Orthogonal Pilot Design for 16m Uplink PUSC

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Purpose:
To include in frame structure section of the physical layer chapter of System Description Document SDD.

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May 05, 2008

Problem Setup

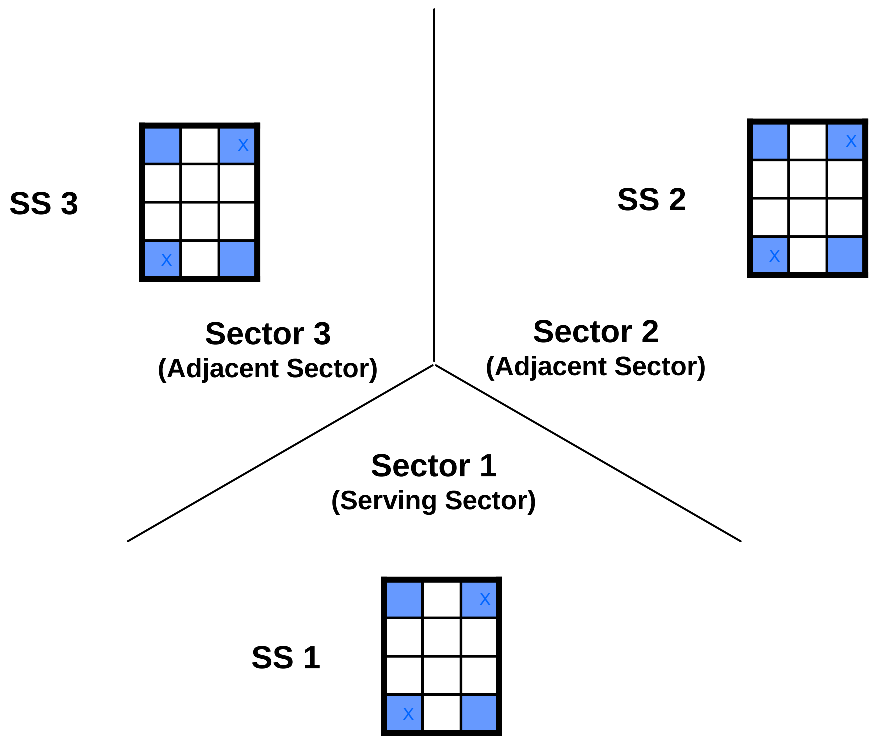
- The quality of the channel estimation in the uplink is critical to the link performance and overall system throughput.

- There are two problems that impact the quality of the channel estimates:
  - A weak signal received at serving sector.
  - Presence of interfering users.

- Uplink is interference limited.
  - Typically there are two or three dominant interferers.

- We shall focus on improvement in channel estimation in UL-PUSC.

System Model



- Current IEEE 802.16e/WiMAX standard use a pseudo random binary sequence to randomize the interference.

System Model

- We shall first consider the case when we have a single dominant interferer from the adjacent sector.
- Signal received at the serving sector on the pilot locations is given by:
  - $y_{11} = c^{(1)}_{11}\, h + c^{(2)}_{11}\, g + n_{11}$
  - $y_{12} = c^{(1)}_{12}\, h + c^{(2)}_{12}\, g + n_{12}$
  - $y_{21} = c^{(1)}_{21}\, h + c^{(2)}_{21}\, g + n_{21}$
  - $y_{22} = c^{(1)}_{22}\, h + c^{(2)}_{22}\, g + n_{22}$

  where
  - $c^{(k)}_{ij}$ is the PRBS code of sector k at pilot location (i,j)
  - h is the channel of the desired user
  - g is the channel of the interfering user
  - n is the noise.
- It is assumed that h and g remain constant both across the tones and the symbols of a tile.

Linear Channel Estimation

- Estimation of the channel of the desired user at the serving sector:
  - Multiply the received signal by the PRBS (de-PRBS) sequence of sector 1.
  - Average the resulting signal at the 4 pilot locations.

- Thus, with linear averaging, the channel estimate is given by

  - $h_{est} = (\sum_{ij} y_{ij} c^{(1)}_{ij})/4$
    $= \; h + [(\sum_{ij} c^{(1)}_{ij} c^{(2)}_{ij})/4]g + (\sum_{ij} n_{ij})/4.$

- The PRBS codes (taking values ±1) are generated independently for the two sectors, thus we have that the channel estimate is given by

$$h_{est} = \begin{cases} h + g + (\sum_{ij} n_{ij})/4 & \text{with probability } 1/16 \\ h + g/2 + (\sum_{ij} n_{ij})/4 & \text{with probability } 4/16 \\ h + (\sum_{ij} n_{ij})/4 & \text{with probability } 6/16 \\ h - g/2 + (\sum_{ij} n_{ij})/4 & \text{with probability } 4/16 \\ h - g + (\sum_{ij} n_{ij})/4 & \text{with probability } 1/16 \end{cases}$$

Key Idea

- We shall not rely on PRBS to provide us protection against interference.
- We shall use orthogonal codes over pilots to completely cancel out interference.
- Each Sector picks a 4-bit/symbol code word for its pilots from an orthogonal set
- Denote the set of orthogonal codes as the following 4x4 Matrix

$$\mathbf{X} = \left[\underline{\mathbf{x}}_1, \underline{\mathbf{x}}_2, \underline{\mathbf{x}}_3, \underline{\mathbf{x}}_4\right]$$

$$\underline{\mathbf{x}}_i = \left[x_{i1} \quad x_{i2} \quad x_{i3} \quad x_{i4}\right]$$

Channel Estimation

- The data sub-carriers have the same PRBS as in 16e (no changes as regards to generation of PRBS for data tones). They receive the same amount of “protection” from interference as in earlier cases.
- The received signal $\underline{\mathbf{y}}$ at the pilot locations in sector 1 is given by:

$$\underline{\mathbf{y}} = h\,\underline{\mathbf{x}}_{\mathbf{1}} + g_2\,\underline{\mathbf{x}}_{\mathbf{2}} + g_3\,\underline{\mathbf{x}}_{\mathbf{3}} + \mathbf{n}$$

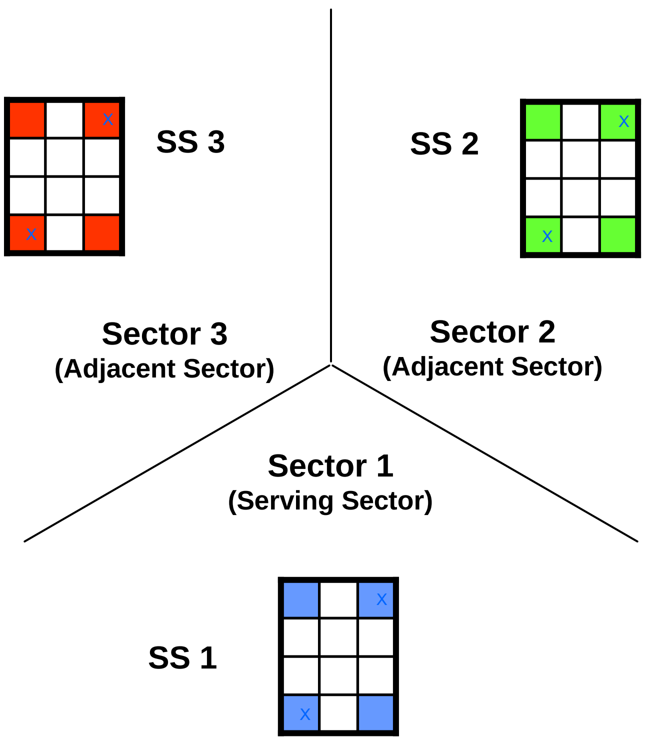
where h, g_2 and g_3 are the channel from SS1, SS2 and SS3 to sector 1 respectively and **n** is the noise at the pilot locations.

- A linear estimate of the channel from SS1 to sector 1 for the tile is given by:

$$\begin{aligned} h_{est} &= <\underline{\mathbf{y}}\,,\,\underline{\mathbf{x}}_{\mathbf{1}}>/4 \\ &= <h\,\underline{\mathbf{x}}_{\mathbf{1}} + g_2\,\underline{\mathbf{x}}_{\mathbf{2}} + g_3\,\underline{\mathbf{x}}_{\mathbf{3}} + \mathbf{n}\,,\,\underline{\mathbf{x}}_{\mathbf{1}}>/4 \\ &= h + <\mathbf{n}\,,\,\underline{\mathbf{x}}_{\mathbf{1}}>/4. \end{aligned}$$

We have thus managed to completely cancel out the interference from the adjacent sectors resulting in a “cleaner” channel estimate!

