Initial PHY proposal for the IEEE802.16.3 Air Interface Standard

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Venue: IEEE802.16.3 – 00/14 Call for Contributions on the topic: Initial PHY Proposals
Base Document: 802.16.3c-00/48

Purpose:This contribution will be discussed for a vote as a possible PHY layer for the IEEE802.16.3 Air Interface Standard

An advanced Single-carrier PHY
For Robust NLOS\LOS
2- 11 GHz Fixed BWA

DESIGN GOALS

- CPE cost to be competitive with xDSL and cable modem
- Robust solution for NLOS and LOS
  - Channel impairments
  - Interference
  - Radio equipment
- High performance
  - High spectral efficiency
  - High coding gain
- High Flexibility
  - FDD, TDD and FSDD
  - Modulation formats
  - Code rates
  - MAC agnostic

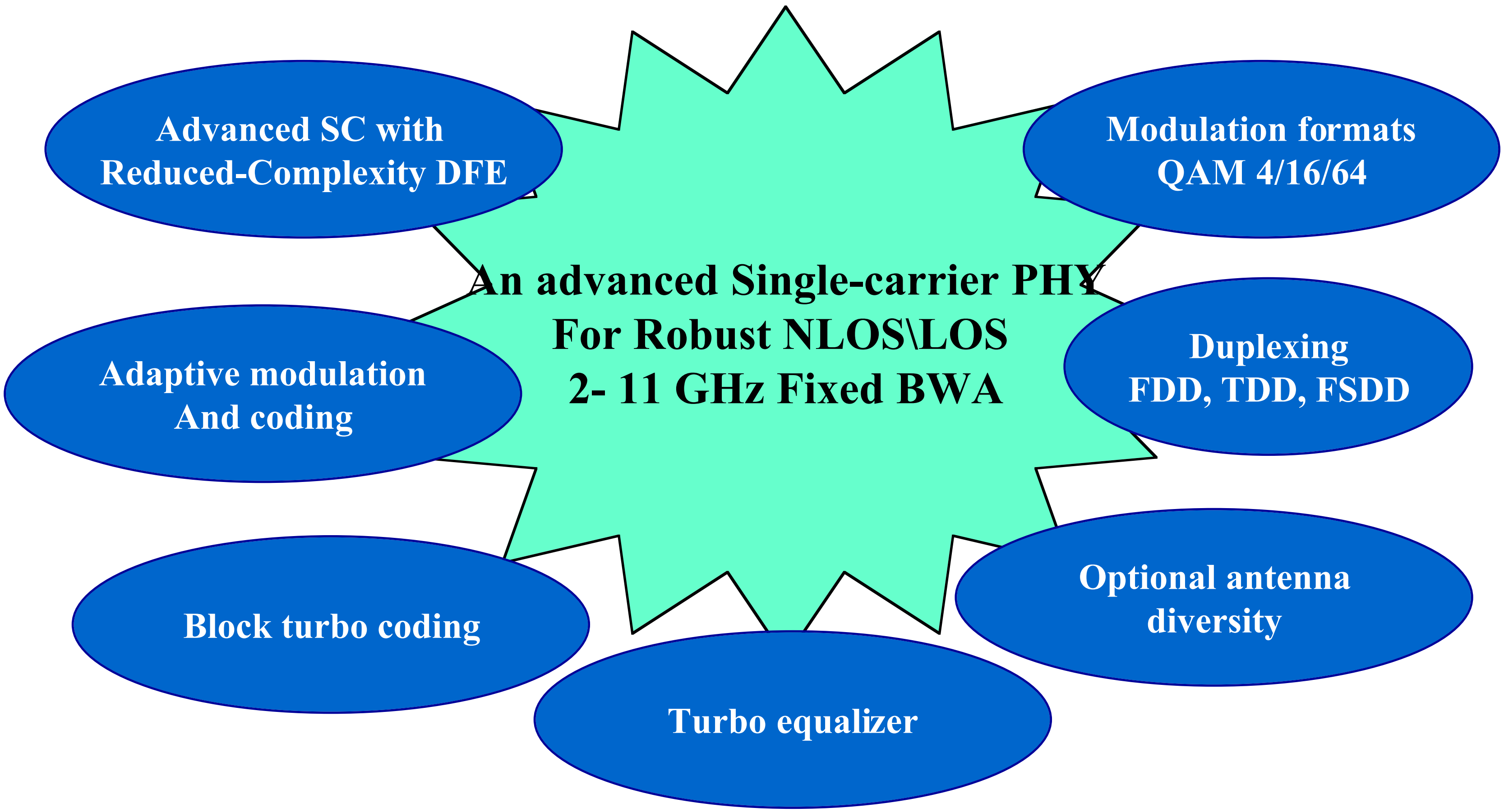
Target frequency bands: 2-11 GHz

- General mathematical model is fading time-varying channels, i.e. $h(t;\tau)$ time varying impulse response
- RF propagation Impairments:
  - Path loss, noise, ACI, CCI
  - Multipath
    - rapid changes in RSS over short time\distance
    - Multipath Delay Spread (time dispersion)
    - Doppler Spread (frequency dispersion)
- (delay spread) * (Doppler spread) << 1 for having a "channel model"

Link Model

- Relevant works (mainly for the 2.5 GHz band)
  rap96 CH3,CH4 and #47, #49, #52 #53
  ….But there are also 3.5, 5, 10.5 GHz bands
- Further work is needed to verify empirically key parameters and their variability range:
  - Fading distributions characteristics
  - Time-variation characteristics (e.g., Doppler spread)
- Properly designed SC + DFE + FEC meets the challenge!

PHY Features



PHY - Main Features

I) Advanced SC + reduced-complexity Decision Feedback Equalizer (DFE)

II) Adaptive Modulation and Coding (AMC)

III) Modulation formats: Gray mapped QAM 4/16/64 – up/down stream

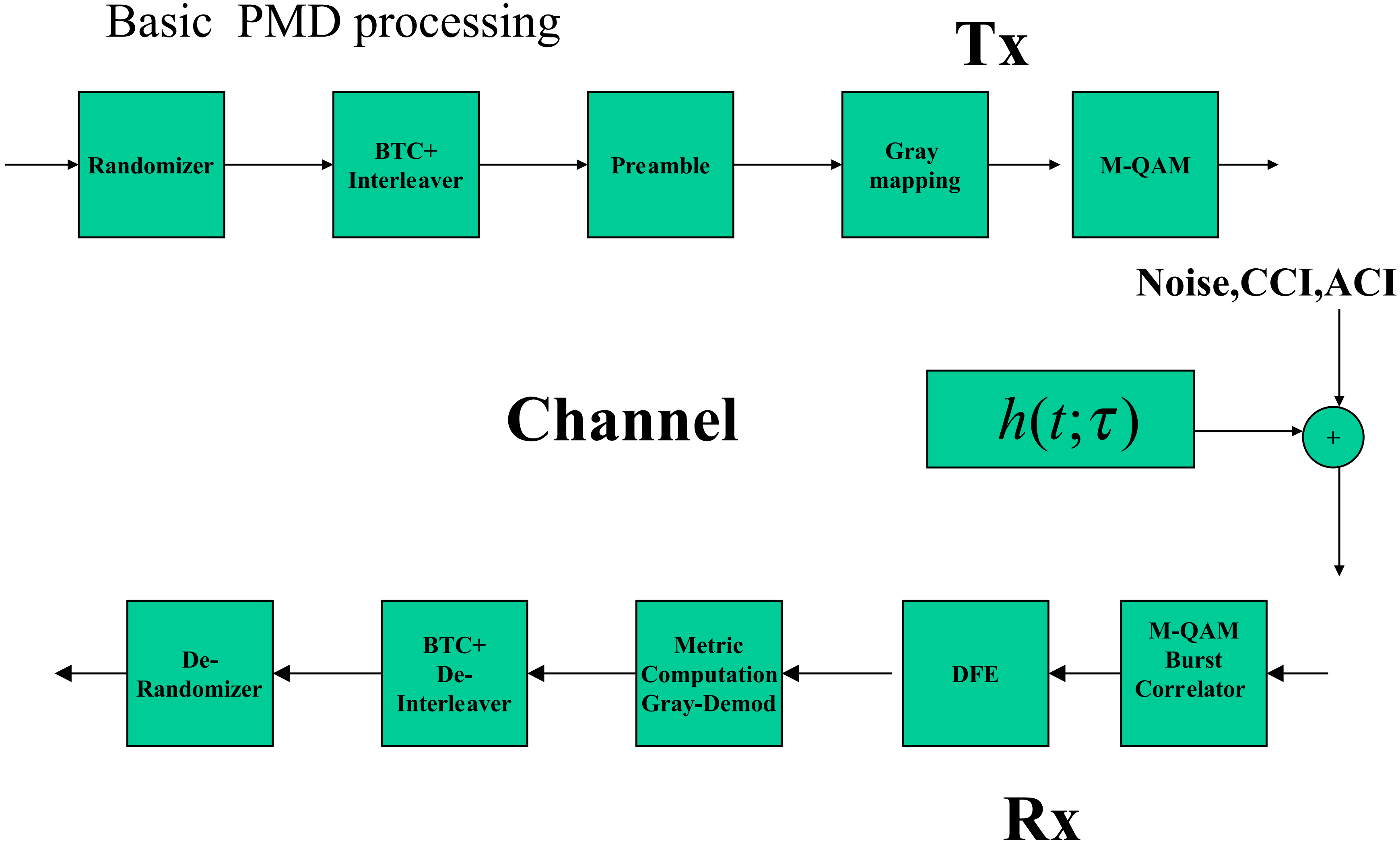
IV) Flexible coding scheme based on BTC

V) FDD (TDD and FSDD as options)

