Further Results on the Performance Evaluation of DL Open Loop SU-MIMO Schemes

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Hosein Nikopourdeilami, Mo-Han Fong, Jun Yuan, Sophie Vrzic, Robert Novak, Dongsheng Yu, Kathiravetpillai Sivanesan

Nortel Networks E-mail: hosein@nortel.com, mhfong@nortel.com

*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Purpose: Discussion and to support proposed SDD text.

Contents

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- Further simulation results and studies
  - Precoder cycling (PC) vs. antenna hopping (AH) with multiple-RU channel estimation (CE)
  - Combined PC and AH
- Discussion on
  - Common pilot vs. dedicated pilot
  - Multiple-RU CE
  - RU-based vs. tone-based DRU resource allocation
- Conclusion

Summary of Results Presented in Kobe Meeting

Summary of Results Presented in Kobe Meeting (08/1193r1) (1/2)

- 4 Tx rate 1
  - Different rate 1 OL MIMO schemes were compared:
    - [C802.16m-MIMO-08/007] STC with antenna hopping and common pilot (STC/AH), precoder is changed over every pair of tones in time and frequency direction.
    - [C802.16m-MIMO-08/017] STC with large delay CDD and common pilot (STC/LDCDD)
    - [C802.16m-MIMO-08/009] STC with antenna permutation and phase shift and dedicated pilot (STC/Permuted CDD)
    - [C802.16m-MIMO-08/014] STC with two dimensional phase shift and dedicated pilot (STC/2D-POD)
    - [C802.16m-MIMO-08/013] STC with 4x2 16e or DFT precoder cycling and/or phase shift and dedicated pilot: Candidate 1, 2 or 4 (STC/16e+CDD, STC/16e, STC/DFT+CDD)
  - Overall, STC/AH + common pilots provides the best goodput performance
  - Difference of tone-based and RU-based DRU is less than 0.4 dB
  - Recommendation:
    - STC/AH
    - Common pilot
    - RU-based DRU

Summary of Results Presented in Kobe Meeting (08/1193r1) (2/2)

- 4 Tx rate 2
  - Different rate 2 OL MIMO schemes were compared:
    - [C802.16m-MIMO-08/016] Double STTD with antenna hopping and common pilot (DSTTD/AH), precoder is changed over every pair of tones in time and frequency direction.
    - [C802.16m-MIMO-08/007] SM with antenna hopping and common pilot (SM/AH), precoder is changed overevery tone in time and frequency direction.
    - [C802.16m-MIMO-08/008] SM with subset antenna hopping and common pilot (SM/sub AH), precoder is changed over every tone in time and frequency direction.
    - [C802.16m-MIMO-08/017] SM with large delay CDD and common pilot (SM/LDCDD)
    - [C802.16m-MIMO-08/009] SM with antenna permutation and phase shift and dedicated pilot (SM/Permuted CDD)
    - [C802.16m-MIMO-08/014] SM with two dimensional phase shift and dedicated pilot (SM/2D-POD)
    - [C802.16m-MIMO-08/013]: SM with 4x2 16e or DFT precoder cycling and/or phase shift and dedicated pilot: Candidat 1, 2 or 4 (SM/16e+CDD, SM/16e, SM/DFT+CDD)
  - Overall, DSTTD/AH and SM/AH has the best performance compared to other schemes evaluated.
  - SM/AH vs. DSTTD/AH
    - If only MMSE receiver is used at the terminal, DSTTD/AH has the overall best performance at the expense of 4x4 matrix inversion for MMSE receiver
    - SM/AH + MMSE can be used to reduce complexity of MMSE receiver to 2x2 matrix inversion. The performance degradation compared to DSTTD/AH + MMSE is about 0.6 dB.
    - If MLD receiver used for SM/AH, the performance of SM/AH is the same or even better than DSTTD/AH + MMSE receiver, while having comparable receiver complexity.
      - As opposed to MMSE receiver, MLD receiver does not need the covariance matrix of the interference + noise
  - The difference of tone-based and RU-based DRU is about 0.6 dB
  - Recommendation:
    - SM/AH
    - Common pilot
    - RU-based DRU

Further Simulation Results and Studies

AH vs. PC with Multiple-RU CE

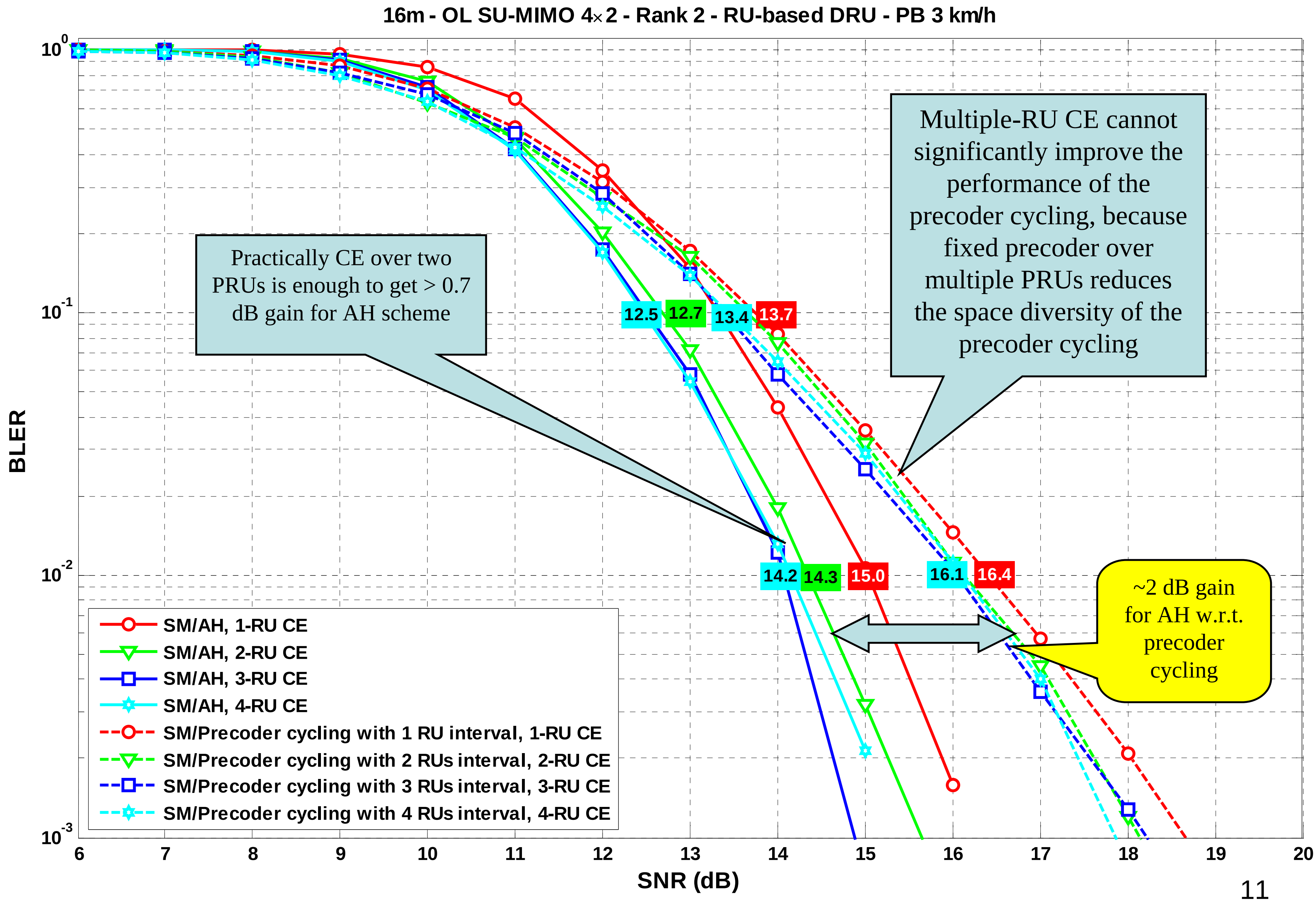
- AH
  - AH precoder is a simple matrix with 0/1 elements
  - AH uses common pilots
  - AH precoder changes even within a PRU from tone to tone to get more space diversity within the coherence time and bandwidth of the fading channel
  - CE over multiple PRUs is possible to reduce CE loss
- PC
  - DFT precoder matrix
  - Dedicated pilot
  - One precoder per PRU or multiple contiguous PRUs
  - If precoder cycle is one PRU then CE over multiple PRUs is not possible
  - If precoder is fixed over multiple PRUs, the space diversity is reduced