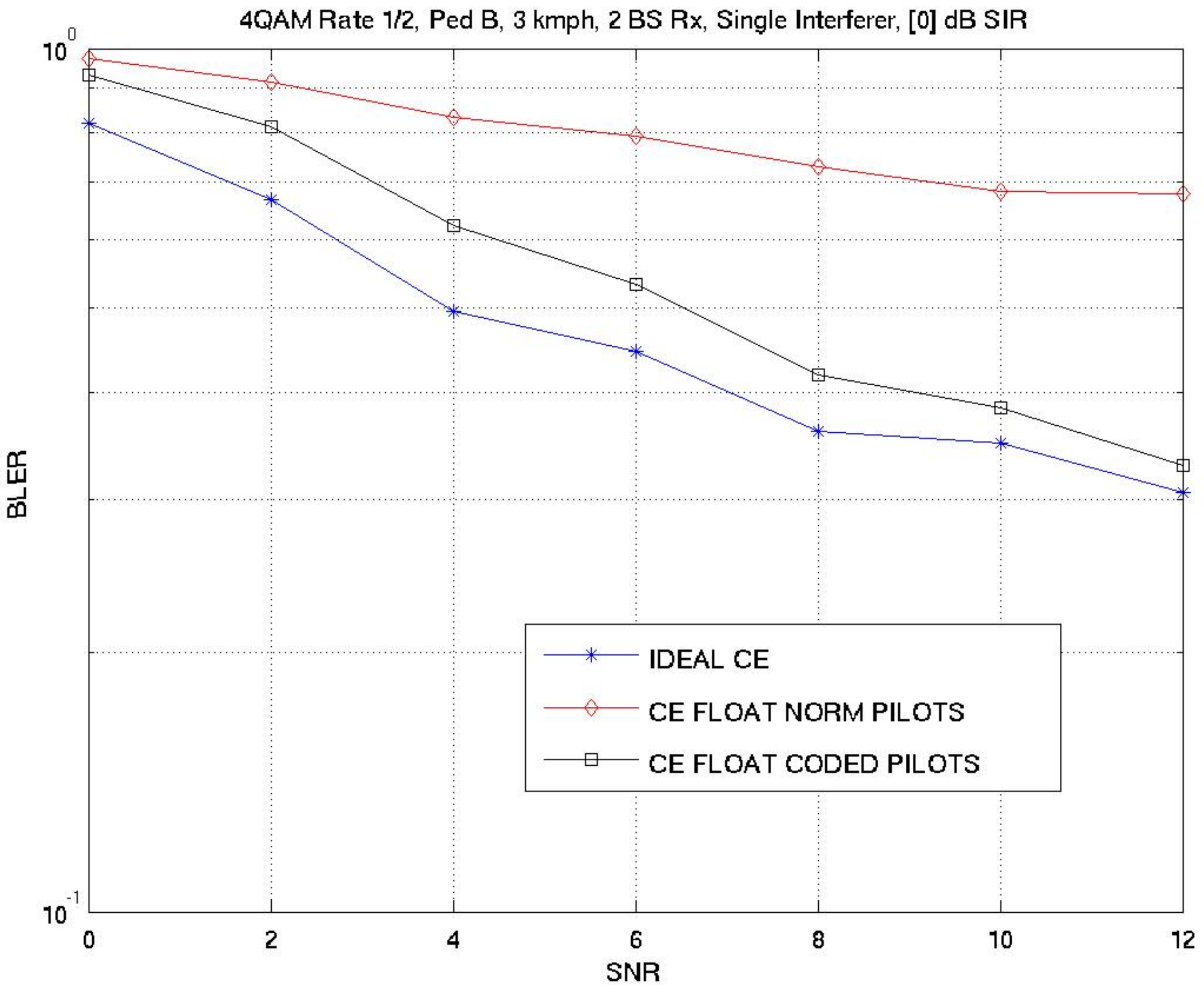
Code Assignment



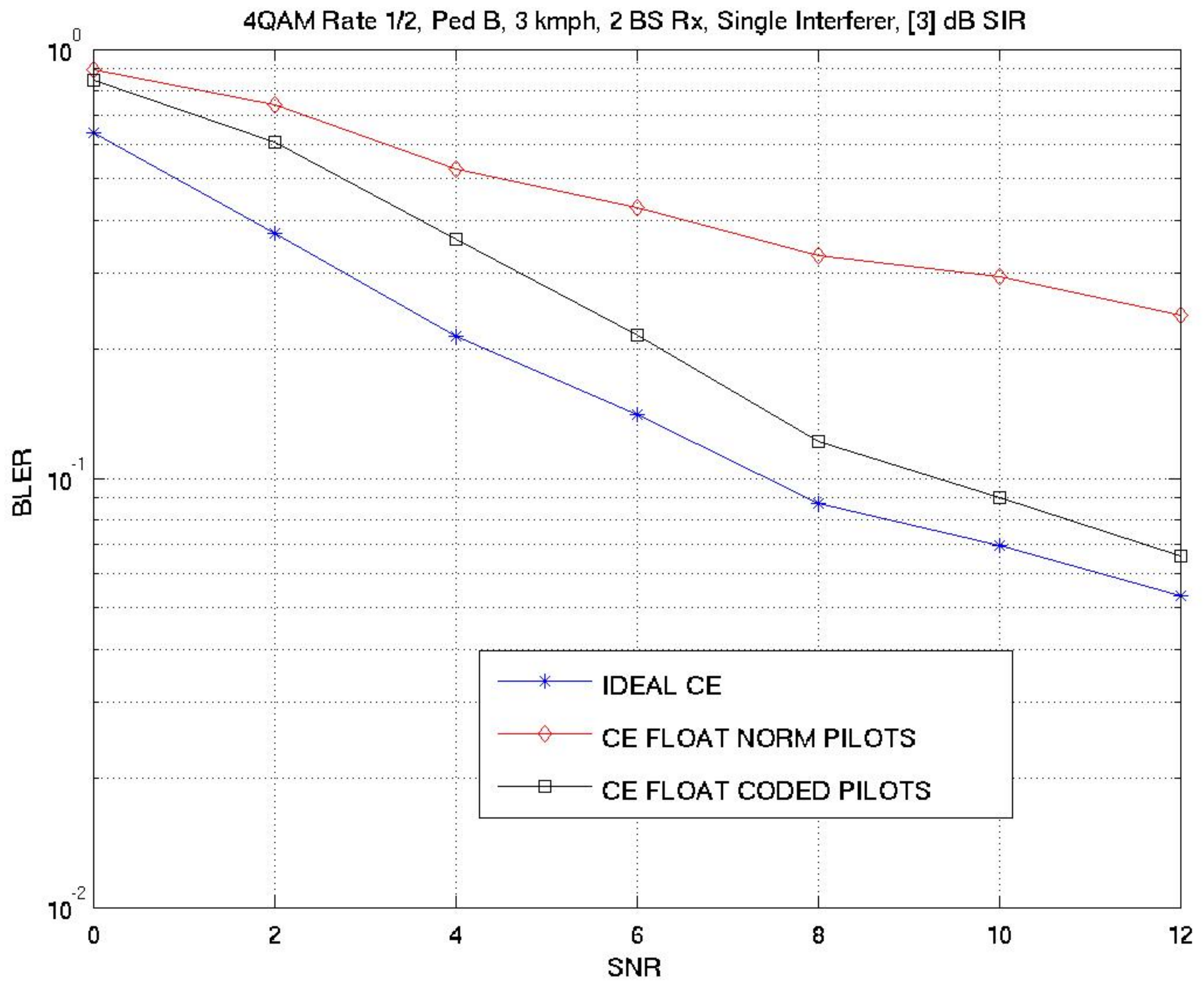
- Each sector uses a different code word from a set of orthogonal codes
- In the assignment above the 3 sectors of a cell use 3 different codes, namely code word 1 ($\underline{x}_1$), code word 2 ($\underline{x}_2$) and code word 3 ($\underline{x}_3$)

Link-Level Simulation Results
2 Rx BS

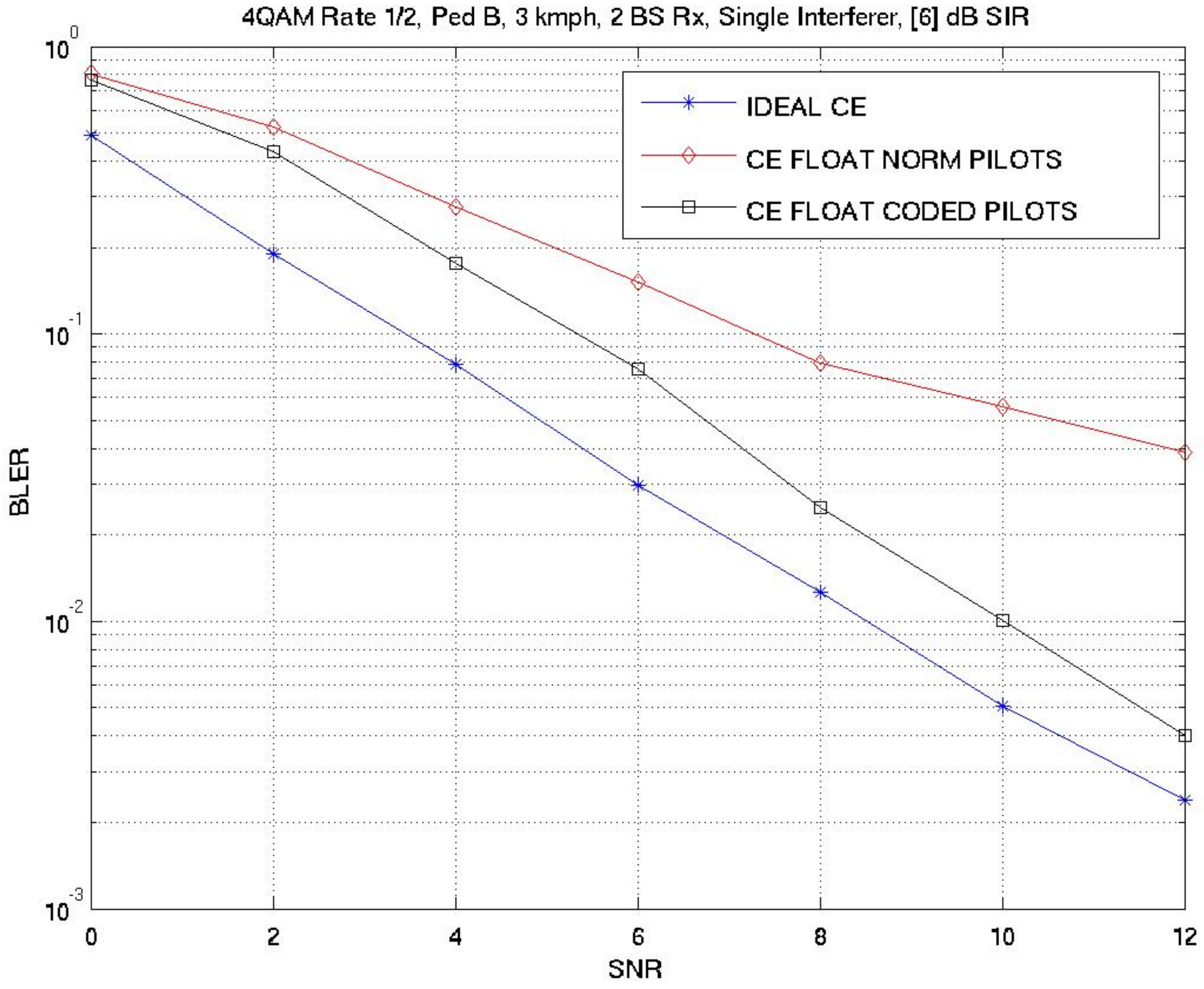
4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [0] dB