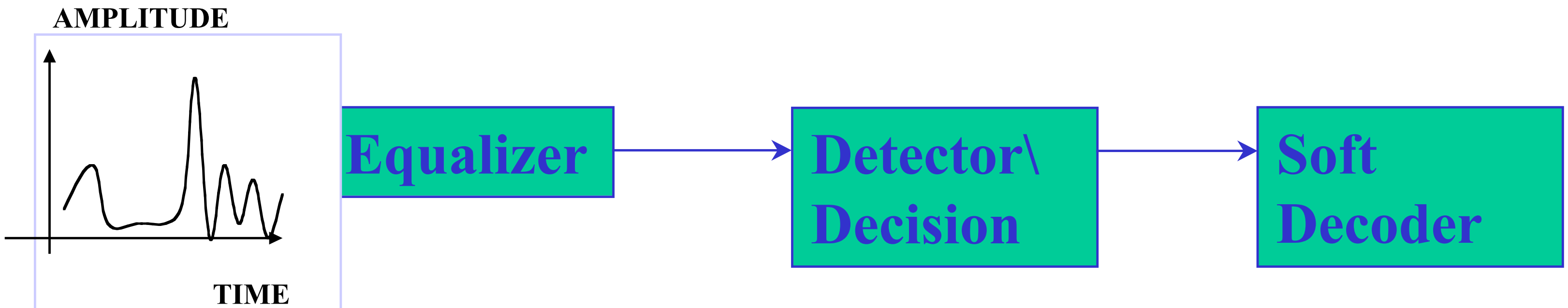
VI) Supports Mega-Cell (LOS) and Multi-Cell (NLOS)

VII) Migration approach : Turbo-Equalizer (TE), Rx diversity, MIMO

Basic PMD processing

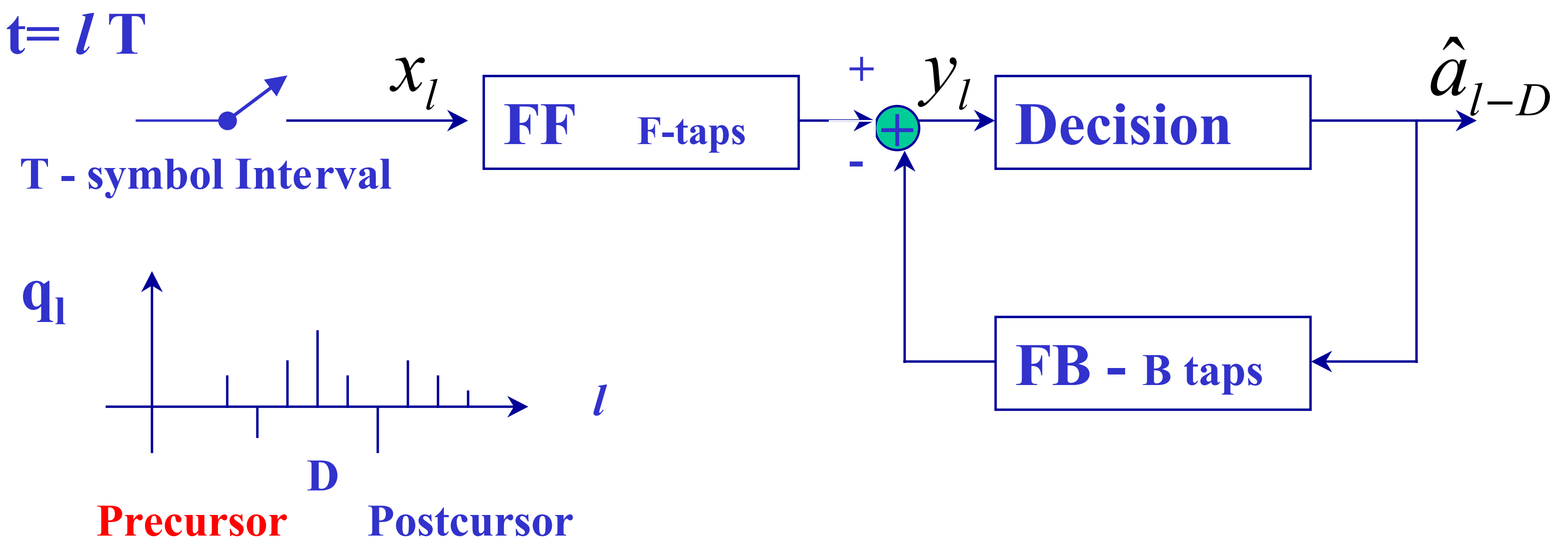


Channel Equalization and Decoding



- **Adaptive receiver based on Channel Equalization, Demodulating and Decoding**
- **Equalizer compensates for the unwanted channel features i.e. channel (including the equalizer) is “matched” to the detector**

Advanced Single Carrier with DFE



$$x_l = \sum_{m=-\infty}^{\infty} a_{l-m} q_m + n_l, \mapsto y_l = x_l - \sum_{m \in \{D+1, D+2, \ldots L\}} a_{l-m} c_m$$

Advanced Single Carrier With DFE

- Simple implementation for *both* LOS and NLOS scenario
  - the NLOS requires the FF part of the DFE
  - No need for guard time overhead
- Enhanced performance under dynamic selective fading scenarios
- No "handshaking" is needed between BS and CPE - only training sequences (preambles) and "decision FB" within the Rx.
- Efficient algorithms to
  - Reduce DFE complexity [Sir97], [Fal00]
  - Fast start-up [Sel98]
  - Combine with Soft decoding - Turbo Equalization (TE) [Nef00]
  - Combine with Interference suppression [Sir00]
  - Combine with MIMO – Space Time Equalizer [Sir99]

Reduced Complexity DFE

Strategy to reduce DFE complexity in BWA channels

- Fast start-up for short packets
- modified DFE [sir97]

- **(delay spread)/(symbol interval) = 25 to 100, for severely distorted channels DFE outperforms OFDM and requires less complexity -**

  see [Sir97] and [Fal00]

- **robust algorithms for fast fading**

Adaptive Modulation & Coding (AMC)

- Basic idea of Adaptive transmissions -
  - Varying Tx power, symbol rate, constellation size, coding rate/scheme, to satisfy end-to-end QoS requirements.
  - Maximizing spectral efficiency under given BER constraints
- AMC based on changing constellation size and coding rate/scheme (M-QAM + BTC) exhibits 20 dB gain under given BER constraints relative to non-adaptive schemes
  - Meet worst case ADF of 0.1 sec for 10 dB below average value
- IEEE802.16.1 MODE B

➢ Penalty paid – more complex burst receivers

BTC Features and Advantages

- LIMITS: 0.5 - 3 dB from Shannon capacity
- Large coding gain: 8-10 dB
- Support SC and OFDM M-QAM : M=4,16,64 pragmatic
- Compliant with IEEE802.16.1 MODE B
- Flexibility: complexity/performance,
  - ❖packets size: 18 to 399 bytes
  - ❖code rate: 0.5 – 0.8
- State-of-the art SD for the components codes: fast convergence & low complexity, short delays, no error-floor at low BER

FDD/TDD/FSDD for duplexing

- AMC in all duplexing MODES
- TDD allows sharing the same frequency between upstream and downstream. Advantageous for non-contiguous frequency channels
- FSDD allows low cost “half duplex” subscriber

Mega-Cell/Multi-Cell topology

Mega-cell topology:

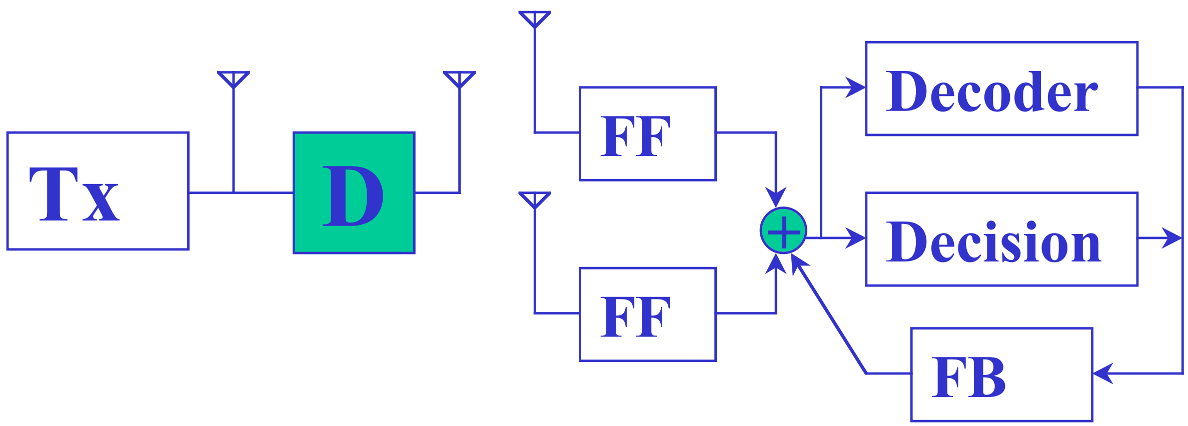
- up to 50 km Tx\Rx separation,
- LOS propagation.
- Directive antenna at both BTS and CPE
- negligible Co-Channel-Interference (CCI).

Multi-cell topology:

- cell radius typically less then 10 km.
- Frequency re-use cellular system.
- A cell may be subdivided into sectors.

Multi/Single Antenna

- Capacity of MIMO Rayleigh fading channels grows linearly with N, when N is both the number of Tx *and* Rx.
- Tx - Rx diversity can be designed to meet flat fading, often the performance-limiting in BWA links with DFE [Sir98]
- This scheme applicable to SC+DFE combined with BTC



PHY Main benefits

- Mature and widely used legacy technology
- High spectral efficiency and flexibility (AMC)
- Flexible Asymmetry: FDD and TDD/FSDD
- Scalability – short to very long PDU
- Much better than OFDM to RF impairments and radio equipment impairment: linearity of power amplifier, frequency instability, phase noise, synchronization errors, Doppler spread etc
- Improved System Gain – due to BTC and better PAP
- Reduction in cost, complexity and network architecture simplification

… concluding

PHY meets the FRD *and* provides best cost-performance PHY for IEEE802.16.3 for both LOS and NLOS systems

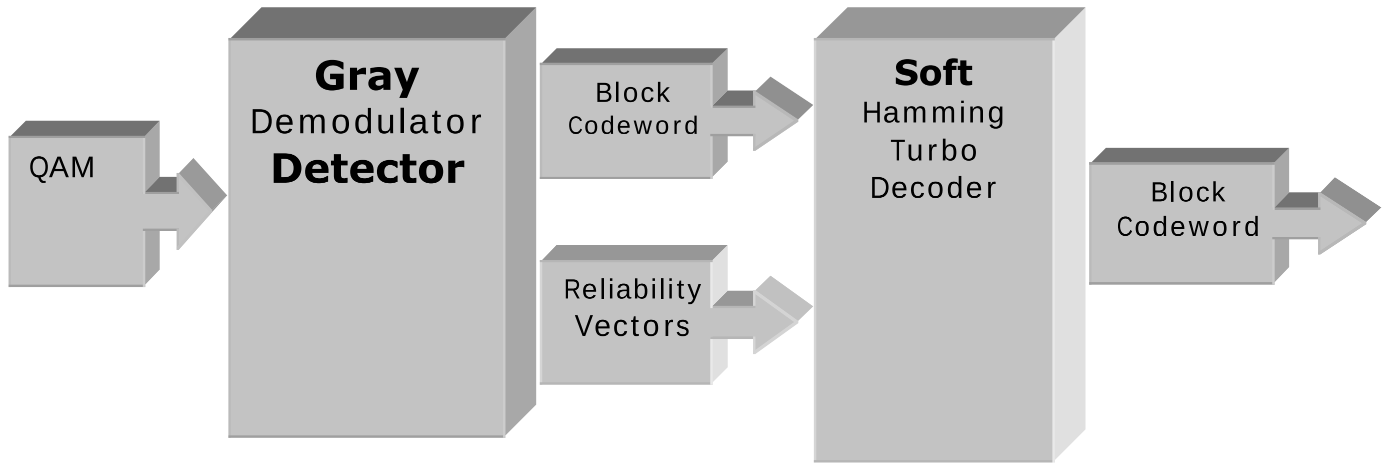
Conclusions

- PHY meets FRD - LOS and NLOS scenario
- Based on matured technology

  Advanced SC + DFE, AMC, BTC
- Implementation simplicity *and* high spectral efficiency
- High immunity to RF Impairments
- Seamless “Migration approach” to TE, Rx diversity

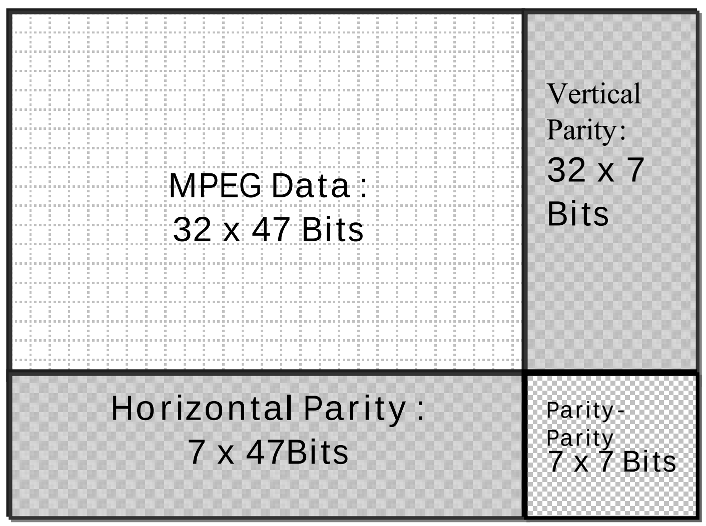
Modulation scheme	SNR [dB] for post FEC 10E-8 RS(71,63) r=0.88	SNR for post FEC 10E-8 BTC r=0.79 N=392bytes		
QPSK	9.4	7.3		
16QAM	16.1	13.5		
64QAM	22	19.8		

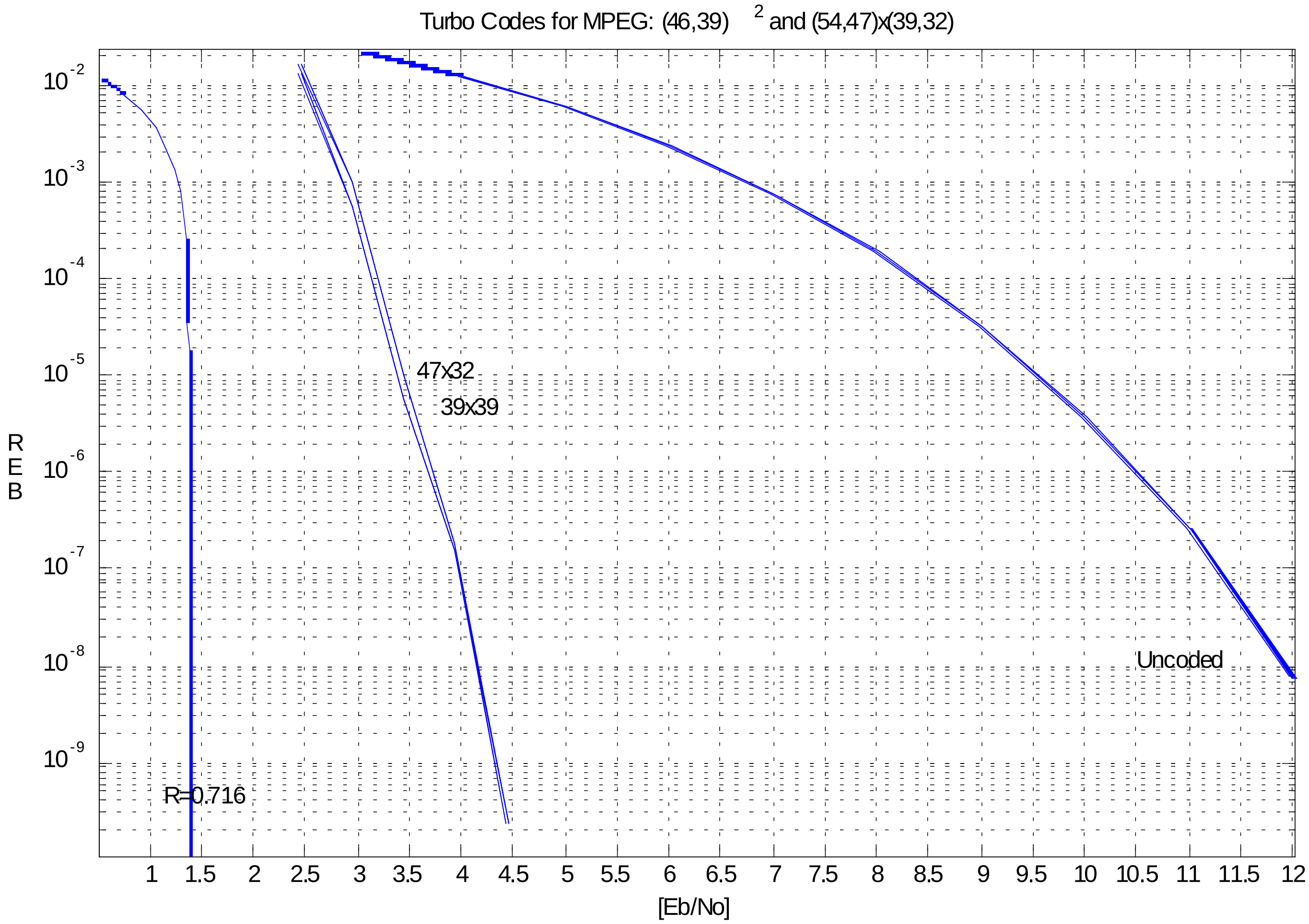
4. TelesciCOM SISO Decoders for BWA Channels