Simulation Parameters

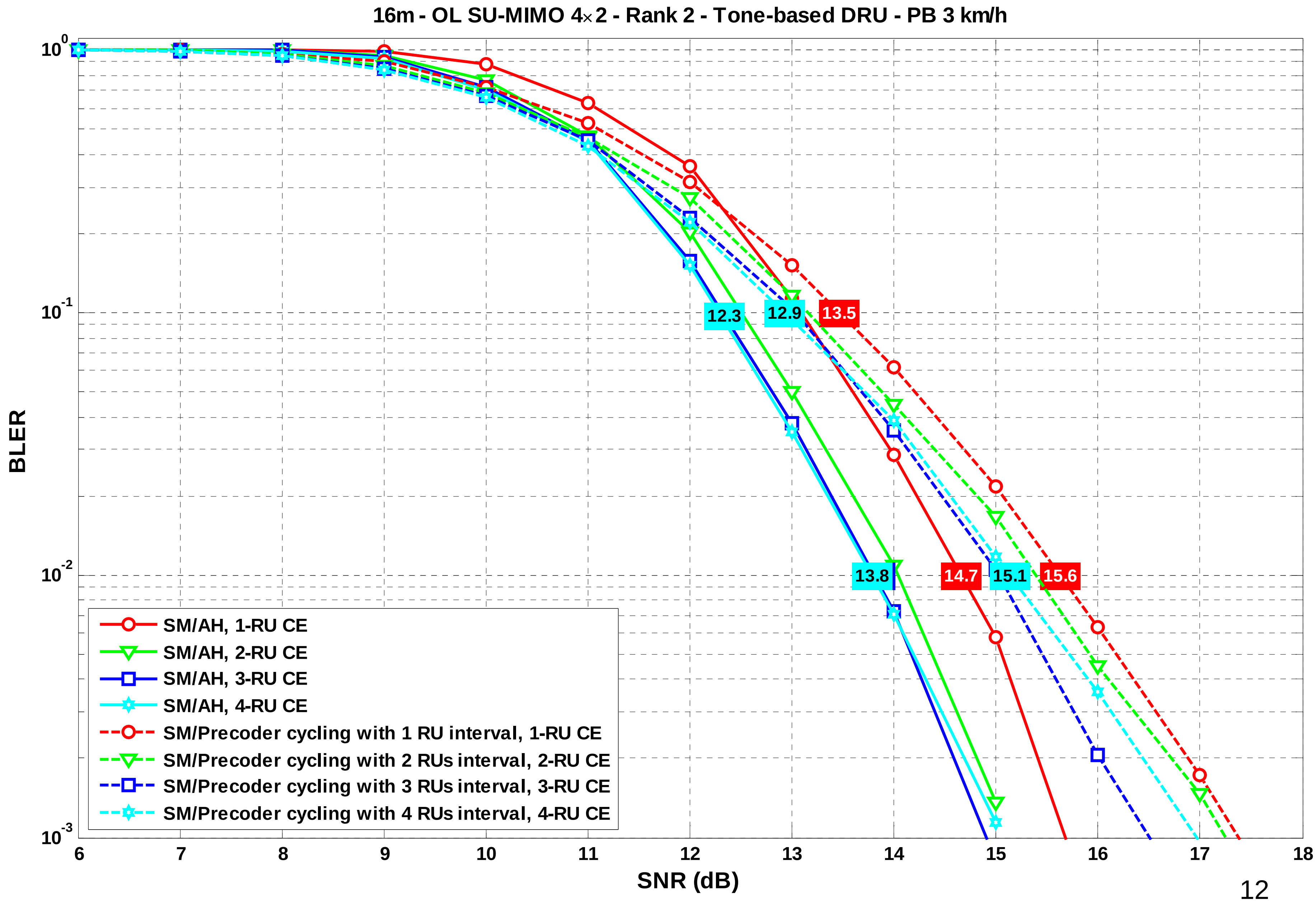
- **Channelization**
  - 10 MHz bandwidth with 48 physical RUs (PRU)
  - RU size is 18×6
  - 4 RUs allocated to a user
  - RU-based distributed RU (DRU). 4 RUs are randomly selected from 48 available PRUs.
  - tone-based DRU. Tones are distributed over 6 or 24 PRUs. PRUs are randomly selected from 48 available PRUs.
- **Antenna**
  - 4 Tx, 2 Rx
  - uncorrelated
  - 0 dB receive power imbalance
- **Fading channel**
  - PB 3 km/h, VA 60 km/h
  - carrier frequency 2.5 GHz
  - 2D MMSE channel estimation
- **Receiver**
  - MMSE
- **Channel Estimation (CE)**
  - 2D-MMSE CE
- **Modulation and coding**
  - 16-QAM
  - rate ½ duo-binary turbo code with 10 decoding iterations
  - 1 or 2 MIMO layers
  - single codeword