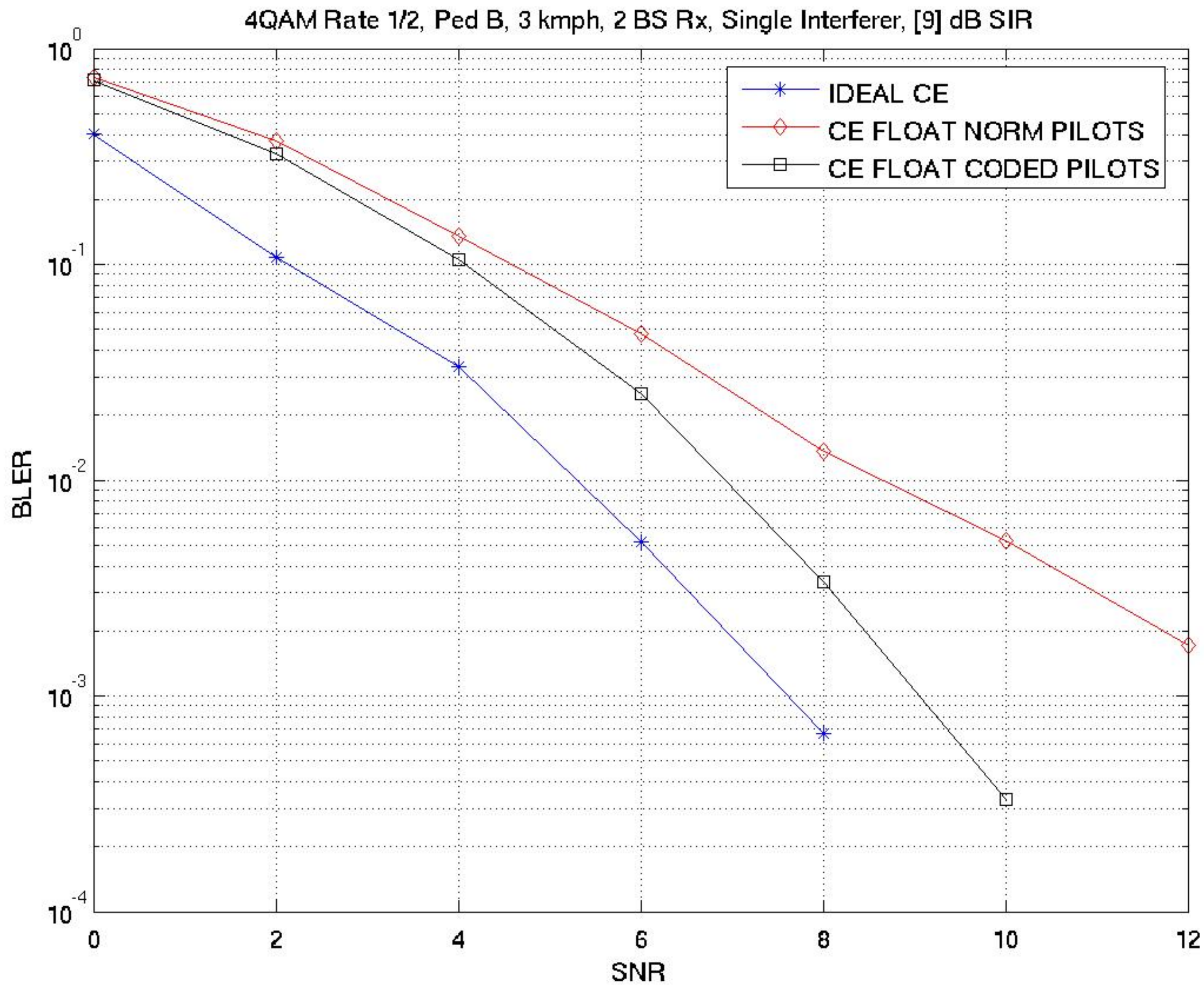
4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [3] dB



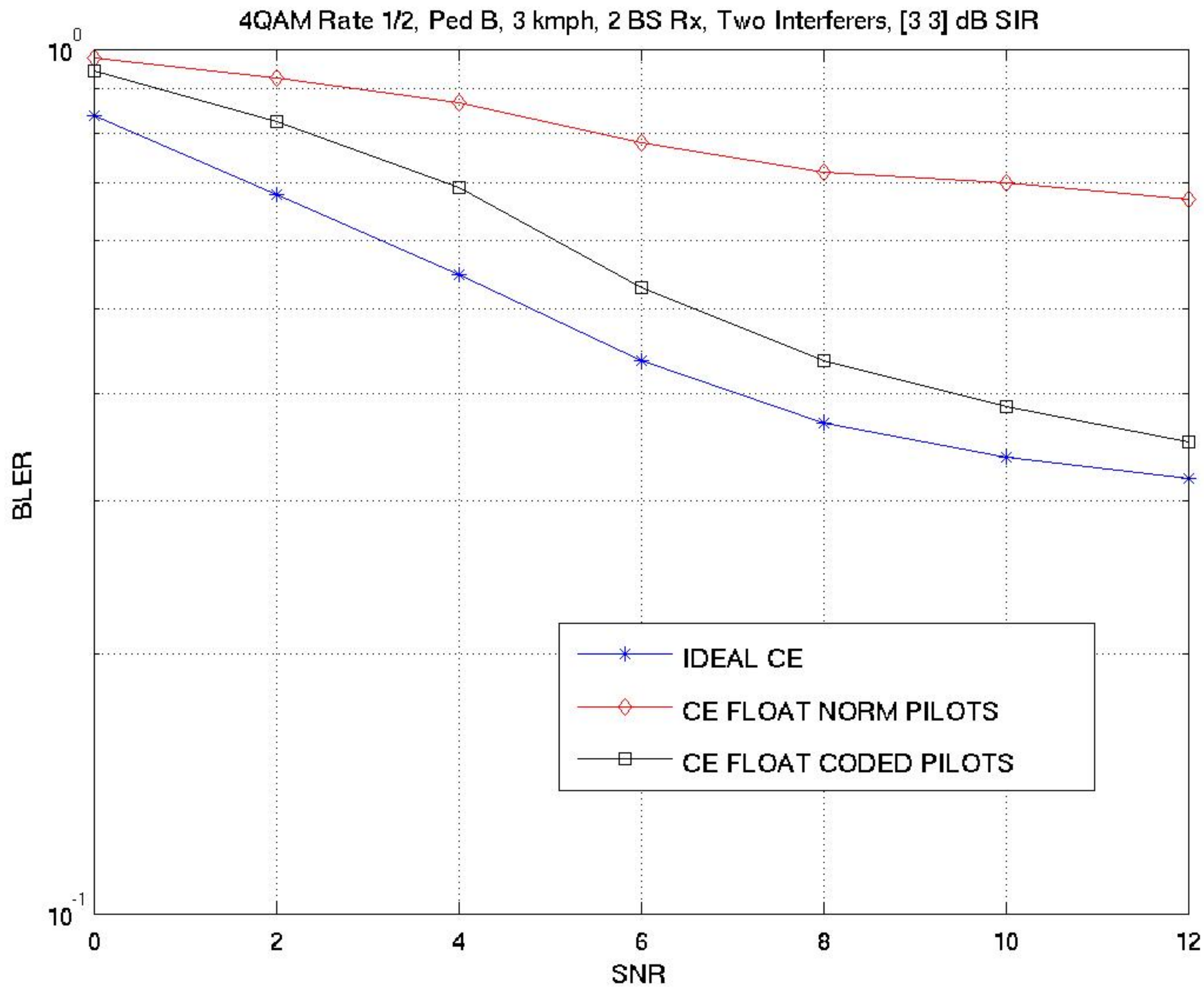
4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [6] dB