The MPEG-2 package format

Data bits are arranged in a 32 × 47 bit rectangle, and encoded as a block code of 39 × 54 bits using a shortened Hamming block encoder (64-25 , 57-25)×(64-10 , 57-10) resulting a overall block of 2106 bits

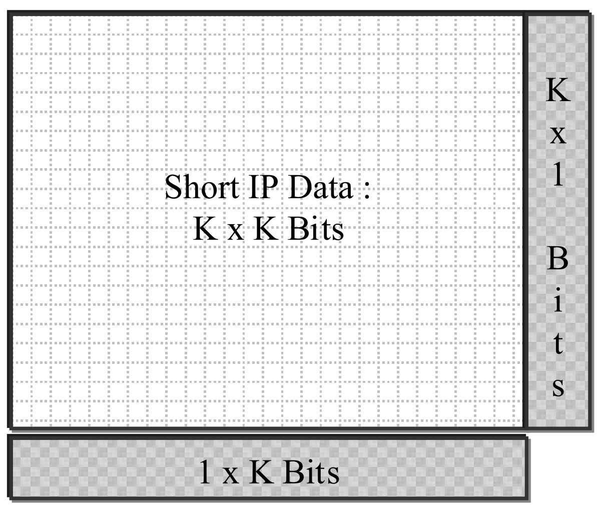



Turbo Codes for MPEG: (46,39) 2 and (54,47)x(39,32)
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
BER
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
[Eb/No]
47x32
39x39
Uncoded
R=0.716

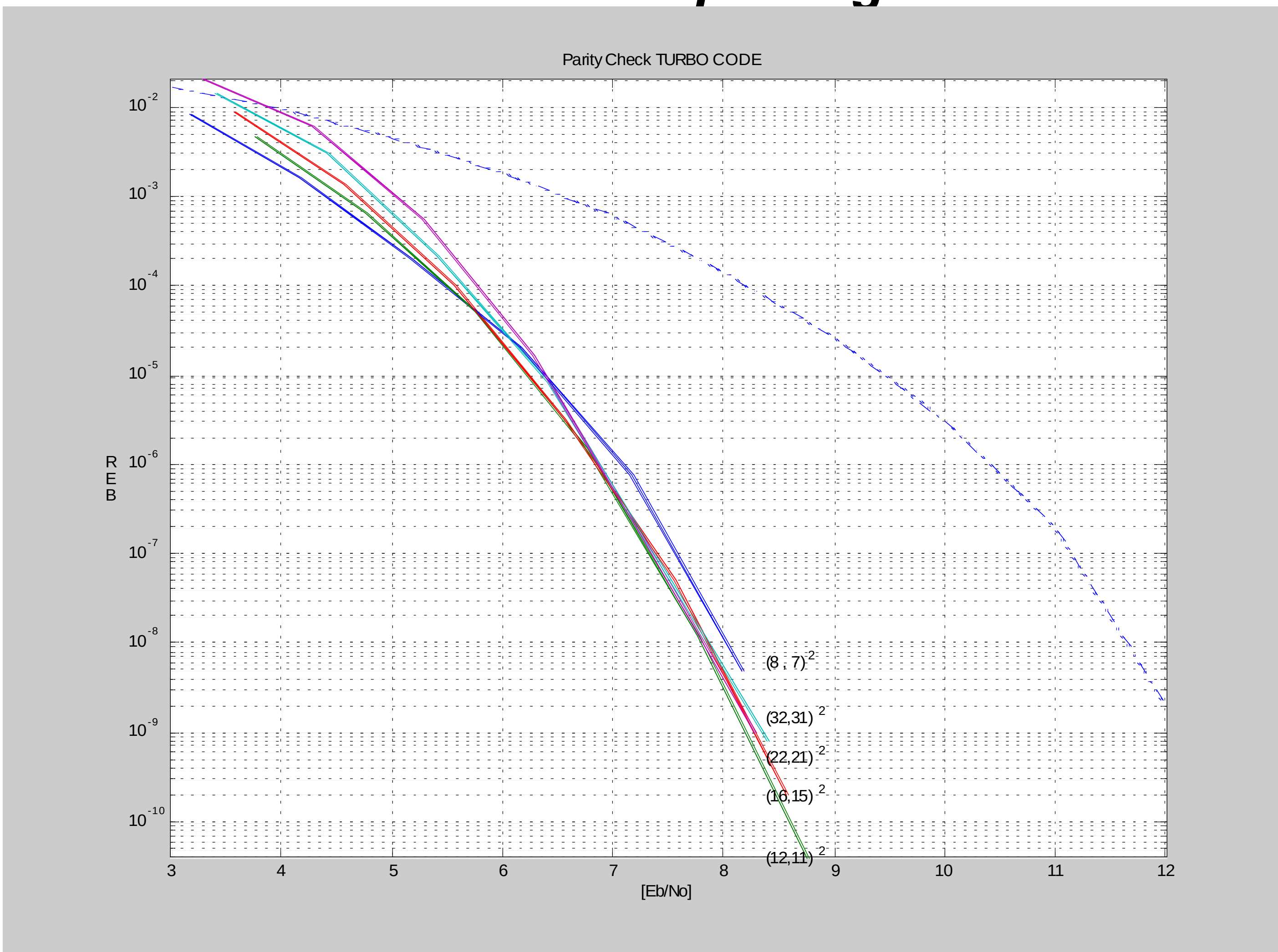
Short IP packages

PCB(9,8)^2 and PCB(17,16)^2 , respectively.

