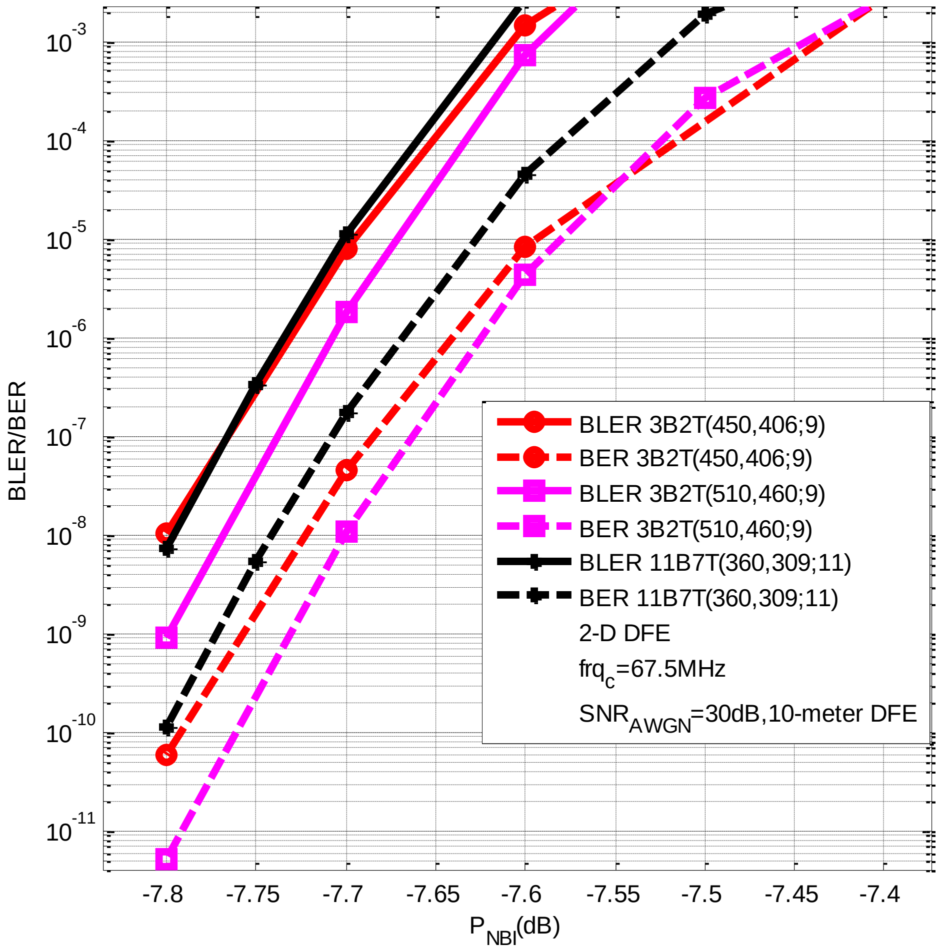
NBI frequency: 337.5MHz



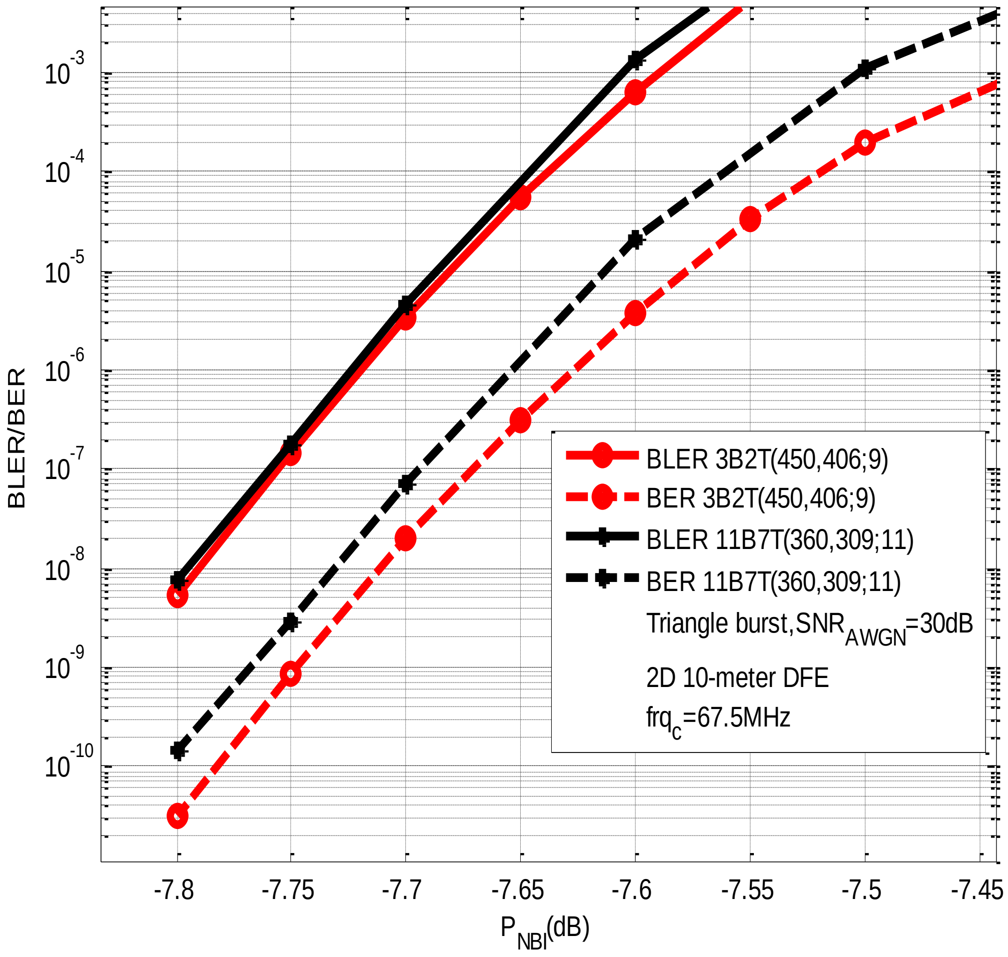
3B2T outperforms 11B7T
>2dB @BLER=1e-6
>2dB @BER=1e-9

Use 2D DFE slicer for 3B2T and 11B7T

NBI only (freq: 67.5MHz)



NBI+ triangular burst



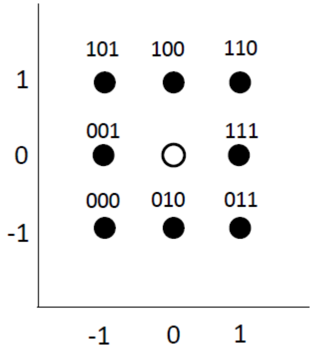
Conclusion

- **3B2T mapping with 750MHz baud rate RS code is the best choice**
  - **Better or same performance** for both NBI only and NBI + impulse noise with DFE error propagation
  - **Low complexity**
    - **For mapping and de-mapping**
    - **For RS code**
      - Smaller symbol size (9 vs.11)
        - » Smaller multipliers
      - Less number of error correction needed (22 vs. 25)
        - » Less iterations for finding the error locations
        - » Less number of evaluations for error values

Baseline proposal

- **Adopt 3B2T mapping with baud rate 750MHz, 8n/8n+1=80/81 9-bit RS (450,406,t=22) code as the baseline.**

Mapping



FEC Code