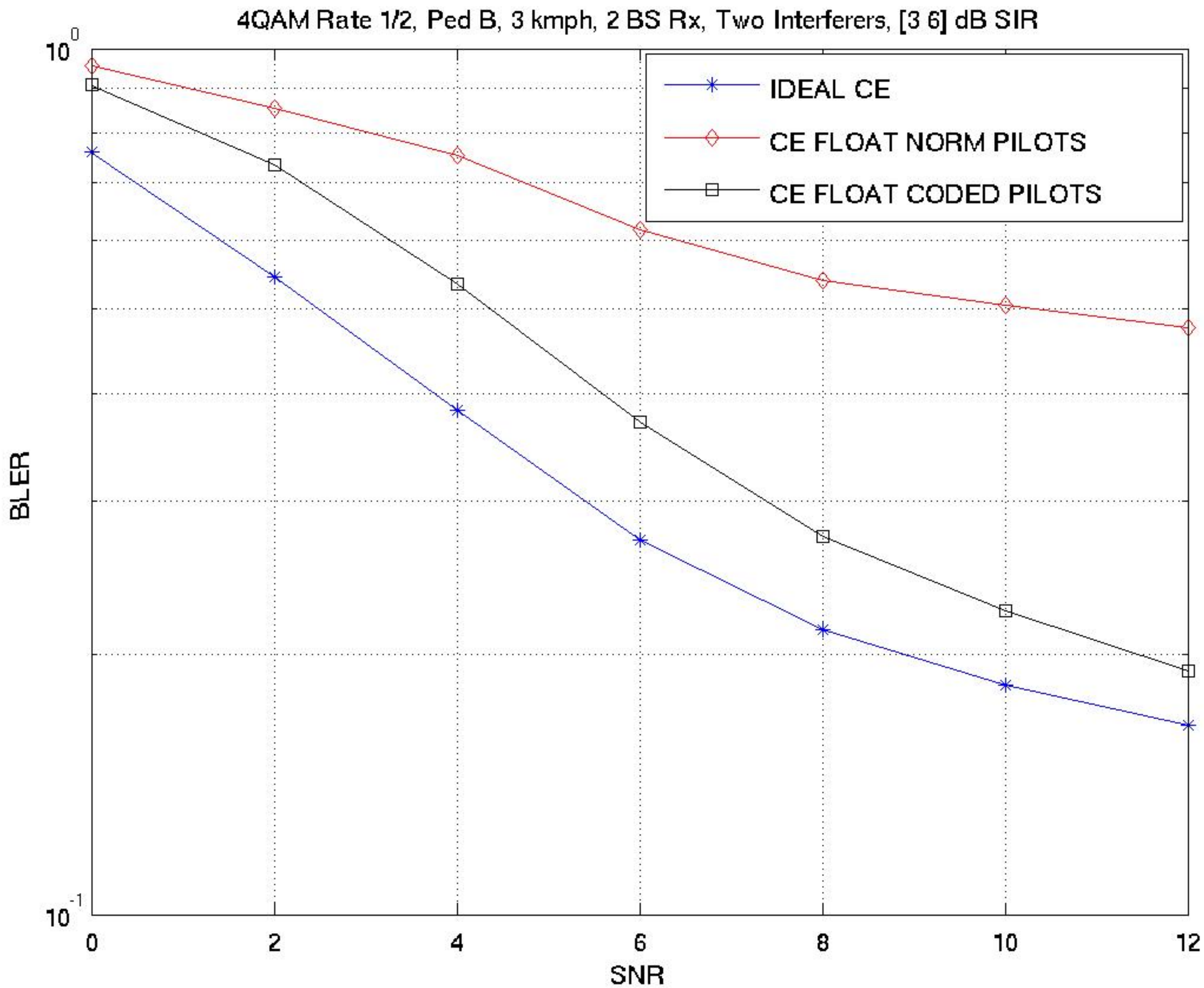
4QAM 1/2,Ped B,3 kmph,2 Rx BS,Single Interferer,SIR [9] dB



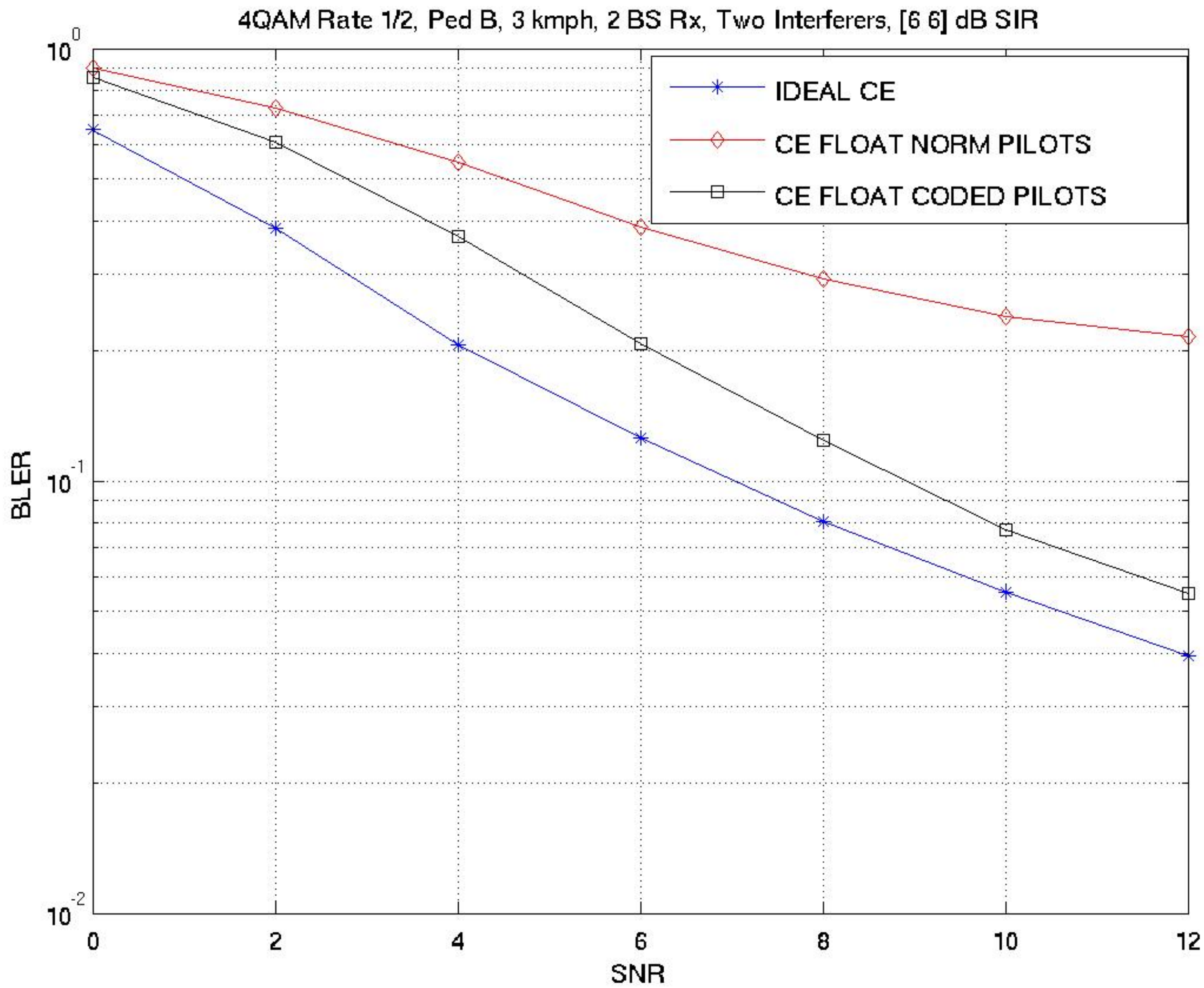
4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [3 3] dB