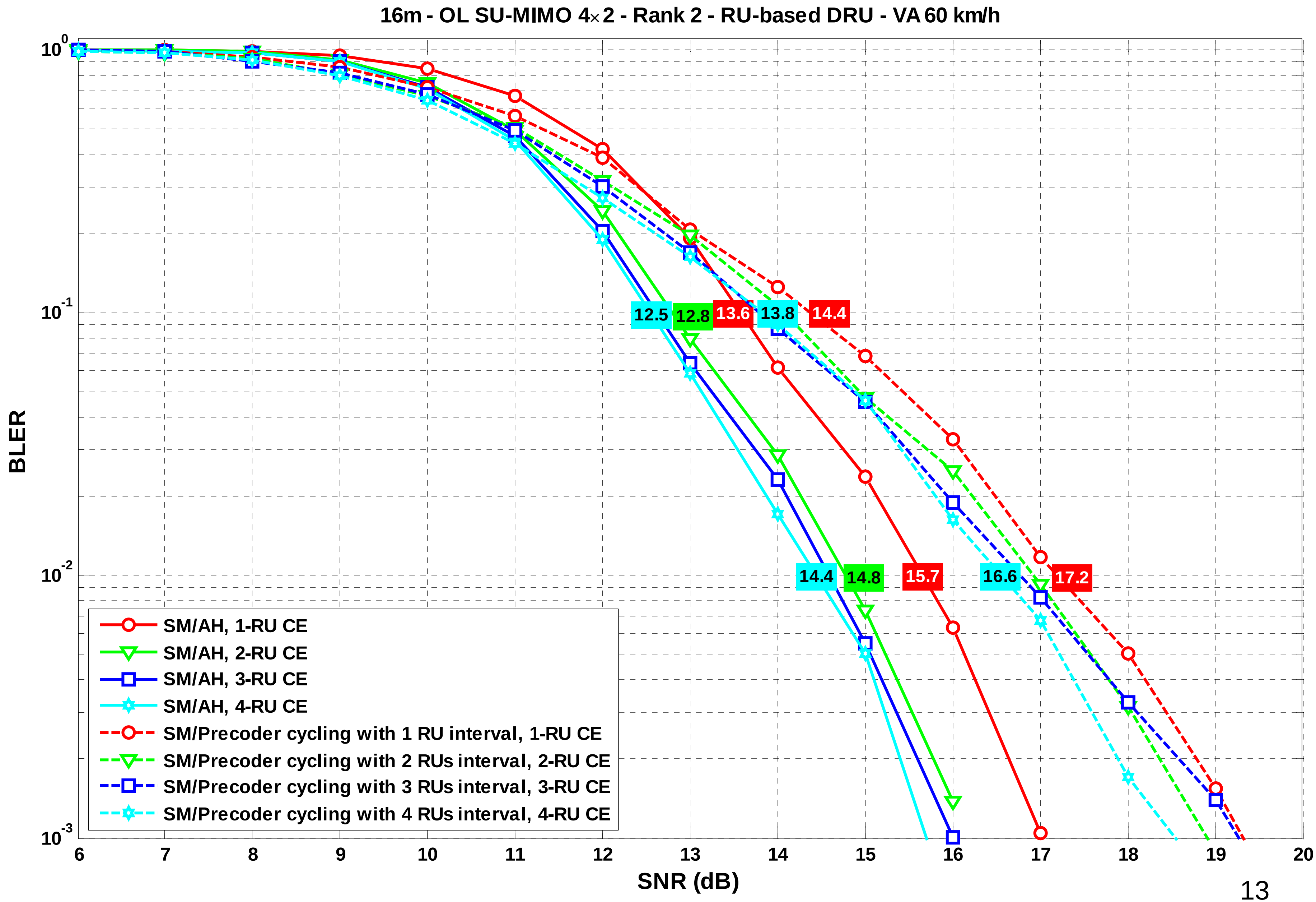
Comparison of AH and PC with Different Precoder Cycles, *Rank 2*

AH vs. PC with Multiple-RU CE
BLER vs. SNR

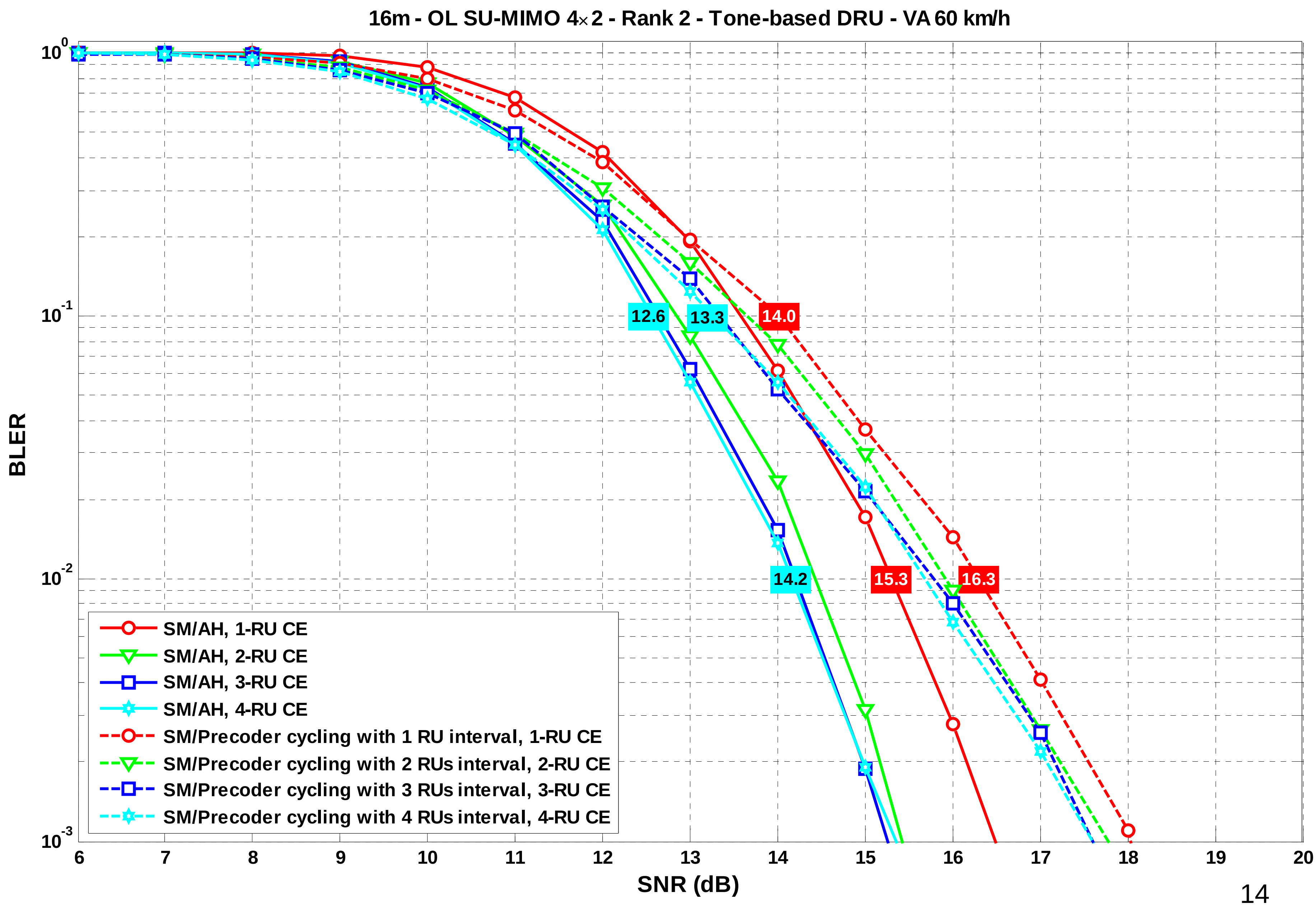


16m - OL SU-MIMO 4×2 - Rank 2 - RU-based DRU - PB 3 km/h
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Practically CE over two PRUs is enough to get > 0.7 dB gain for AH scheme
Multiple-RU CE cannot significantly improve the performance of the precoder cycling, because fixed precoder over multiple PRUs reduces the space diversity of the precoder cycling
~2 dB gain for AH w.r.t. precoder cycling
12.5
12.7
13.4
13.7
14.2
14.3
15.0
16.1
16.4
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE


16m - OL SU-MIMO 4×2 - Rank 2 - Tone-based DRU - PB 3 km/h
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
6
7
8
9
10
11
12
13
14
15
16
17
18
12.3
12.9
13.5
13.8
14.7
15.1
15.6
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE

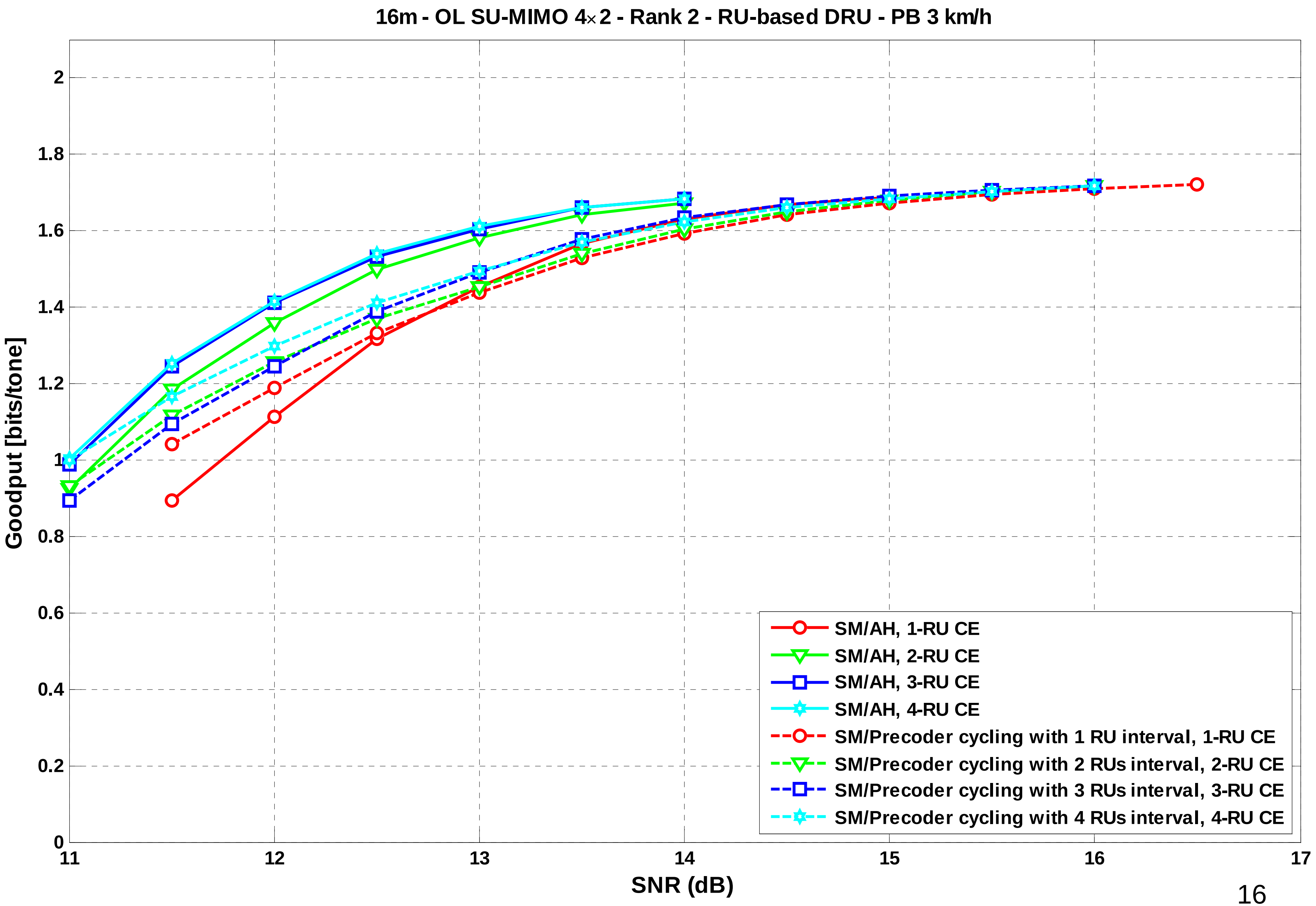


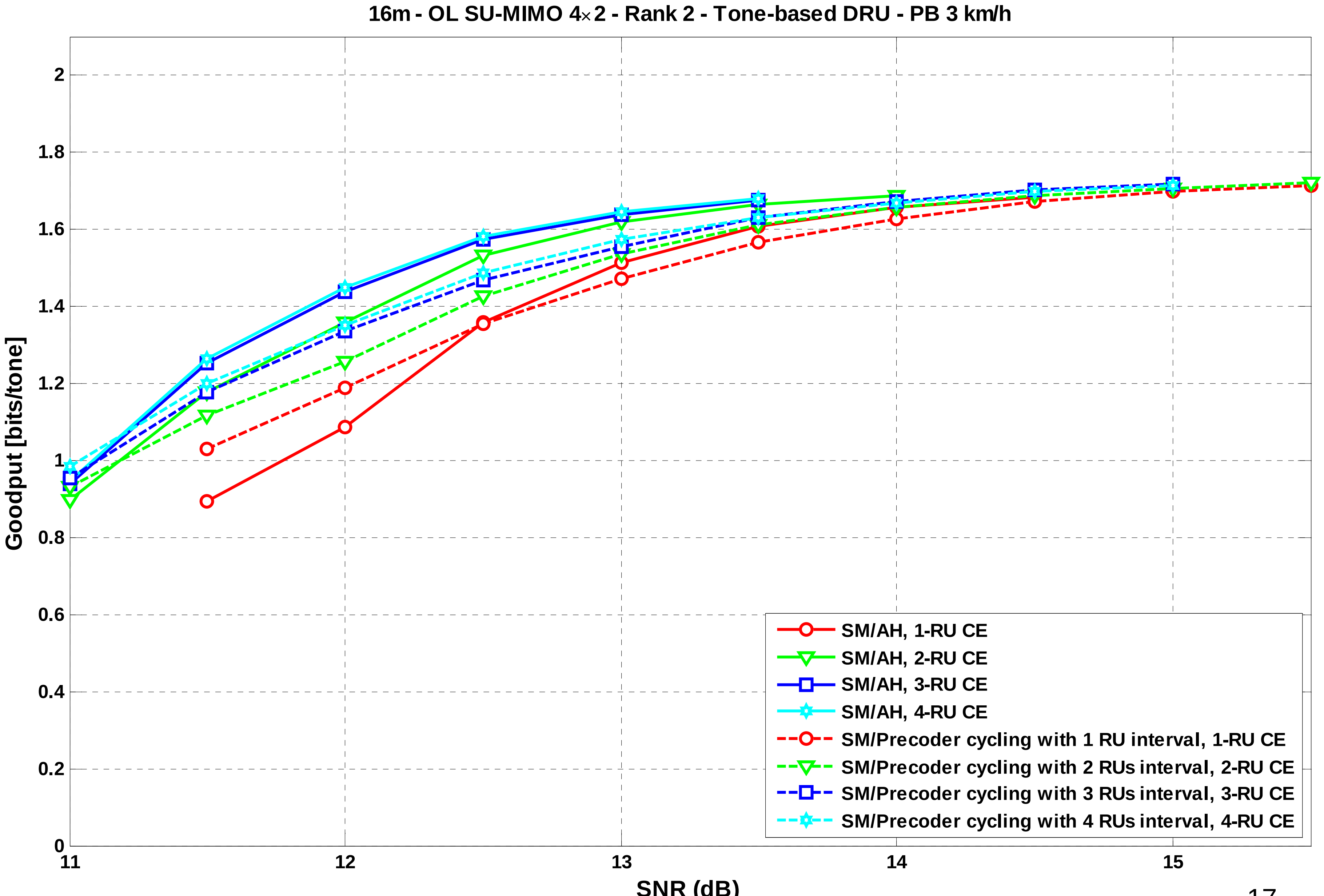
16m - OL SU-MIMO 4×2 - Rank 2 - RU-based DRU - VA 60 km/h
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
12.5
12.8
13.6
13.8
14.4
14.4
14.8
15.7
16.6
17.2
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE

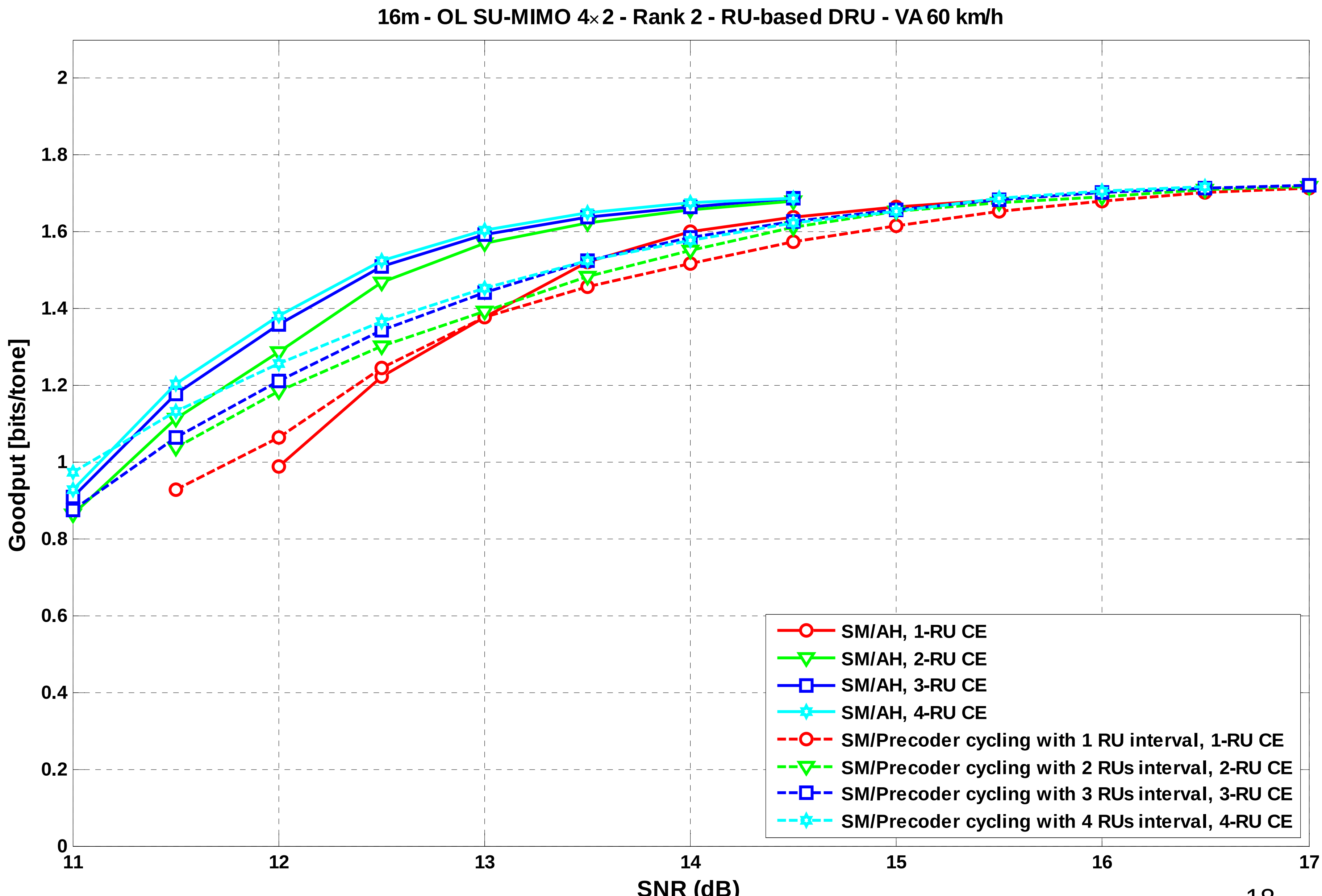


16m - OL SU-MIMO 4×2 - Rank 2 - Tone-based DRU - VA 60 km/h
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
12.6
13.3
14.0
14.2
15.3
16.3
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE

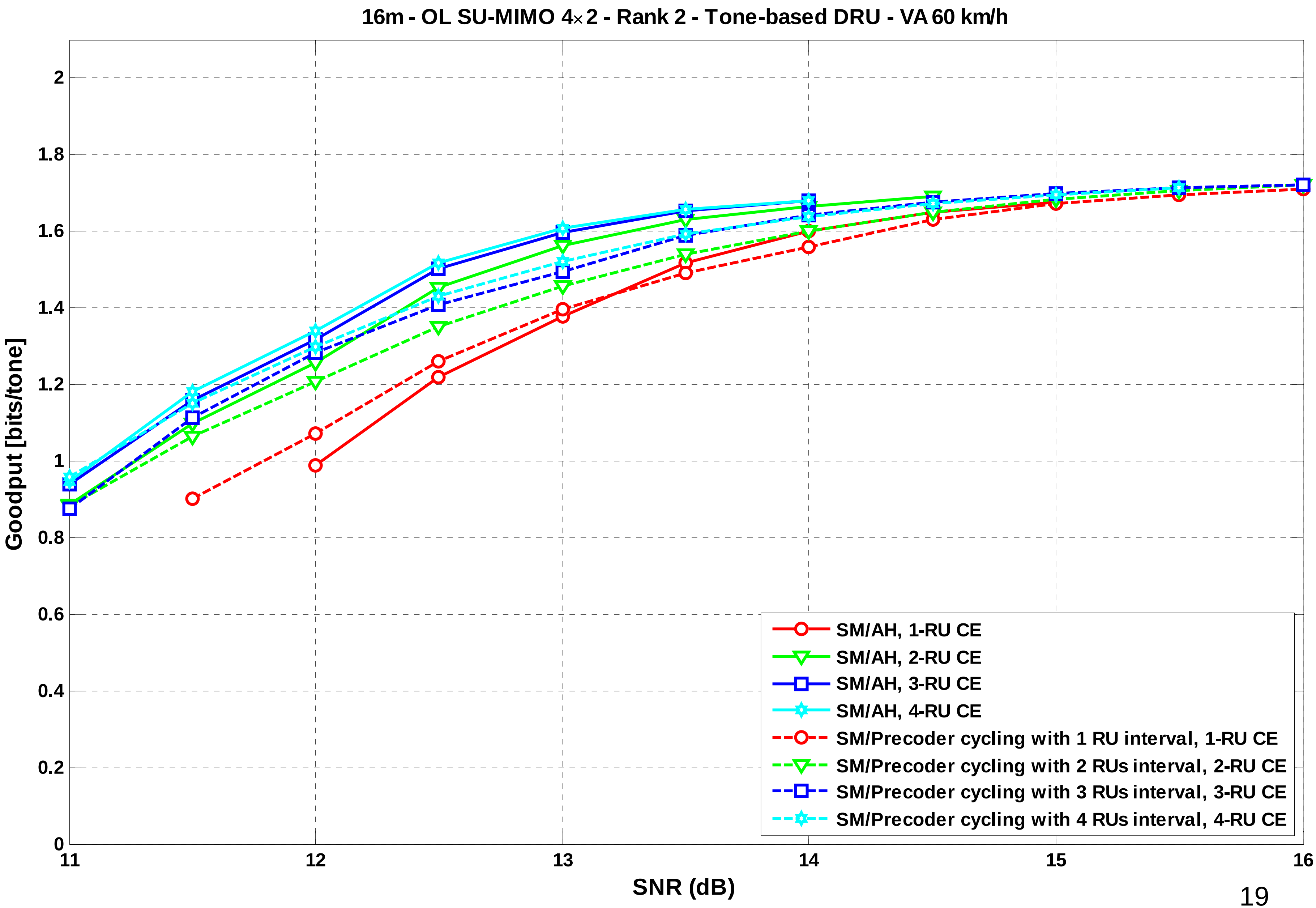
AH vs. PC with Multiple-RU CE Goodput vs. SNR


16m - OL SU-MIMO 4×2 - Rank 2 - RU-based DRU - PB 3 km/h
Goodput [bits/tone]
SNR (dB)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
11
12
13
14
15
16
17
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE


16m - OL SU-MIMO 4×2 - Rank 2 - Tone-based DRU - PB 3 km/h
Goodput [bits/tone]
SNR (dB)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
11
12
13
14
15
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE



16m - OL SU-MIMO 4×2 - Rank 2 - RU-based DRU - VA 60 km/h
Goodput [bits/tone]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
11
12
13
14
15
16
17
SNR (dB)
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE


16m - OL SU-MIMO 4×2 - Rank 2 - Tone-based DRU - VA 60 km/h
Goodput [bits/tone]
SNR (dB)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
11
12
13
14
15
16
SM/AH, 1-RU CE
SM/AH, 2-RU CE
SM/AH, 3-RU CE
SM/AH, 4-RU CE
SM/Precoder cycling with 1 RU interval, 1-RU CE
SM/Precoder cycling with 2 RUs interval, 2-RU CE
SM/Precoder cycling with 3 RUs interval, 3-RU CE
SM/Precoder cycling with 4 RUs interval, 4-RU CE

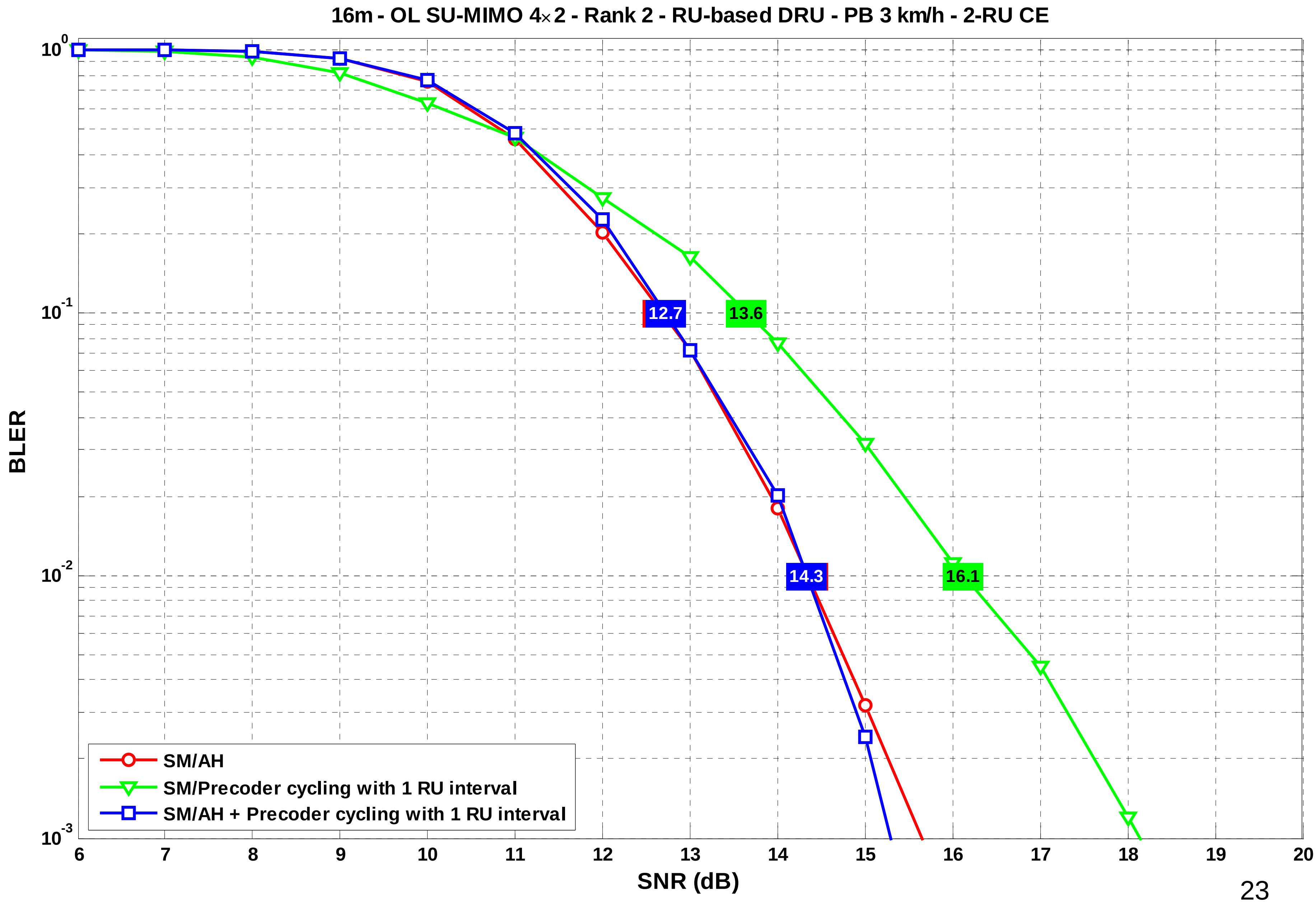
Observation on Multiple-RU CE

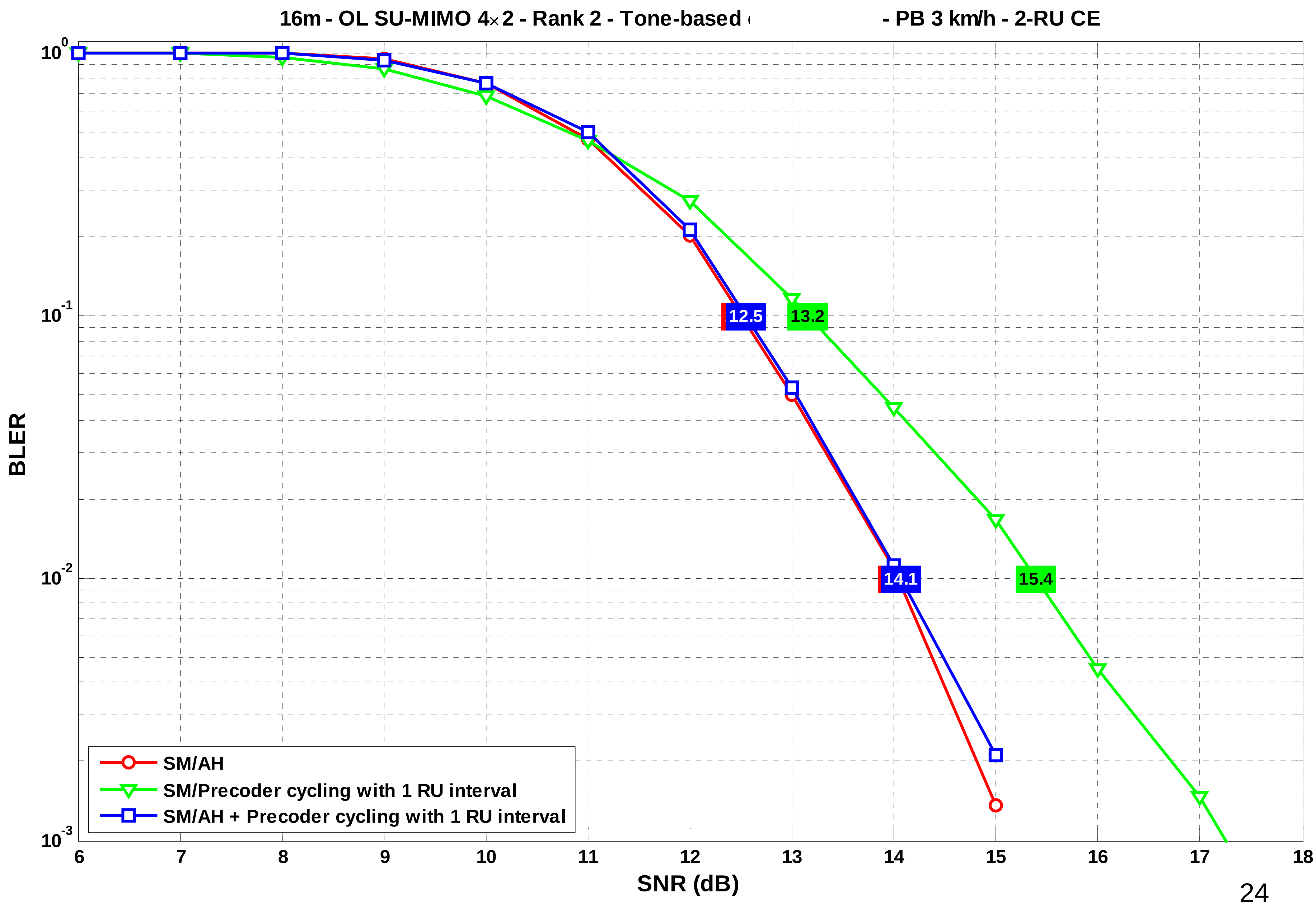
- Multiple-RU CE cannot significantly improve the performance of the PC
  - fixed precoder over multiple PRUs reduces the space diversity of the precoder cycling
- Practically, CE over two PRUs is enough to get more than 0.7 dB gain for AH scheme.
- AH outperforms precoder cycling in terms of goodput with multiple-RU CE