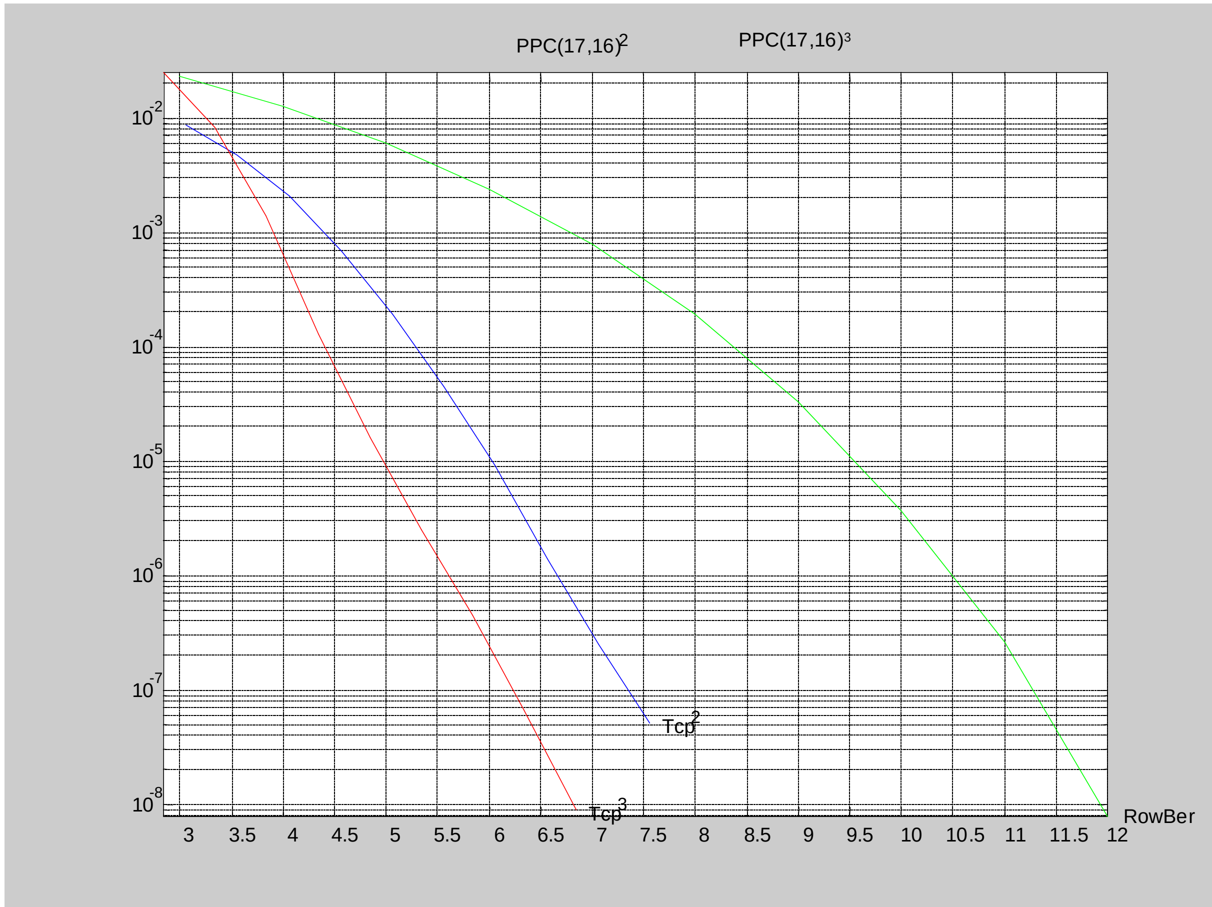
PCB(9,8)^2 code has rate R=0.8 and its Shannon Limit is :
$[Eb/No]_{Shannon}$ (0.8) = 2.04 dB
PCB(17,16)^2 code has rate R=0.889 and its *Shannon Limit* is ***:***
$[Eb/No]_{Shannon}$ (0.889) = 3.026 dB