4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [3 6] dB

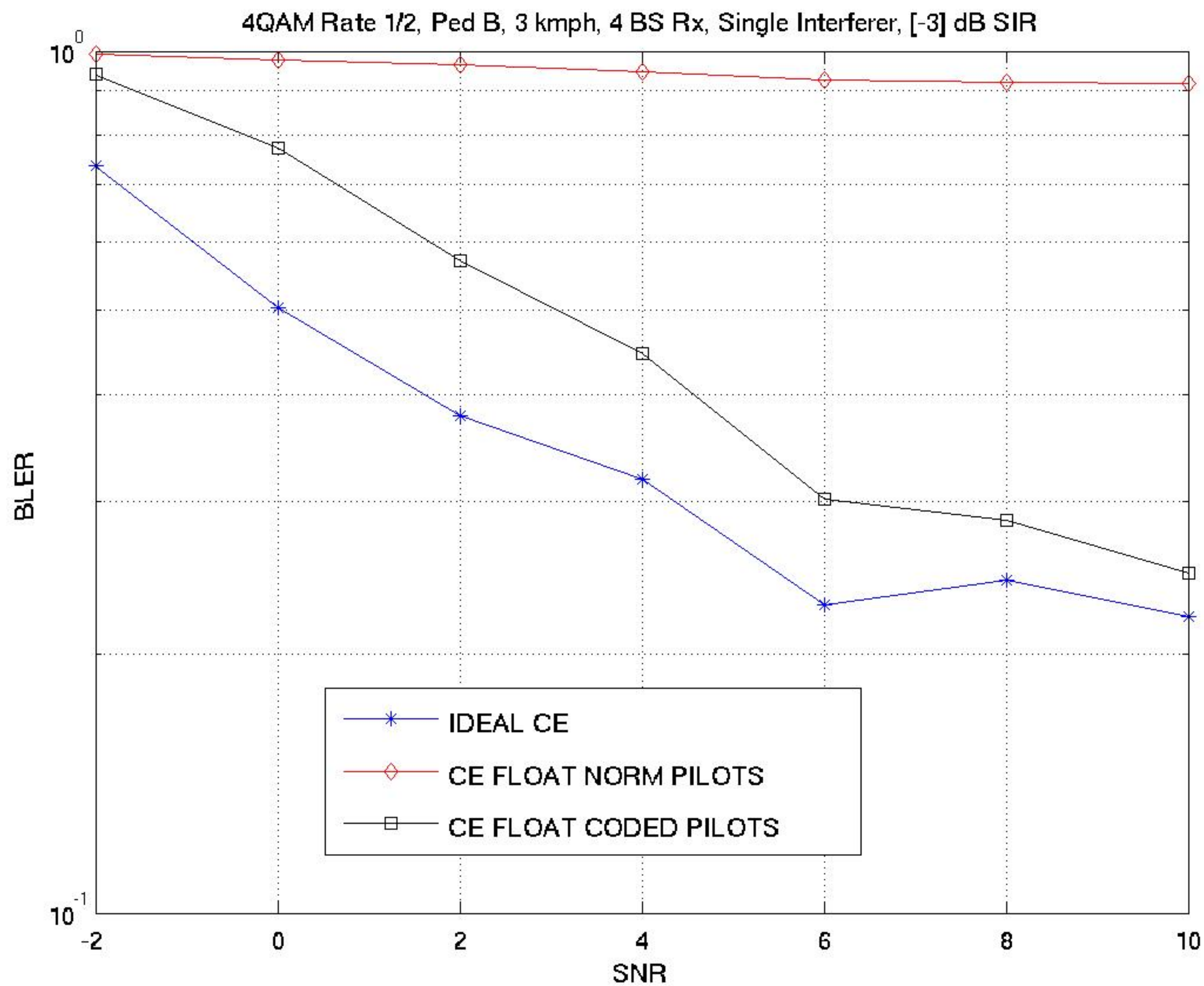


4QAM 1/2,Ped B,3 kmph,2 Rx BS,Two Interferers,SIR [6 6] dB

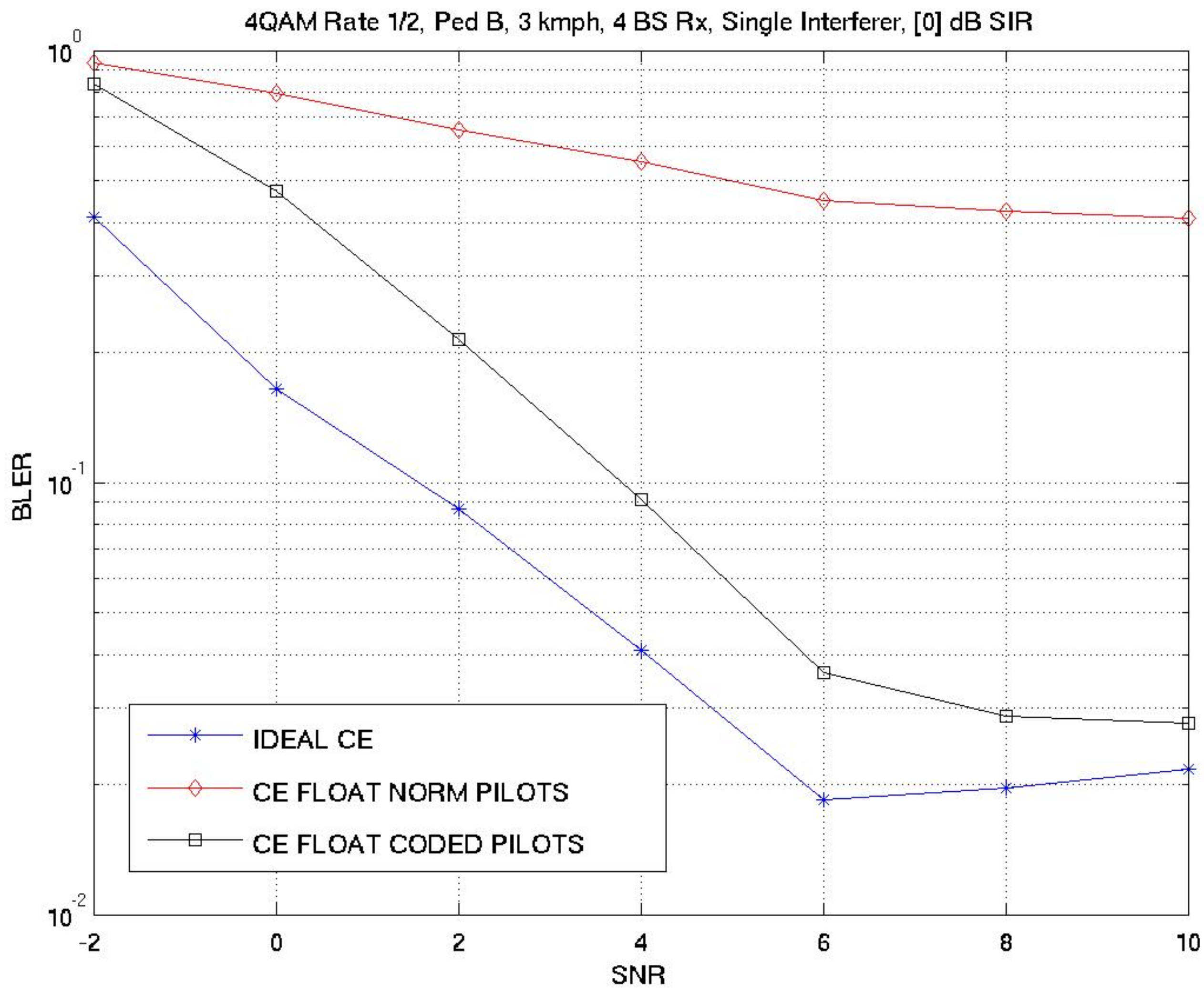


Link-Level Simulation Results
4 Rx BS

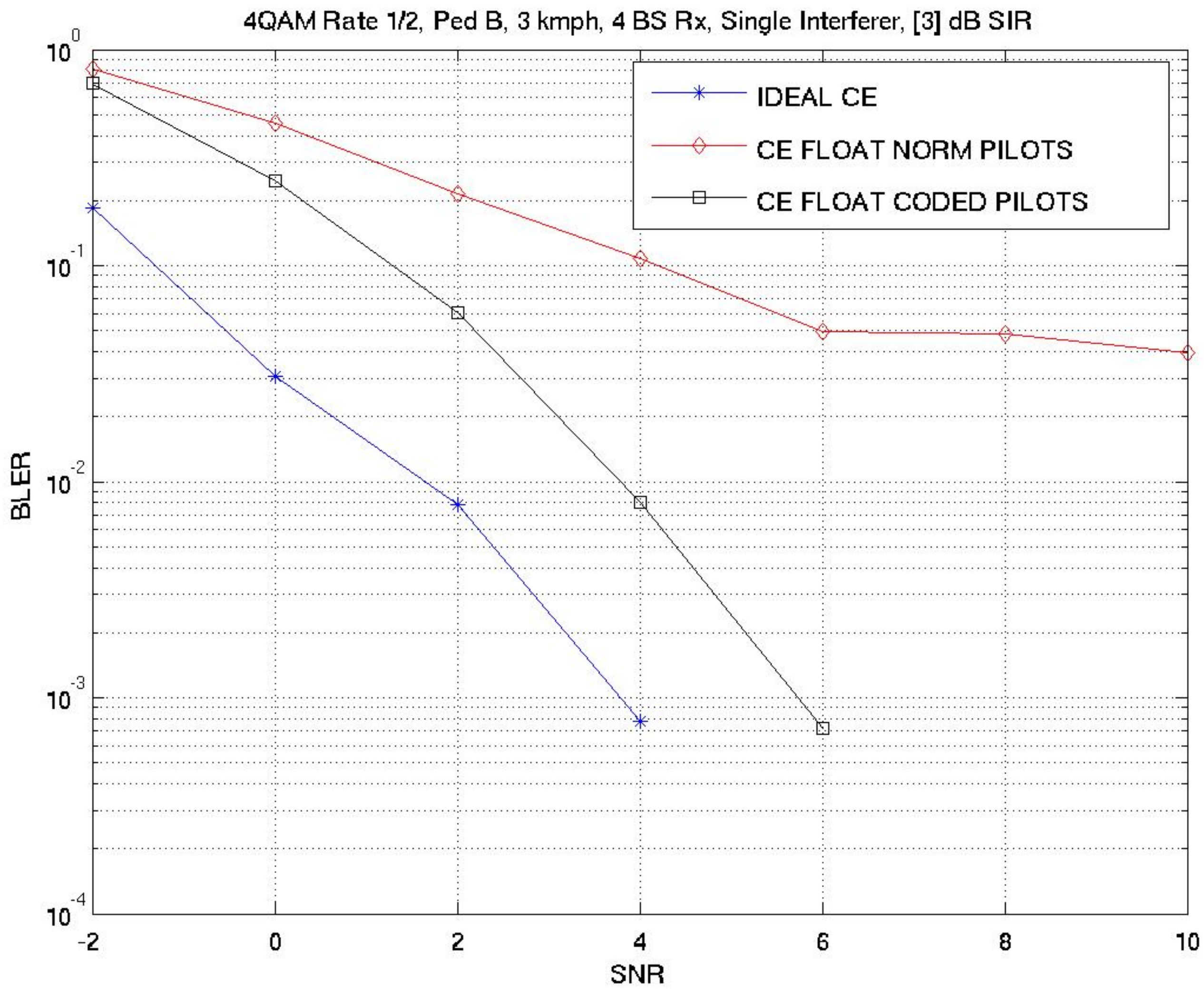
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [-3] dB



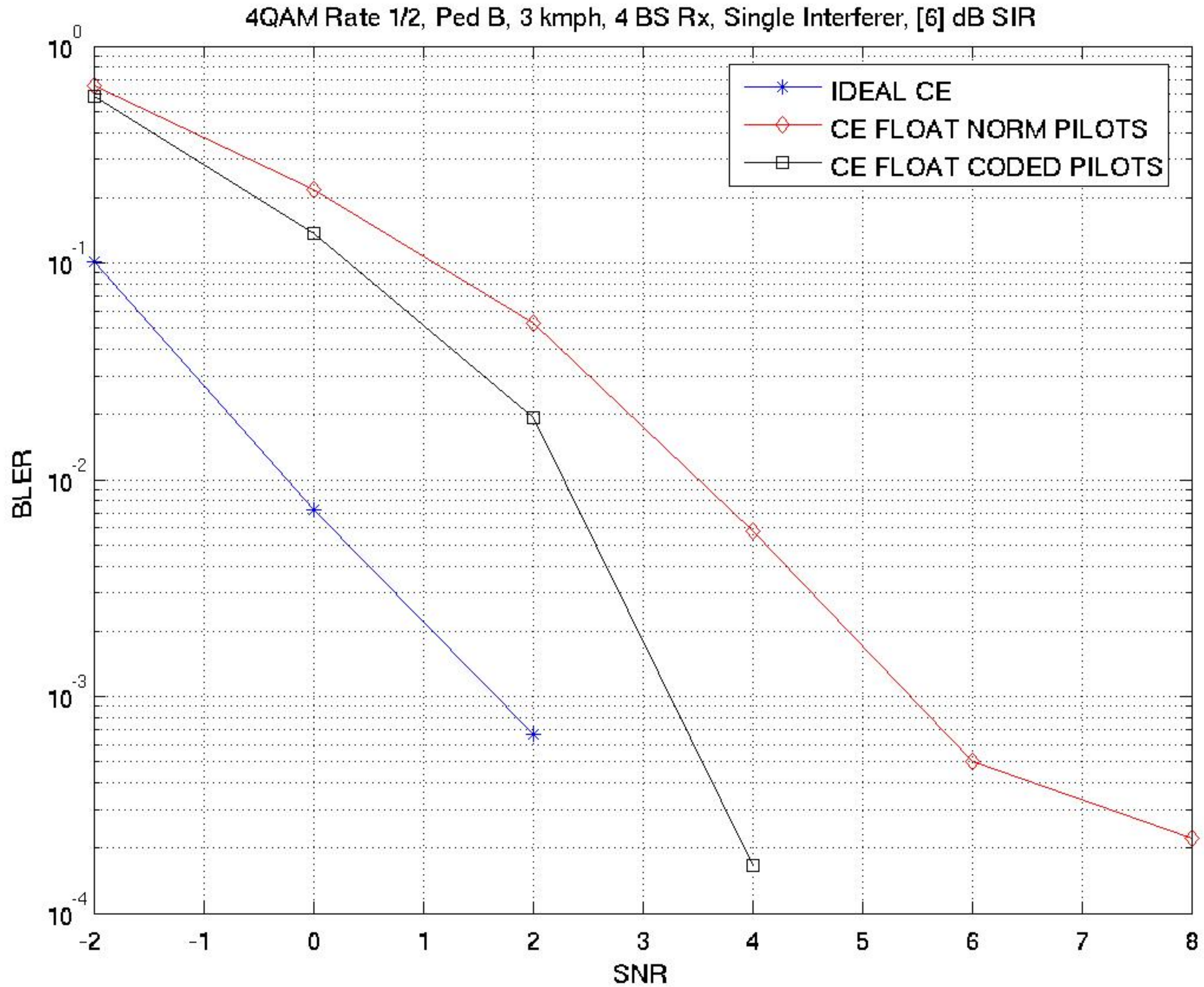
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [0] dB