Mapping	8n	8n+1	RS m	RS N	RS K	FEC rate	OAM bits	RS N-K	FEC Block ns	Correction ns	FEC latency ns	OAM Mbps
3B2T	80	81	9	450	406	0.902	9	44	3600	176.00	3952.00	2.50

Other considerations

- FEC bypass option (under consideration by OEMs):
  - Adopt William Lo’s idea: keep FEC encoder and bypass FEC decoding
  - Total FEC buffer latency reduced to 352nsec
- Additional 3B2T FEC choices:

8n	8n+1	RS m	RS N	RS K	FEC rate	OAM bits	RS N-K	FEC Block ns	Correction ns	FEC latency ns	OAM Mbps
80	81	9	270	244	0.903	9	26	2160	104	2368	4.17
80	81	9	300	271	0.903	9	29	2400	112	2632	3.75
80	81	9	360	325	0.903	9	35	2880	136	3160	3.13
80	81	9	390	352	0.903	9	38	3120	152	3424	2.88
80	81	9	420	379	0.902	9	41	3360	160	3688	2.68
80	**81**	**9**	**450**	**406**	**0.902**	**9**	**44**	**3600**	**176**	**3952**	**2.50**
80	81	9	480	433	0.902	9	47	3840	184	4216	2.34
80	81	9	510	460	0.902	9	50	4080	200	4480	2.21

main choice

alternative choice *

*: from “Lo_3bp_0614_FEC Proposal_updated2”, page 8.