3GPP TSG RAN WG1 Meeting #87 **R1-1612186**
Reno, USA 14th - 18th November 2016

Source: **CMCC**
Title: **Phase Noise Reference Signal Design for High Frequency Systems**
Agenda Item: **7.1.3.2**
Document for: **Discussion and Decision**

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1. Introduction

In RAN1#86 meeting, the following agreements on phase noise reference signal (PN RS) were achieved [1]:

- *In addition to the front-loaded RS agreed to study in RAN1#85, same or extended/additional RS is studied in NR of at least the following:*
  - *Compensate phase rotation and frequency offset*

In RAN1#86bis meeting, the following agreements on PN RS were achieved:

- *At least the following RSs are supported for NR downlink and uplink* [2]:
  - *Reference signal for phase tracking*
    - *FFS: Whether DM-RS extension can be applied or not*
    - *FFS whether new RS or RS for other functionalities can be used*
- *Study multi-set DL/UL RS for control and/or data demodulation* [3]:
  - *The first set is front-loaded (i.e. loaded in the front of RB)*
  - *Other set(s) can be configured for different purposes*
    - *Details FFS (e.g. higher frequency/time density, Rx beam detection, RSRP/CSI-reporting, phase noise compensation)*
- *For CP-OFDM waveform, for the RS enabling phase tracking, the following should be studied* [4]:
  - *Time domain pattern*
    - *Alt-1: Continuous mapping, i.e., on every OFDM symbol*
    - *Alt-2: Non-continuous mapping, e.g., every other OFDM symbol*
    - *Switching between Alt-1 and Alt-2 can also be considered*
  - *Frequency domain pattern*
    - *Alt-A: Shared and across full carrier bandwidth with fixed density/spacing*
    - *Alt-B: Within each UE's scheduled bandwidth and with configurable density/spacing*
    - *Other patterns are not precluded*

Regarding the above issues about PN RS patterns in both time and frequency domains, i.e., whether it should be continuous mapping or non-continuous mapping in time domain, and whether it should be with fixed or configurable density in frequency domain, in this contribution these two issues are investigated and based on the analysis and extensive simulation results, our views on these two problems are given.

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2. Phase Noise Reference Signal Pattern in Time Domain

It has been agreed in NR that OFDM-based waveform is supported in both downlink and uplink for eMBB for up to 40GHz [5]. The effect of PN on OFDM-based systems is its induced common phase error (CPE) and inter-carrier interference (ICI) [6]. The CPE, which is the average phase shift and is (almost) the same across all subcarriers, can be estimated using pilot symbols and compensated at the receiver. The ICI can be mitigated by increasing the subcarrier spacing, with which an increased portion of PN will be transformed into CPE and then compensated.

CPE is in fact the DC part of a PN process [5], i.e., it belongs to the low-frequency part of PN. The PN process within one OFDM symbol is illustrated as the following figure 1:

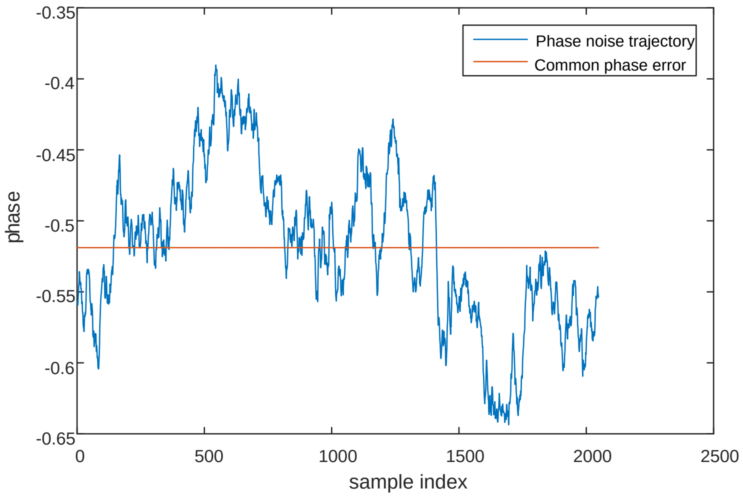

Fig.1. Example of a PN realization and its CPE within one OFDM symbol

Considering the fact that the PN changes randomly from one OFDM symbol to another [7]，the CPE within each PN also changes randomly from one OFDM symbol to another. An example that illustrates a PN process within one slot is shown in the following figure 2. In this figure, their adjacent CPEs are adopted to interpolate symbols 2, 4, 6, 8, 10, 12 in order to obtain their own CPEs if PN RS is non-continuous mapping in the time domain (in this case the PN RS is mapped on every other OFDM symbol). It can be seen from figure 2 that due to the randomness of PN, there is barely any correlation between adjacent CPE values. Therefore, interpolation error occurs which will significantly degrade the system performance. In summary, the PN RS should be continuous (i.e., on every OFDM symbol) in the time domain to track the fast-changing PN.