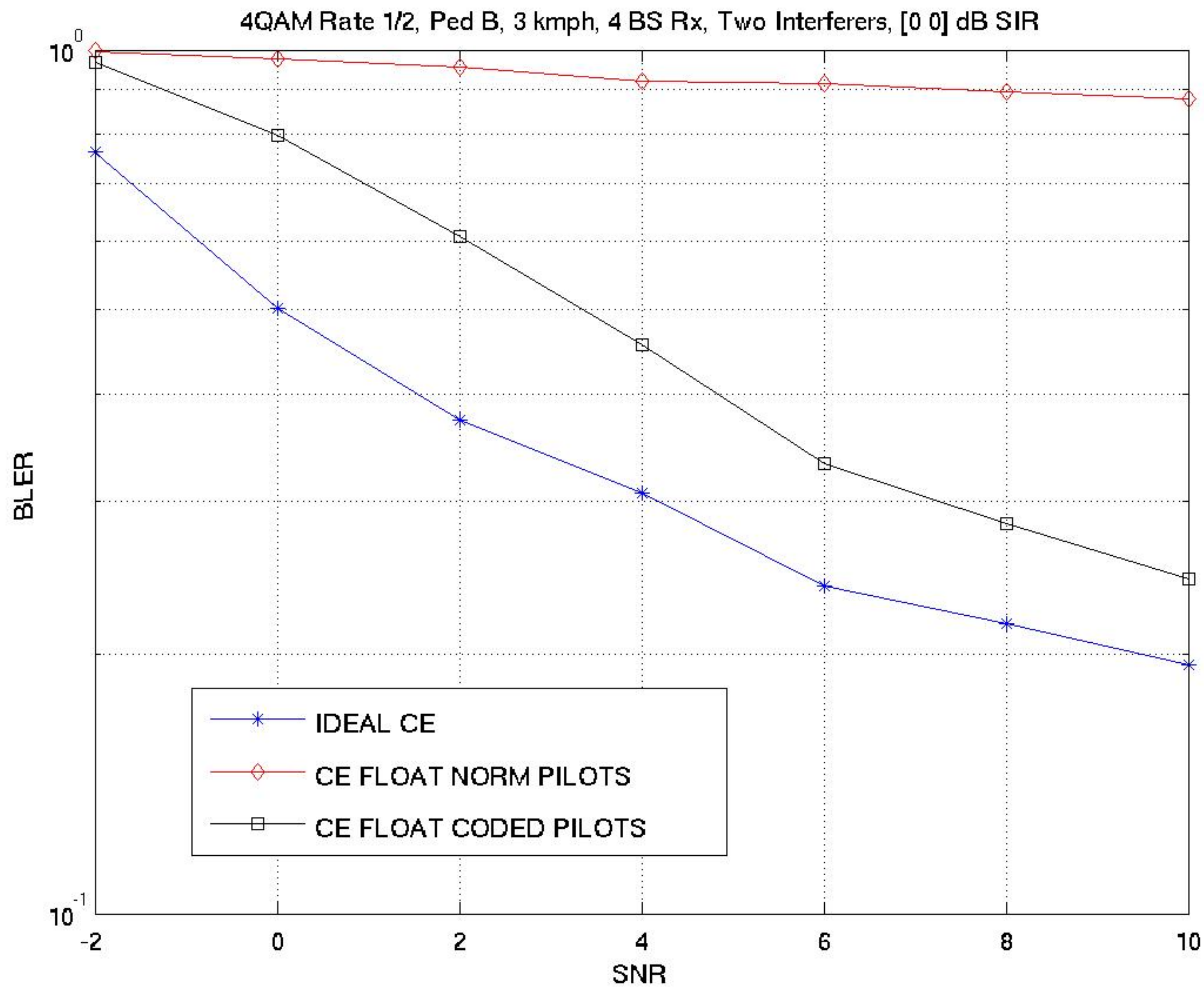
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [3] dB



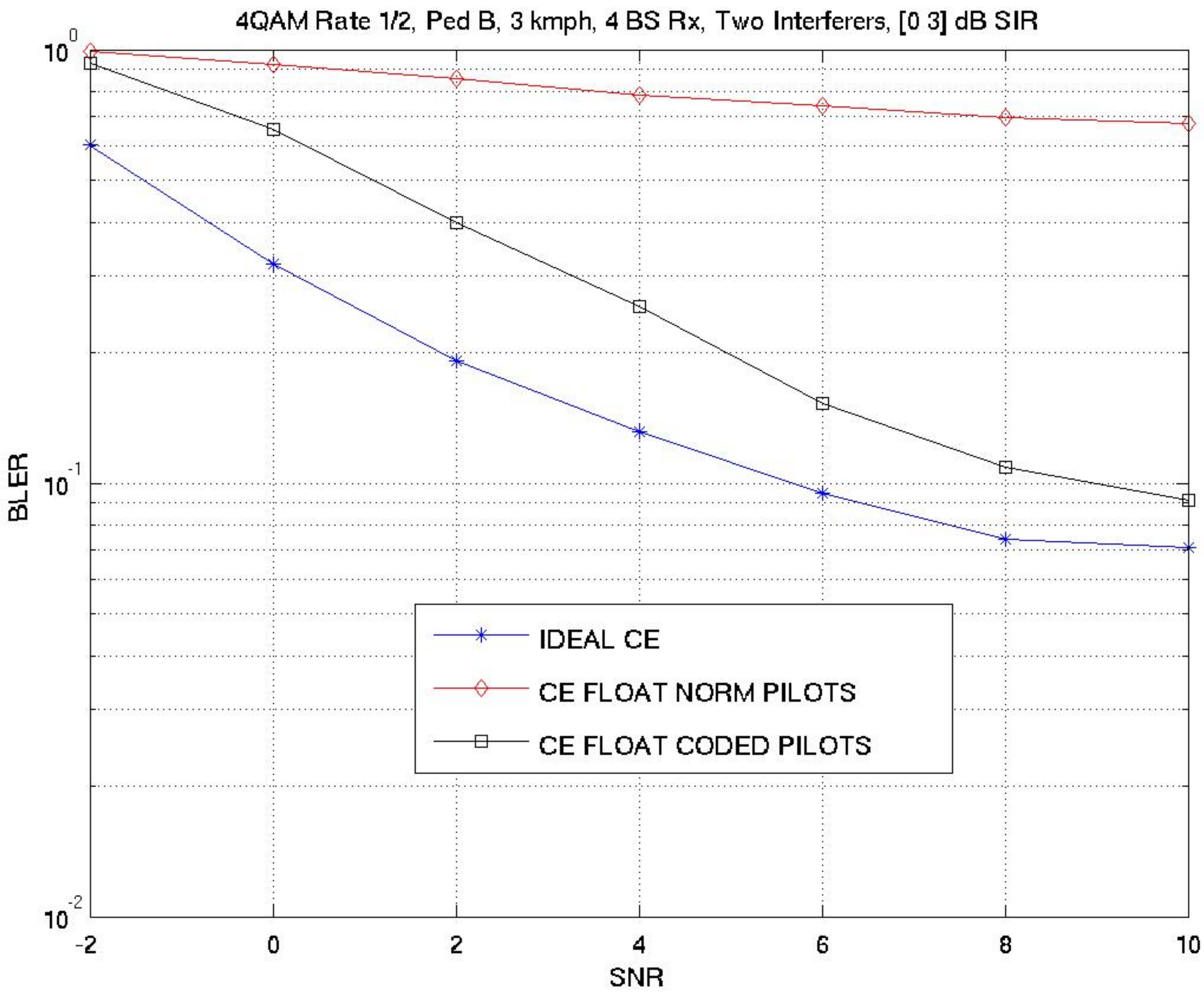
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Single Interferer,SIR [6] dB