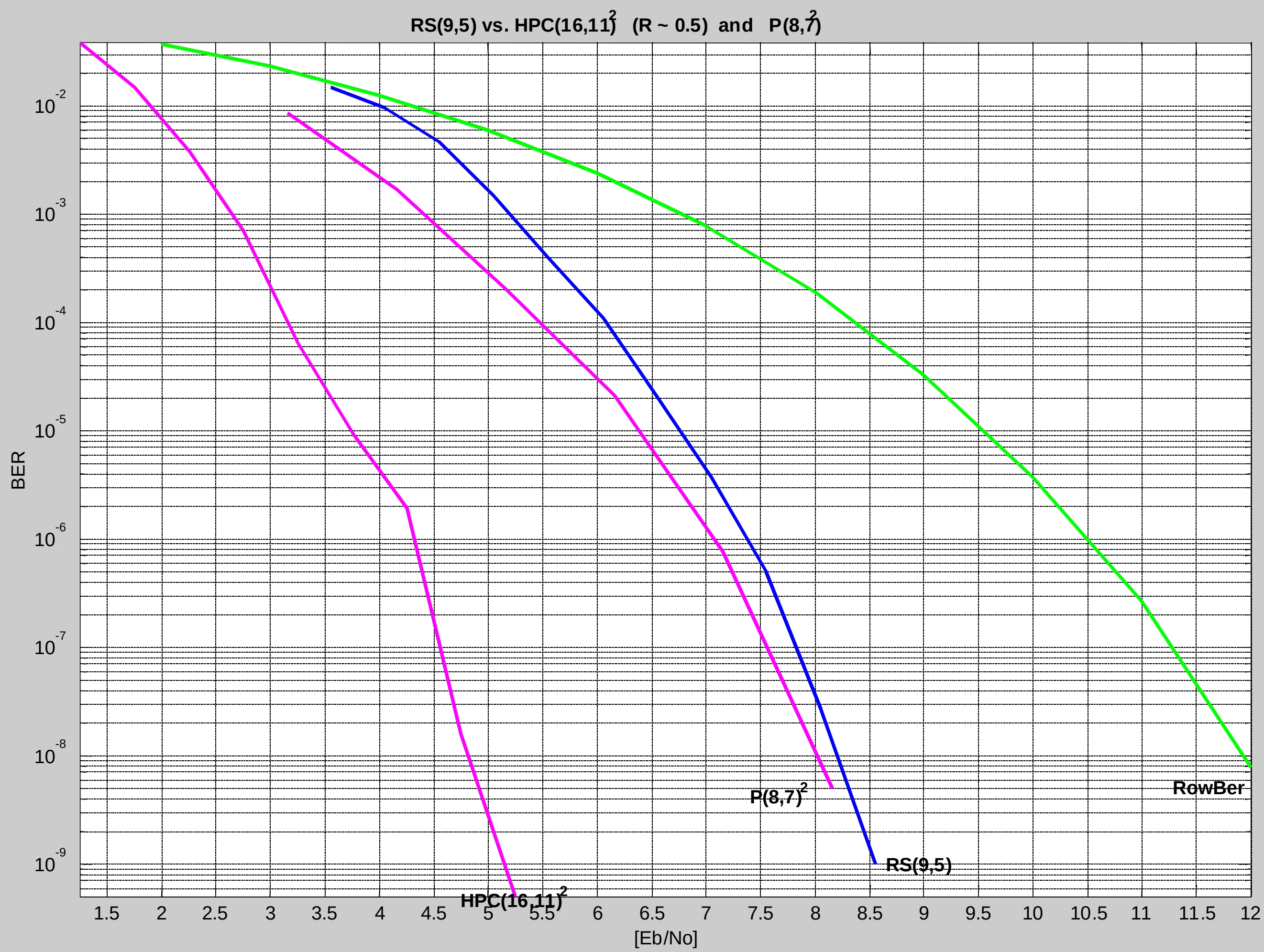


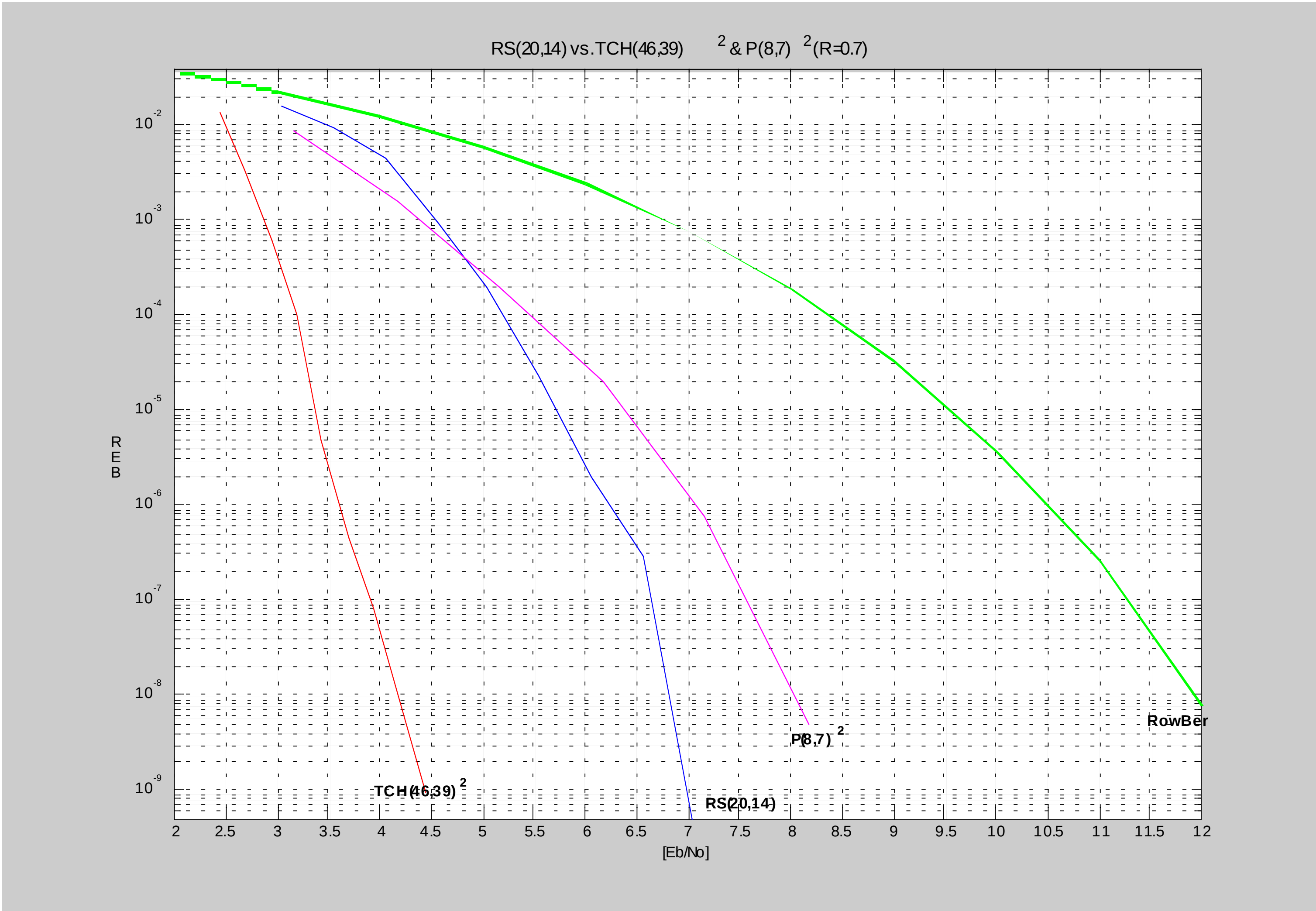
Performance with Short IP packages

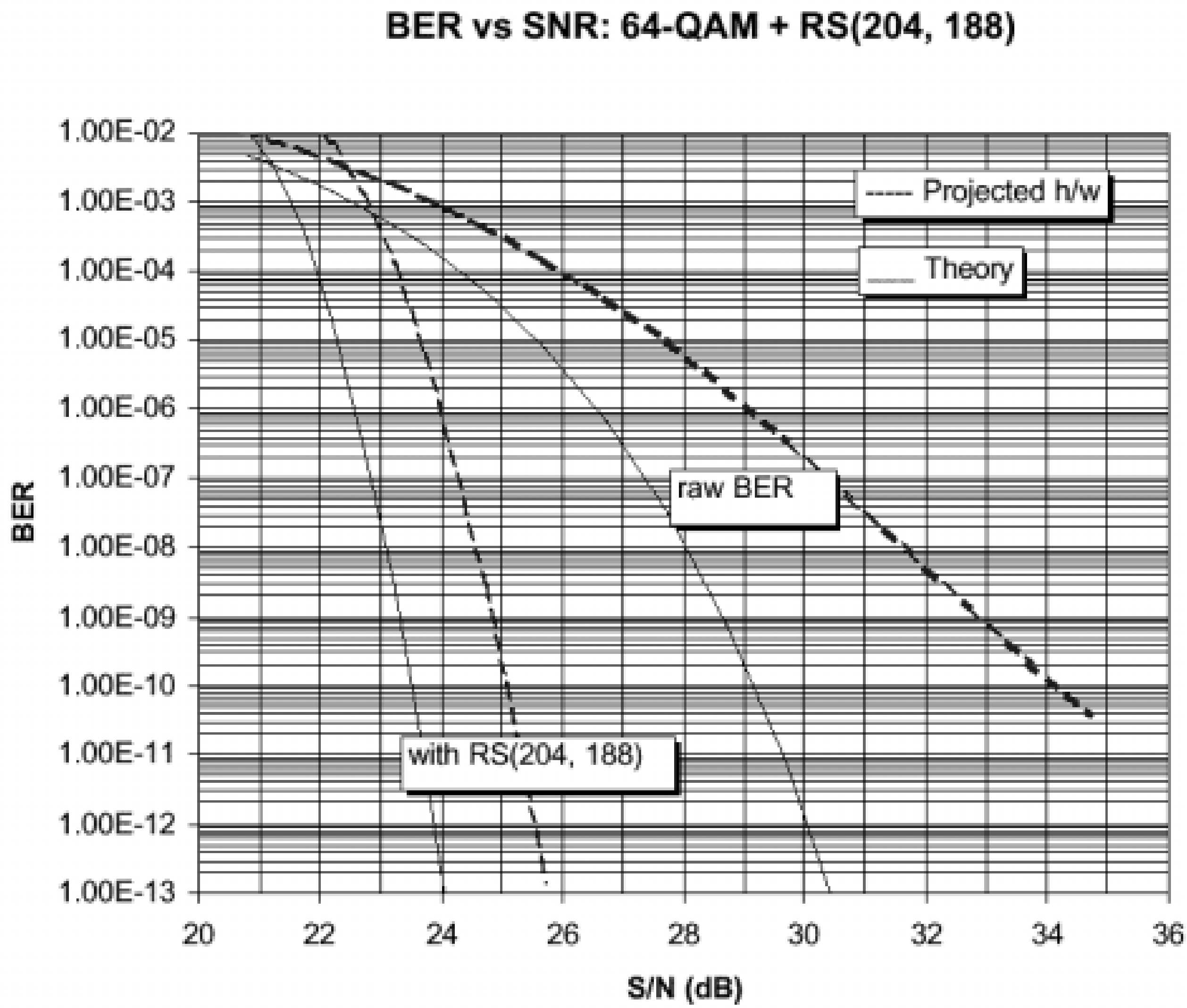


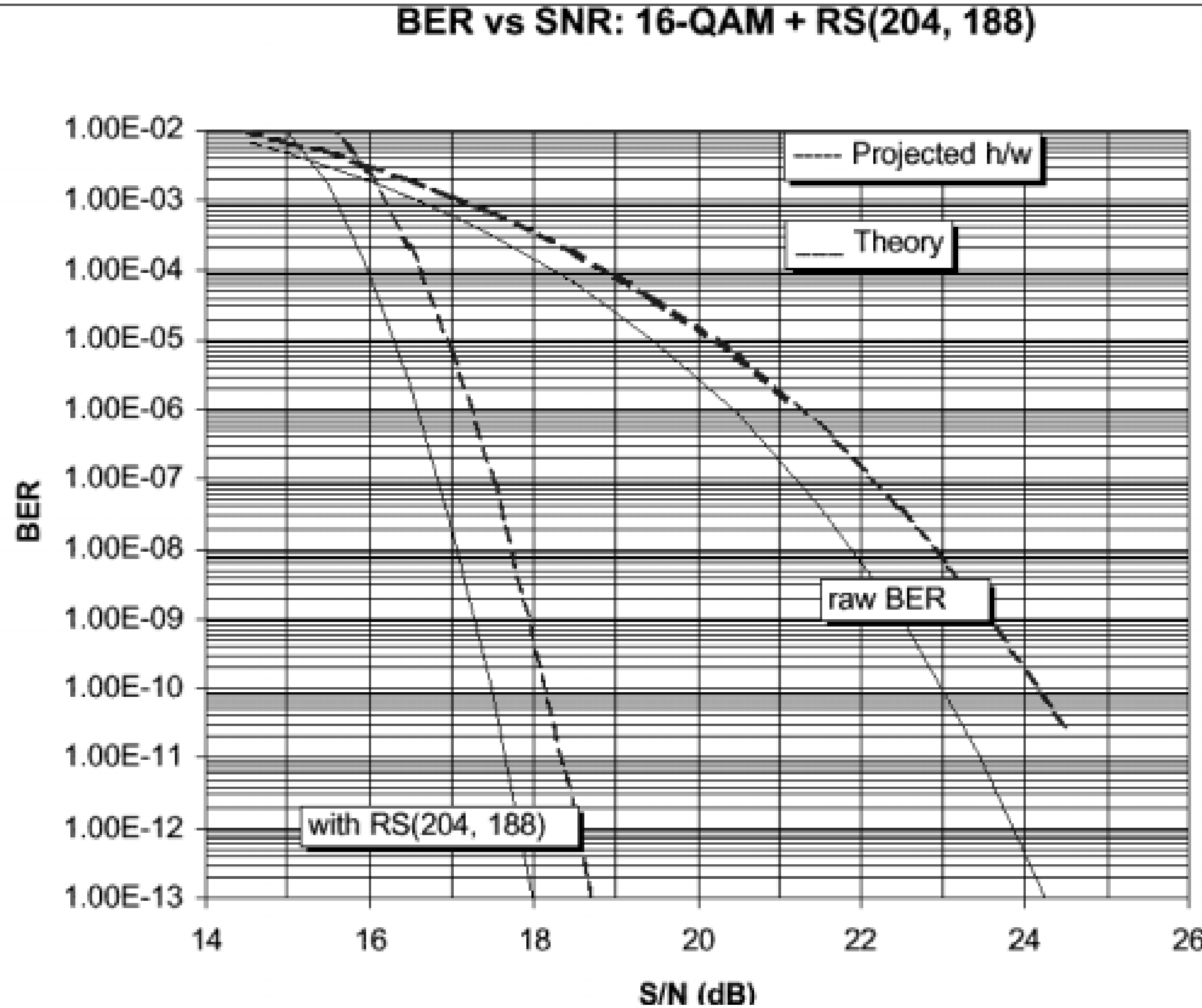
Performance with Short IP packages



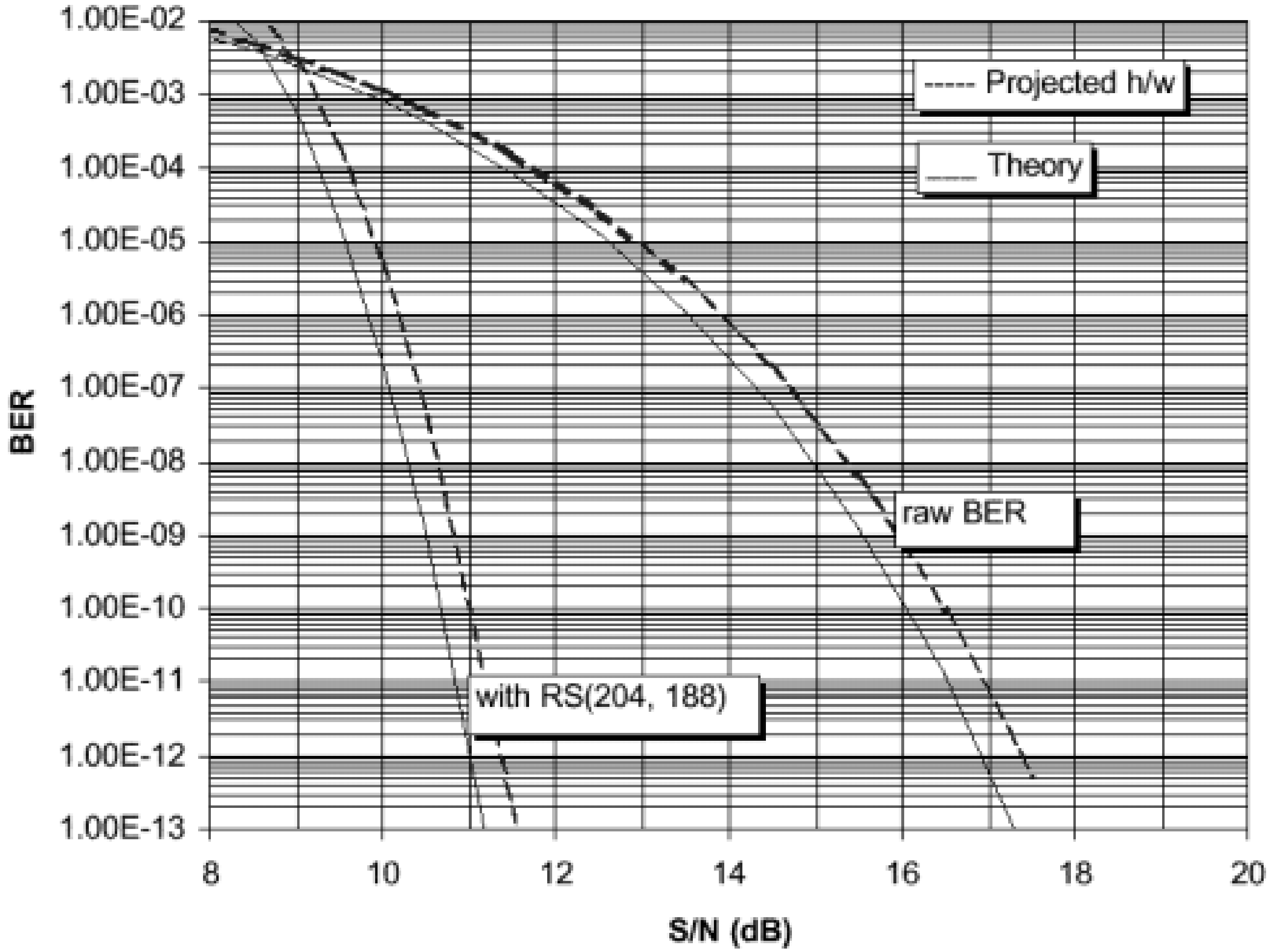

RS(9,5) vs. HPC(16,11)2 (R ~ 0.5) and P(8,7)2