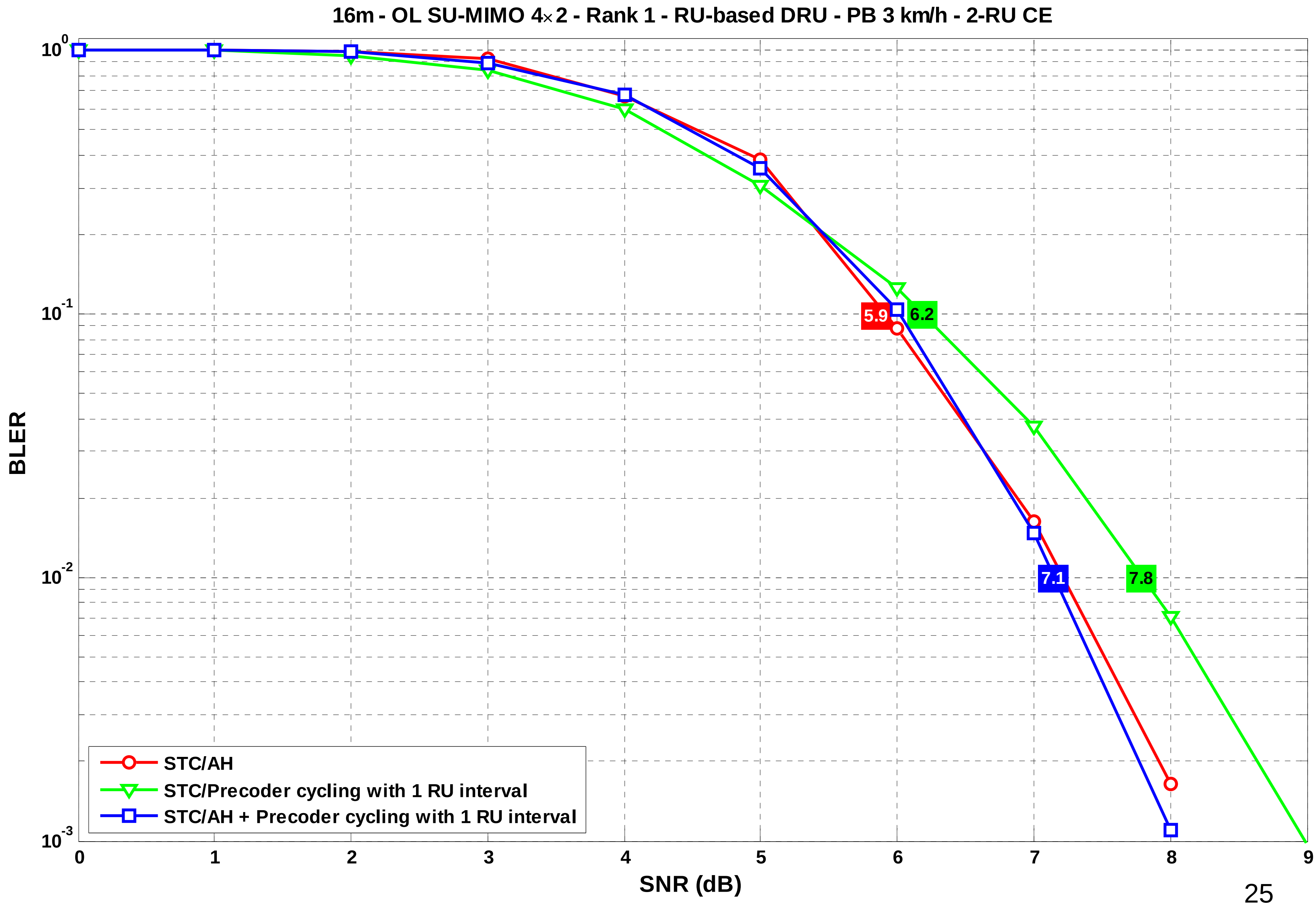
Combination of AH and PC

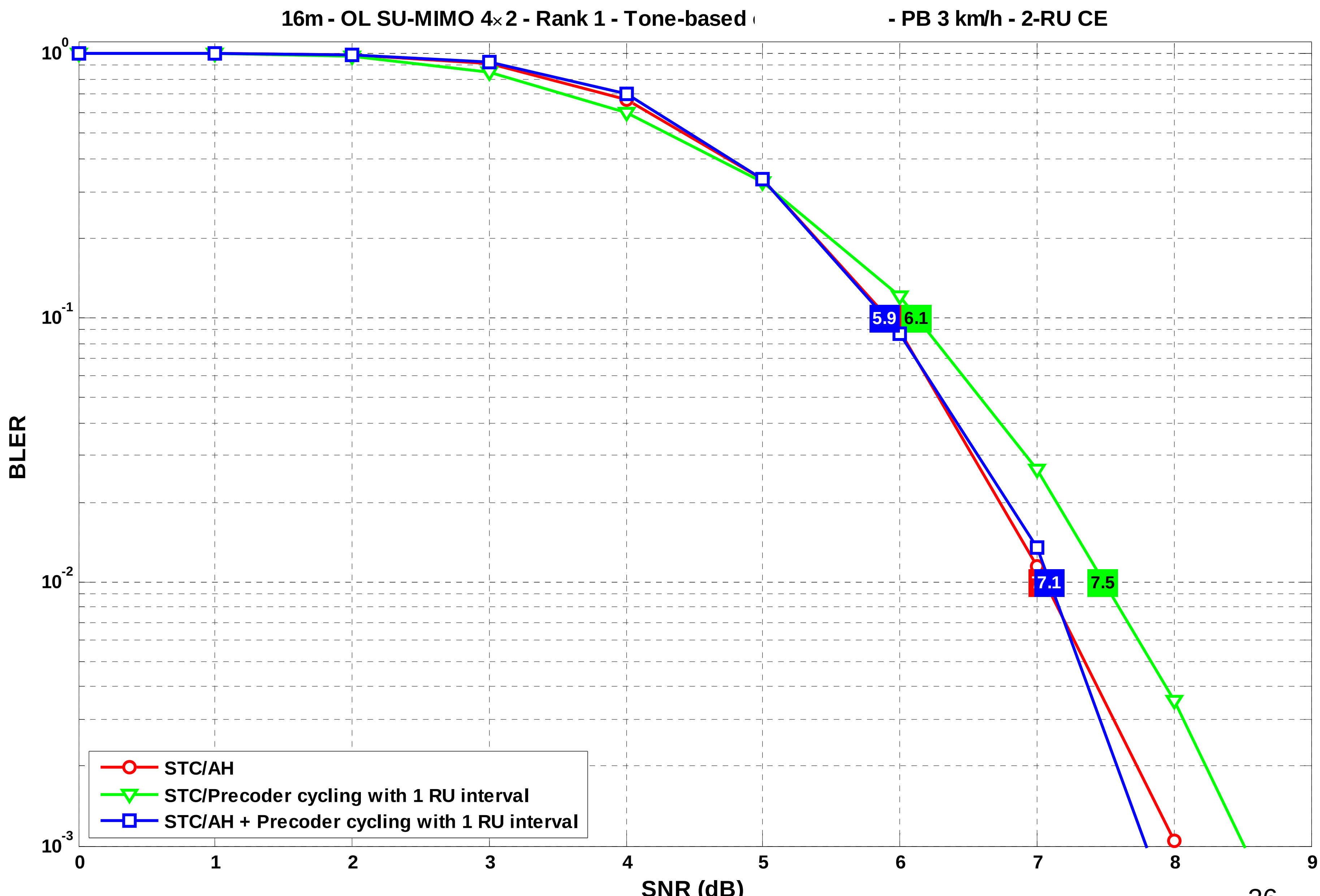
- AH precoder is the inner precoder changing form tone to tone
- DFT precoder is the outer precoder fix over the precoder cycle
  - fixed precoder for one PRU
- Common pilot
  - Multiple-RU CE is possible