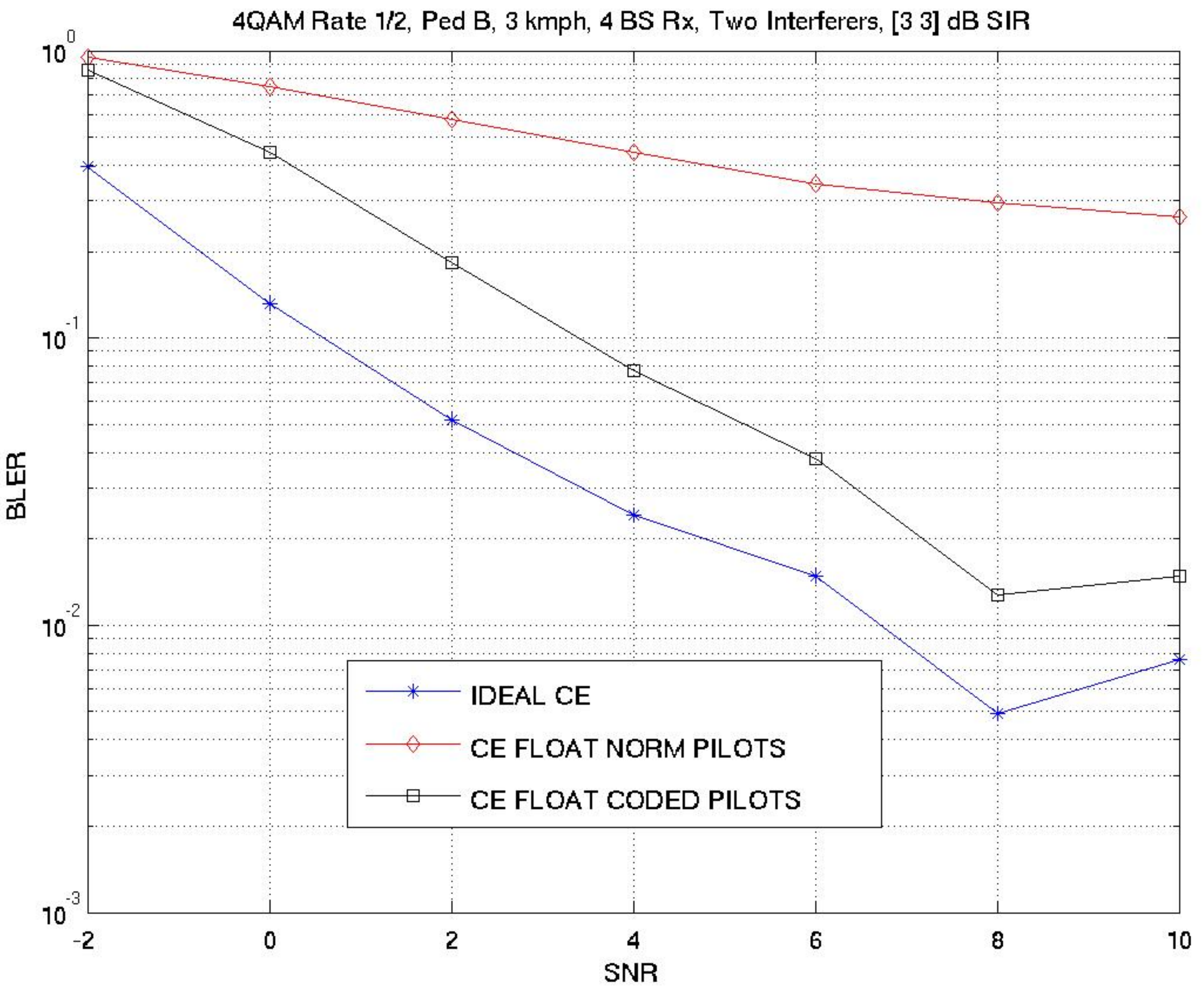
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [0 0] dB



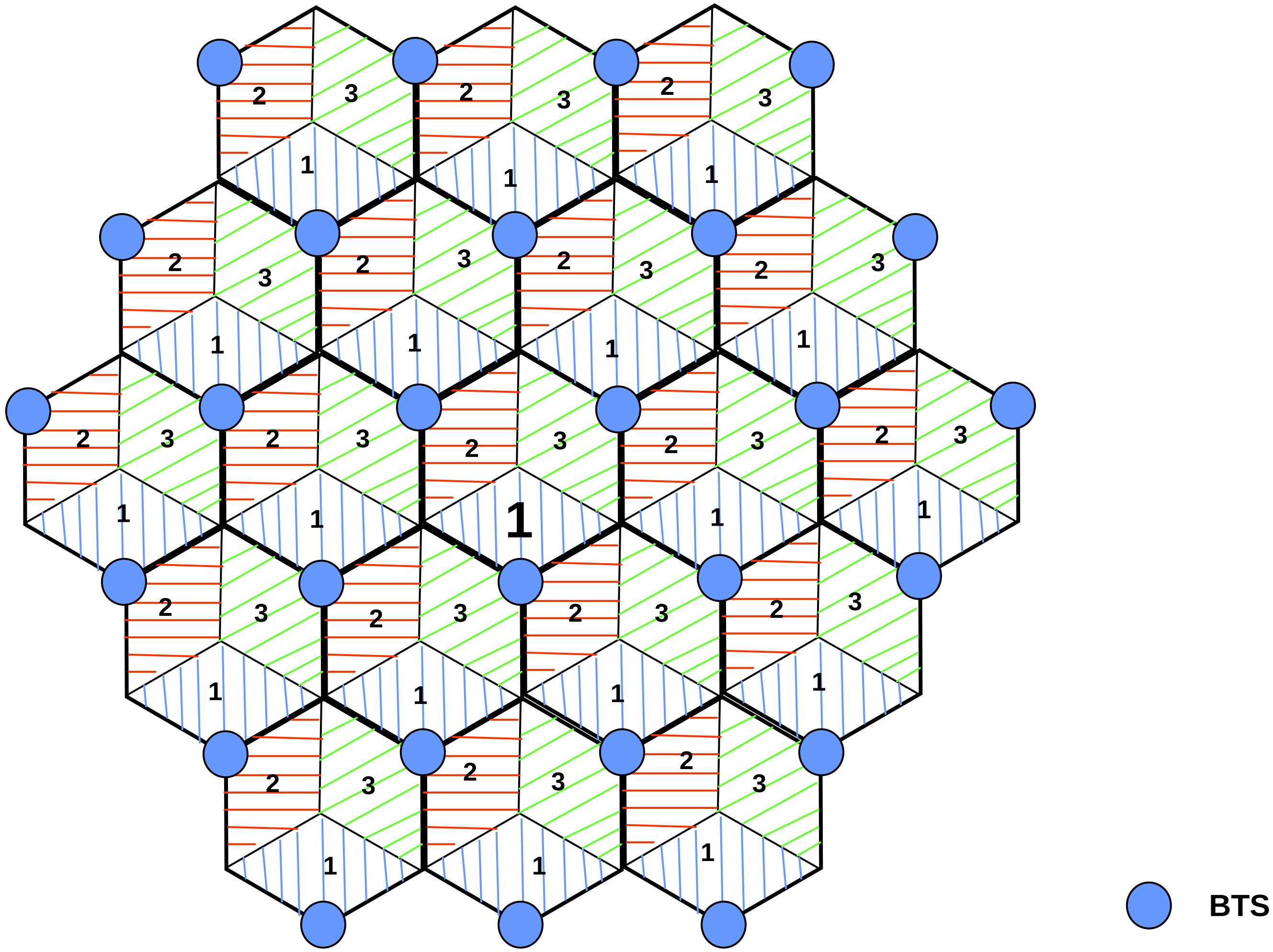
4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [0 3] dB



4QAM 1/2,Ped B,3 kmph,4 Rx BS,Two Interferers,SIR [3 3] dB



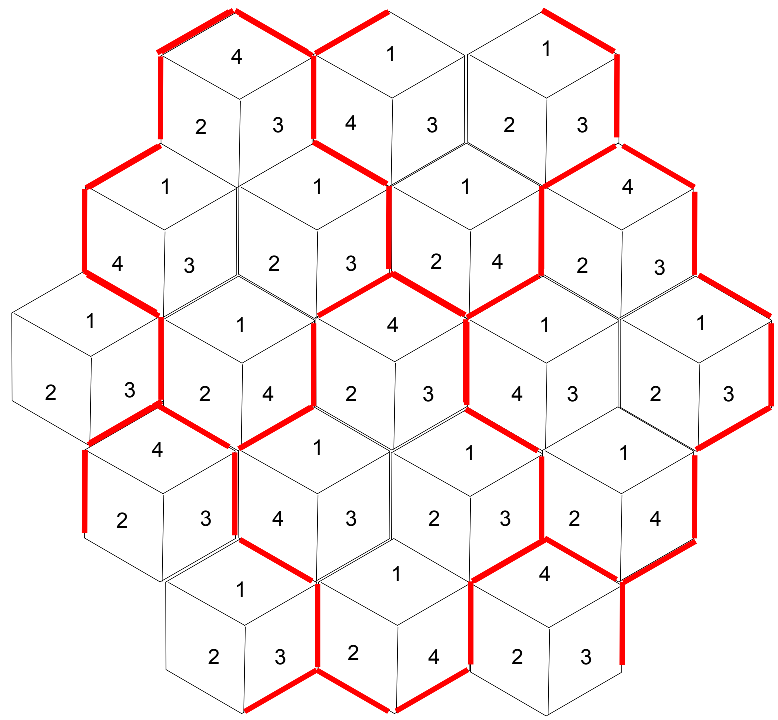
3 Code Arrangement



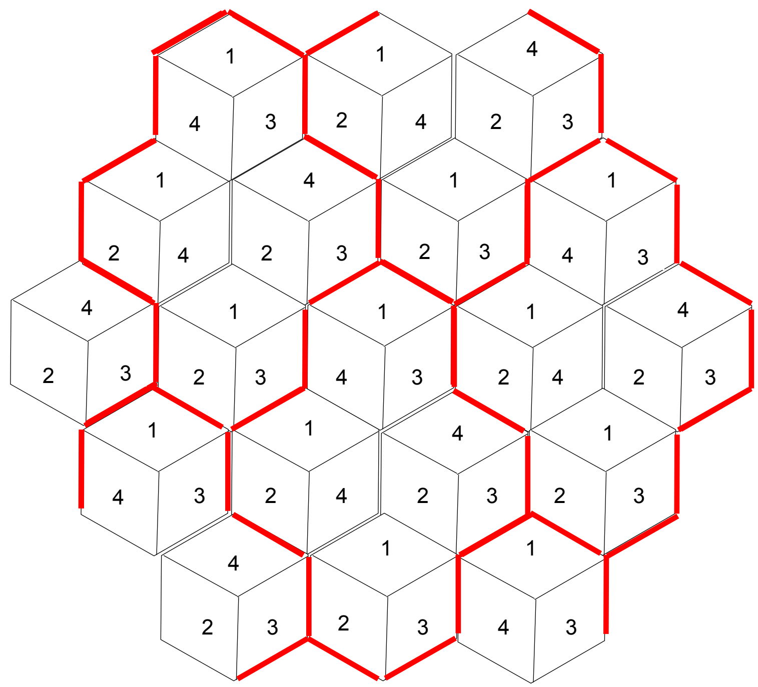
4 Code Arrangements

- Consider arrangements where all 4 codes of the mutually orthogonal set are used in the network
- There are cells with 3 sectors, thus the basic unit for planning is 4 cells which leads to 12 sectors in total that will share the 4 orthogonal codes.
- Two example uniform 4 code system arrangements shown below.
- Chosen based on the high pilot C/I ratio as well as less variation among pilot C/I ratios of 1, 2, 3 and 4 code sectors.
- The basic unit of repetition is shown in red below.