BER
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
[Eb/No]
P(8,7)2
RowBer
RS(9,5)
HPC(16,11)2

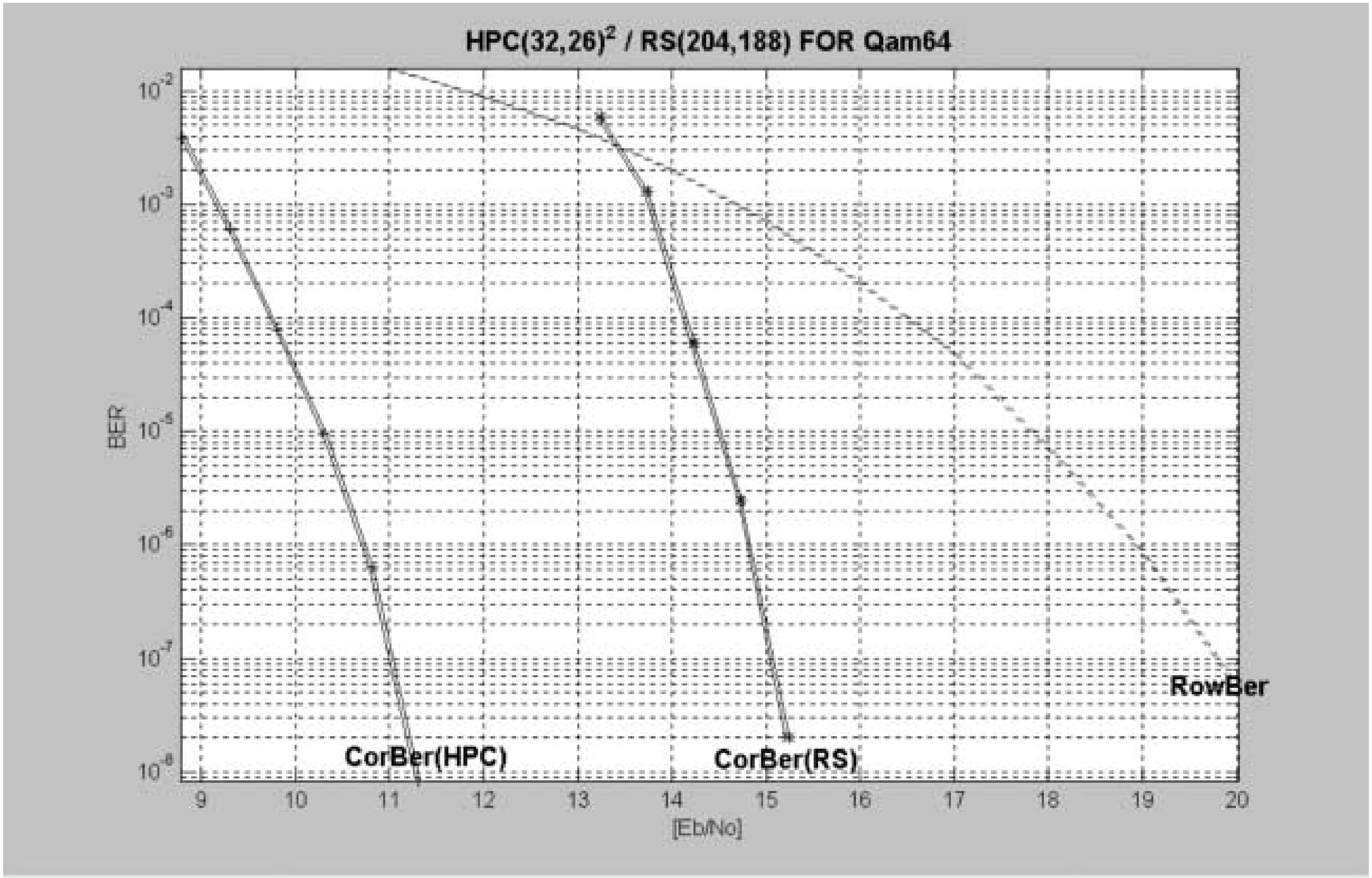

RS(20,14) vs.TCH(46,39) 2 & P(8,7) 2 (R=0.7)
BER
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
[Eb/No]
TCH(46,39) 2
RS(20,14)
P(8,7) 2
RowBer