Performance of Combined Method with 2-RU CE


16m - OL SU-MIMO 4×2 - Rank 2 - RU-based DRU - PB 3 km/h - 2-RU CE
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
12.7
13.6
14.3
16.1
SM/AH
SM/Precoder cycling with 1 RU interval
SM/AH + Precoder cycling with 1 RU interval


16m - OL SU-MIMO 4×2 - Rank 2 - Tone-based - PB 3 km/h - 2-RU CE
BLER
SNR (dB)
12.5
13.2
14.1
15.4
SM/AH
SM/Precoder cycling with 1 RU interval
SM/AH + Precoder cycling with 1 RU interval


16m - OL SU-MIMO 4×2 - Rank 1 - RU-based DRU - PB 3 km/h - 2-RU CE
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
0
1
2
3
4
5
6
7
8
9
5.9
6.2
7.1
7.8
STC/AH
STC/Precoder cycling with 1 RU interval
STC/AH + Precoder cycling with 1 RU interval



16m - OL SU-MIMO 4×2 - Rank 1 - Tone-based
- PB 3 km/h - 2-RU CE
BLER
SNR (dB)
10^0
10^-1
10^-2
10^-3
0
1
2
3
4
5
6
7
8
9
5.9
6.1
7.1
7.5
STC/AH
STC/Precoder cycling with 1 RU interval
STC/AH + Precoder cycling with 1 RU interval

Observation on Combined Scheme

- The performance of the combined scheme is practically the same as AH scheme but with higher complexity due to the extra DFT precoder
- Conclusion:
  - AH precoder has the best performance with lower complexity

Discussion

The Difference Between Common Pilot and Dedicated Pilot (1/2)

- Common pilot
  - It is possible to change OL MIMO precoder form tone to tone (not form RU to RU) to get more space diversity within the coherence time and coherence bandwidth of the fading channel
  - No need for midamble for the sake of channel measurement
  - Ability of multiple-RU channel estimation to reduce channel estimation loss
    - More than 0.7 dB gain even for two-RU channel estimation
  - Overhead is 14.8% which is higher than dedicated pilot
    - According to the simulation results, antenna hopping with common pilot provides better goodput compare to precoder cycling with dedicated pilot

The Difference Between Common Pilot and Dedicated Pilot (2/2)

- Dedicated pilot
  - One OL precoder is used for each PRU and pilots are passed through the same precoder as the data tones
    - Lower space diversity due to the fixed precoder within one PRU
  - Channel estimation is limited to one PRU
    - Channel estimation loss is higher compare to common pilot with multiple-RU channel estimation capability
    - If one fixed precoder applied to multiple contiguous PRUs, it is possible to do multiple-RU channel estimation for dedicated pilots as well. However, fixed precoder over multiple RUs reduces the space diversity of the system and eventually the gain due to multiple-RU channel estimation is negligible.
  - Need for midamble for the sake of channel measurement
    - If one OFDMA symbol is assigned to midamble every superframe, it causes 100/46% = 2.17% extra overhead
  - Pilot overhead is 11.1% which is lower than common pilot
    - Although overhead is less, according to the simulation results, AH with common pilot provides better goodput compare to precoder cycling with dedicated pilot

Multiple-RU Channel Estimation Is Possible Even for FFR Case

- With common pilots, CE can be done over multiple PRUs where common pilot exists
- With dedicated pilots, CE can only be done within one PRU
- As defined in the SDD (IEEE 802.16m-08/003r5), for non FFR case, the outer-permutation unit is 4 PRUs.
- For FFR case, the outer-permutation unit can be 1 or 2 PRUs.
  – To have reasonable subband feedback overhead, 2 PRUs are preferable.
  – E.g., in 10MHz, there are 48 PRUs. Assuming 4 FFR zones, each zone has 12 PRUs. 2 PRUs per sub-band will give 6 sub-bands for more reasonable feedback overhead.
  – For larger system bandwidth or lower number of FFR zones or unequal size FFR zones, the outer-permutation unit of 2 PRUs is even more crucial to ensure reasonable number of sub-bands per FFR zone and therefore reasonable amount of feedback overhead
- Even when there are multiple FFR zones, common pilots can exist across the FFR zones which can be used by an MS for channel estimation.

Comparison of RU-Based and Tone-Based DRU Resource Allocation (1/4)

- Tone-based DRU provides more frequency diversity only if the number of RUs allocated to LDRU zone is large enough, otherwise RU-based and tone-based DRU performs identically.
  - If 4 FFR zone exist and each FFR zone is partitioned into two equal size LDRU and LLRU zones, the number of RUs allocated to the LDRU partition of each FFR zone is limited to only 6 RUs for 10 MHz bandwidth

Comparison of RU-Based and Tone-Based DRU Resource Allocation (2/4)

- Higher frequency diversity of the tone-based DRU helps to improve the performance only if one or two RUs is allocated to a user
  - If number of RUs allocated to a user is two or more, the advantage of tone-based over RU-based DRU diminishes

Comparison of RU-Based and Tone-Based DRU Resource Allocation (3/4)

- Antenna hopping (AH) scheme reduces the performance gap between tone-based and RU-based resource allocation
  - According to the simulation results, the performance degradation of AH scheme with RU-based DRU is less than 0.5 dB wit respect to AH with tone-based DRU allocation

Comparison of RU-Based and Tone-Based DRU Resource Allocation (4/4)

- If AH scheme is adopted with RU-based DRU, there is no need for tone-based DRU zone partitioning
  - Better MAC efficiency compare to the case that both LLRU and LDRU zones exist is a subframe

Conclusion

Overall Conclusion

- 4 Tx Rate 1
  - STC/AH where precoder is changed form tone to tone
  - Common pilot
  - RU-based DRU
- 4 Tx Rate 2
  - SM/AH where precoder is changed form tone to tone
  - Common pilot
  - RU-based DRU
- FFR zone outer-permutation unit should be set at 2 or more PRUs to leverage from the channel estimation performance gain of 0.7dB