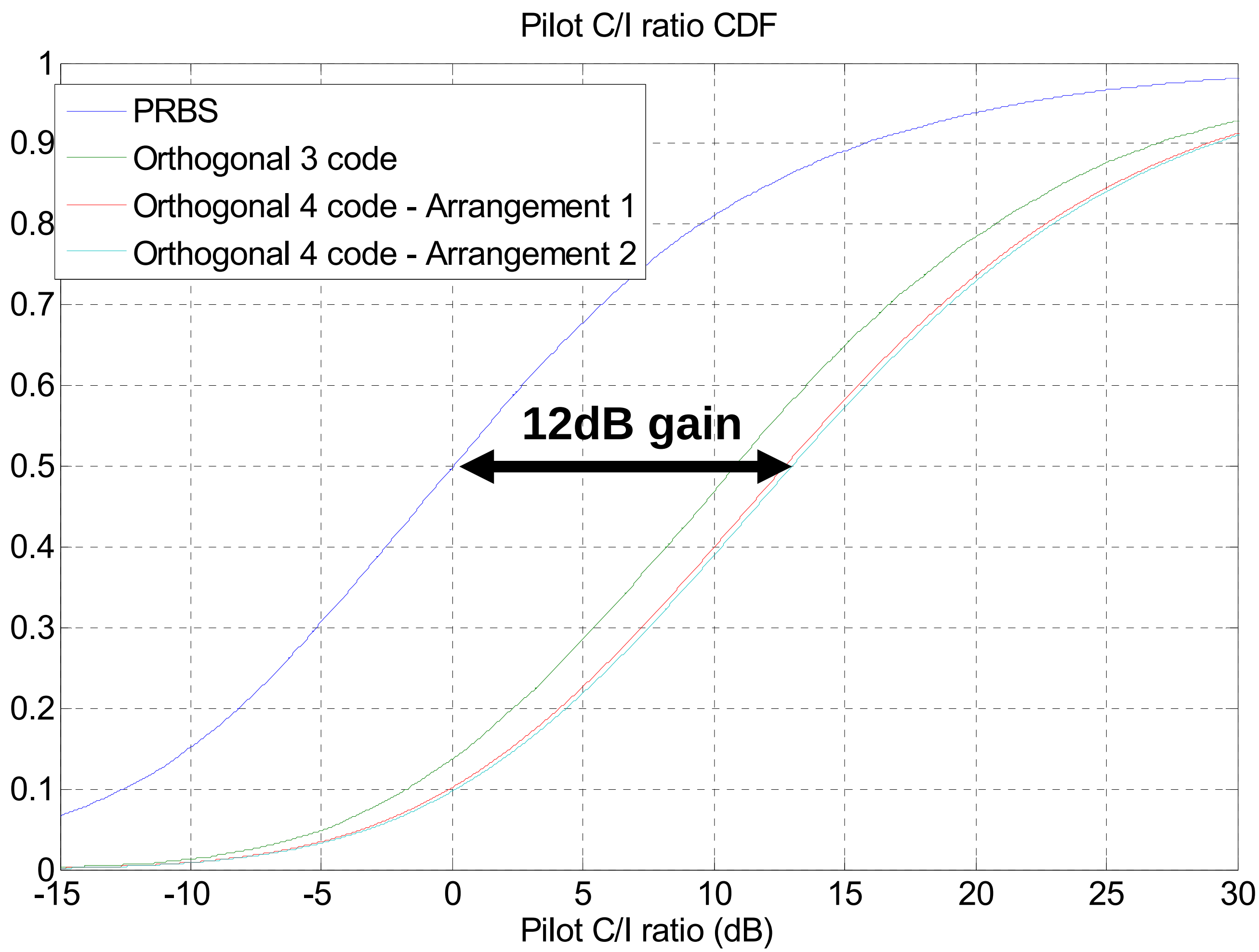
4 Code Arrangement 1



4 Code Arrangement 2

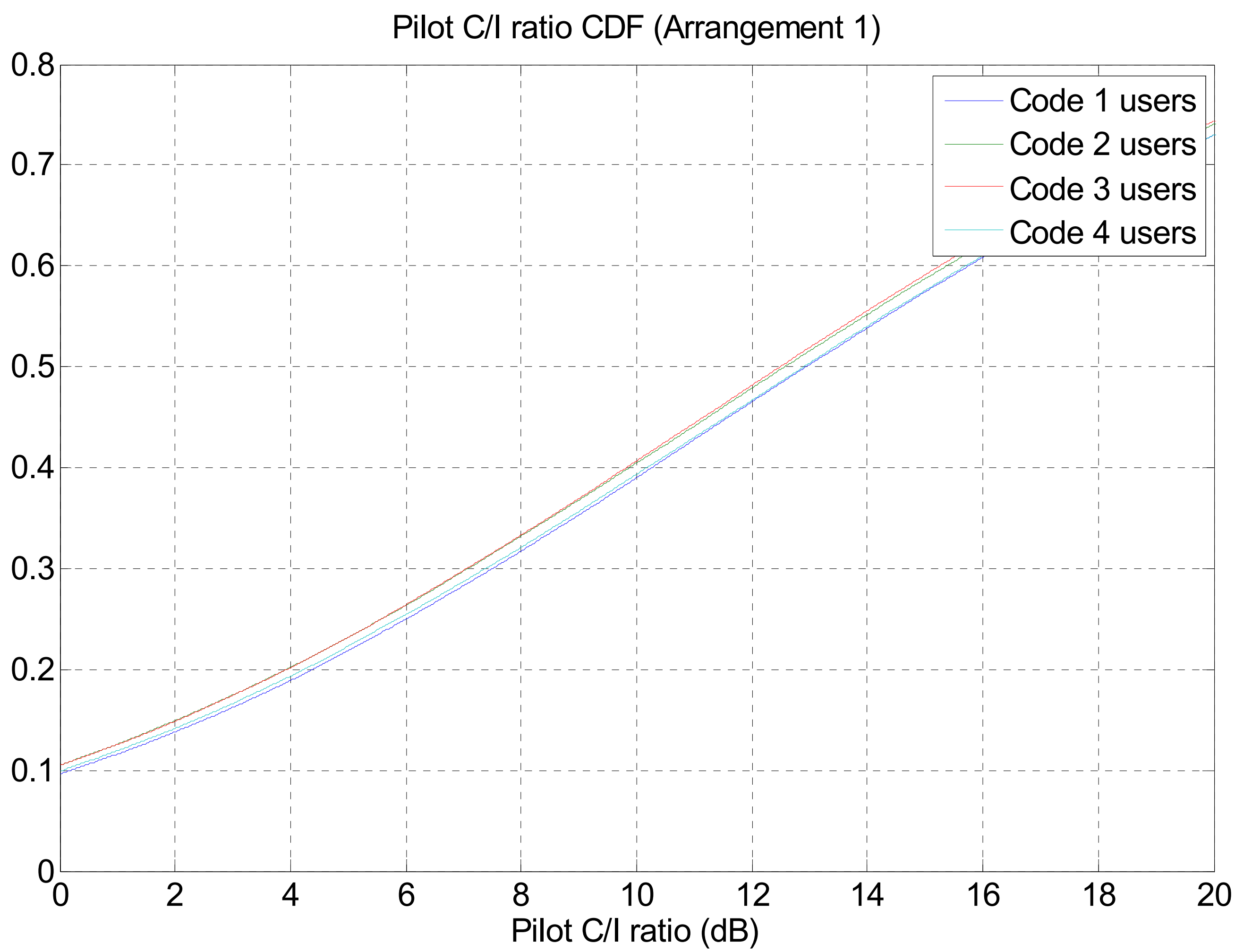


Overall Pilot C/I ratio in comparison to 3 code system



Note: there is an additional 6dB protection from the PRBS code, thus the actual gain in the channel estimate C/I is 6dB when using the orthogonal codes.

C/I ratios of 1, 2, 3 and 4 code users – Arrangement 1



C/I ratios of 1, 2, 3 and 4 code users – Arrangement 2

Text for the SDD

1. Sectors of a cell in the system shall be assigned an index (4 possible indices)
2. Based on the sector index, each sector of a cell shall use its index to assign its users a code word chosen from a set of orthogonal constellations for use on the pilot tones:
   - Data tones in a tile shall use PRBS
   - Pilot tones in a tile shall use the orthogonal code word assigned by the sector
3. Orthogonal code words are derived from a set of:
   - Walsh-Hadamard matrix, or
   - Complex 4-QAM (±1±j) constellation
   - That are known at the SS receiver