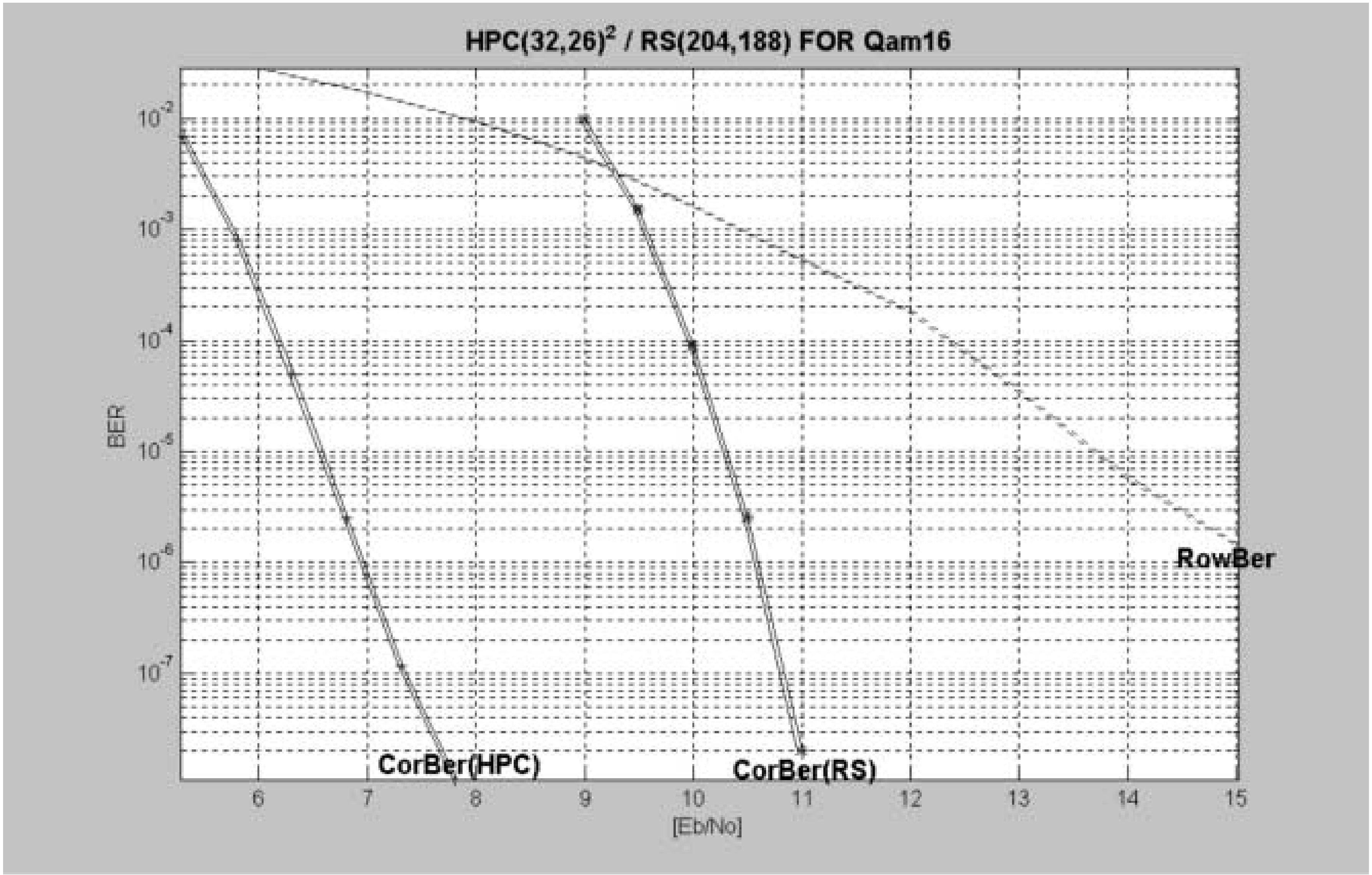

BER vs SNR: 64-QAM + RS(204, 188)
BER
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
20
22
24
26
28
30
32
34
36
S/N (dB)
----- Projected h/w
___ Theory
raw BER
with RS(204, 188)

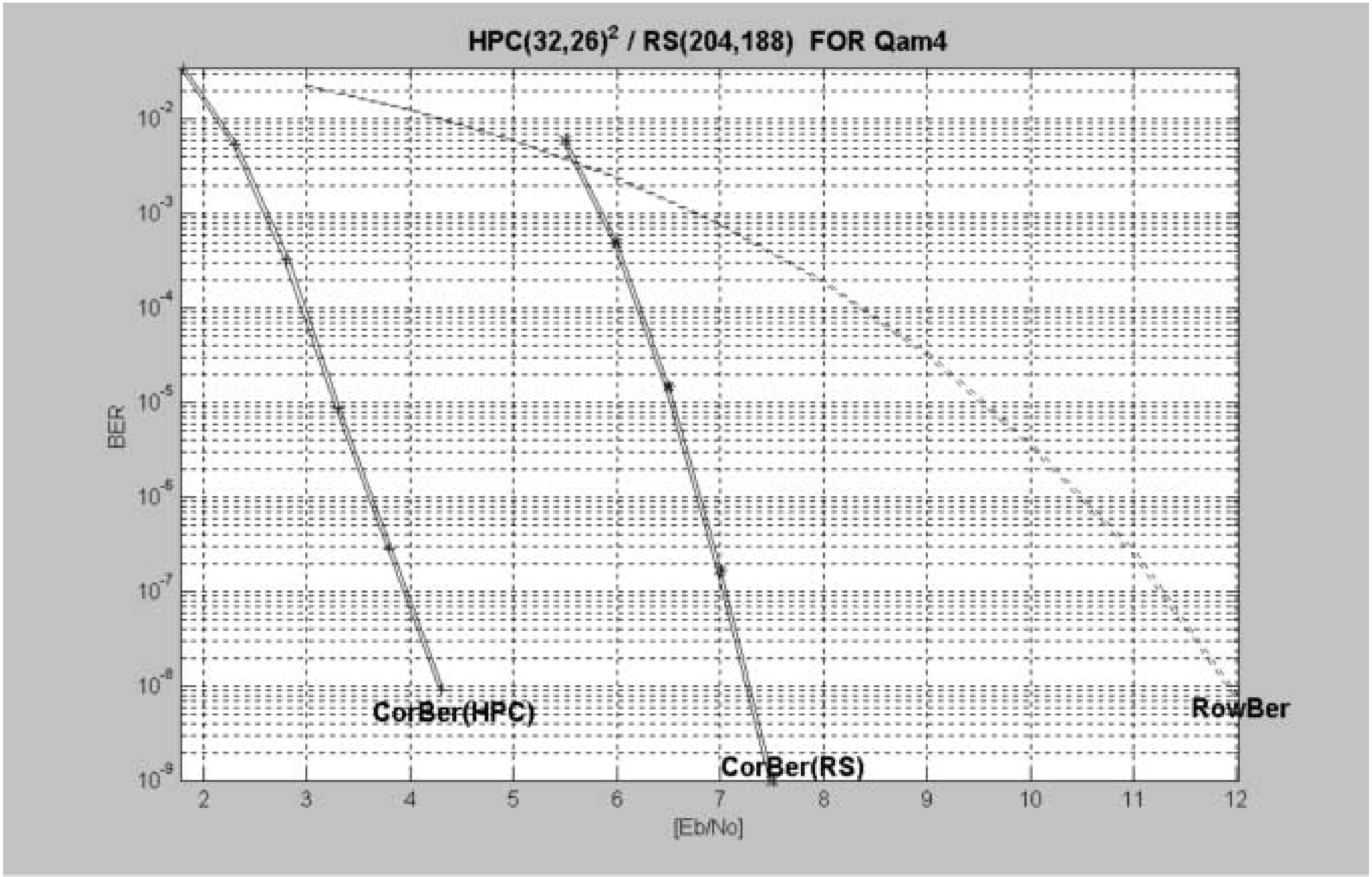

BER vs SNR: 16-QAM + RS(204, 188)
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
BER
14
16
18
20
22
24
26
S/N (dB)
----- Projected h/w
___ Theory
raw BER
with RS(204, 188)

BER vs SNR: 4-QAM + RS(204, 188)




HPC(32,26)^2 / RS(204,188) FOR Qam64
BER
[Eb/No]
CorBer(HPC)
CorBer(RS)
RowBer


HPC(32,26)^2 / RS(204,188) FOR Qam16
BER
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
6
7
8
9
10
11
12
13
14
15
[Eb/No]
RowBer
CorBer(HPC)
CorBer(RS)


HPC(32,26)^2 / RS(204,188) FOR Qam4
BER
[Eb/No]
CorBer(HPC)
CorBer(RS)
RowBer
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
2
3
4
5
6
7
8
9
10
11
12