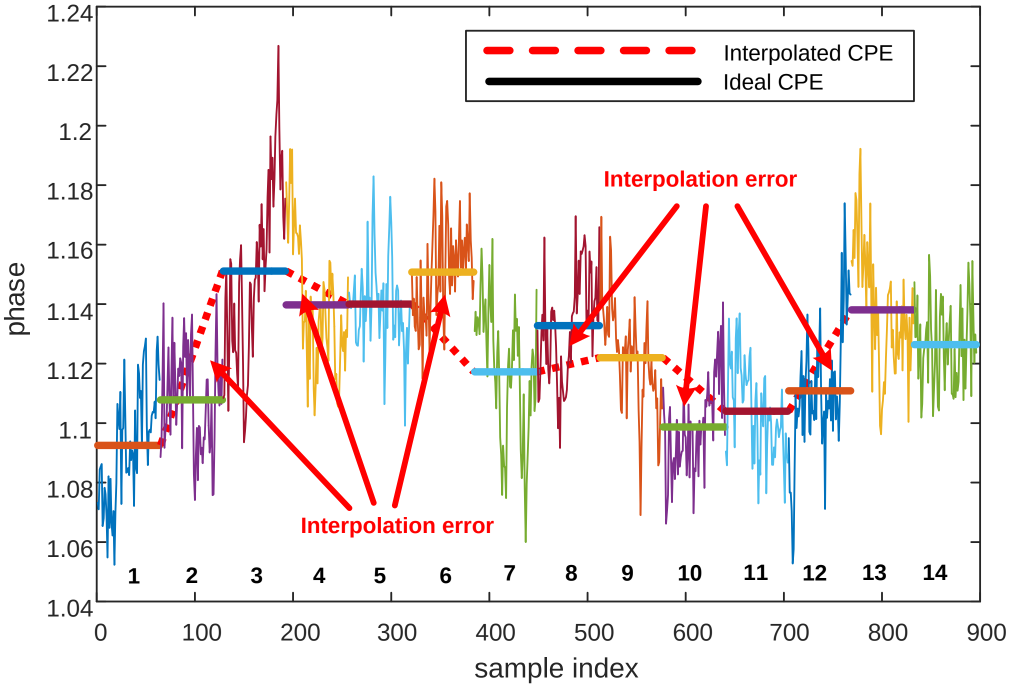

Fig.2. Example of a PN realization and its CPEs within one slot (14 OFDM symbols, 64 samples per OFDM symbol)

- **Proposal 1:** *For NR high frequency systems, the PN RS should be continuous (i.e., on every OFDM symbol) in the time domain to track PN.*

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3. Phase Noise Reference Signal Pattern in Frequency Domain

In order to investigate the PN pattern in frequency domain, i.e., the density or spacing of PN RS in frequency domain, extensive simulation results considering different traffic RBs, MCSs, SCSs and density of PN RS within traffic RBs according to the following table 1 are given.

Table 1: Simulation Parameters

Carrier frequency	30GHz
PN model	Proposed PN model in [8]
PN compensation scheme	Only compensate CPE
CPE estimation scheme	Method in [9]
Waveform	OFDM
TX/RX number	1 TX/1 RX
FFT size	2048
# of Traffic RBs	4, 32, 64
MCS (MCS cases in LTE)	QPSK：MCS 1, MCS 10 16QAM：MCS 11, MCS 17 64QAM：MCS 18, MCS 28
Subcarrier spacing (SCS)	60, 120, 240, 480KHz
Density of PN RS within traffic RBs	[0.0204,0.0400,0.0588,0.0769,0.0943] (PN RS is evenly placed within RBs)
Channel coding	LTE Turbo, 1/3 rate
Channel model	AWGN

■ Comparison of different traffic RBs and MCSs

- ***4 RB case：***

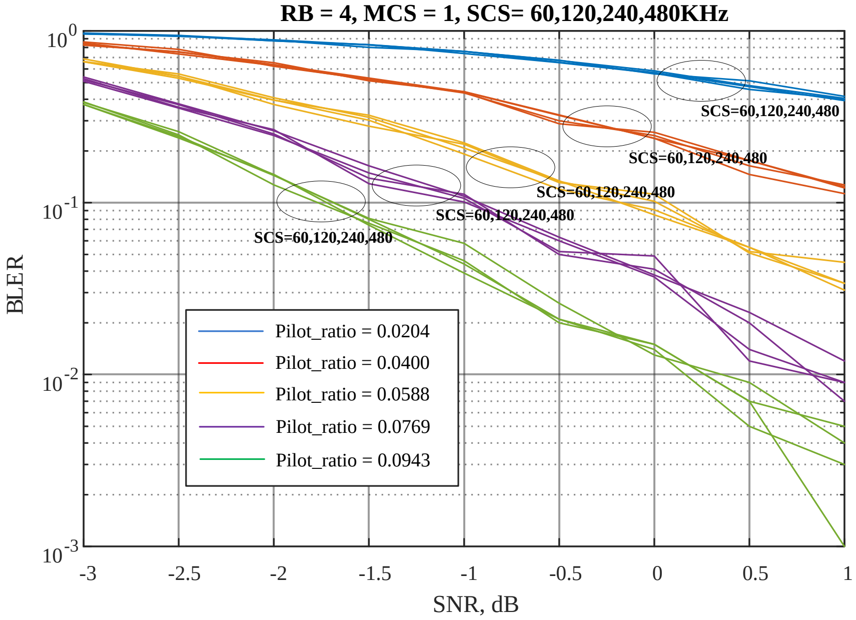

Fig.3. RB=4, MCS=1, SCS=60, 120, 240, 480KHz

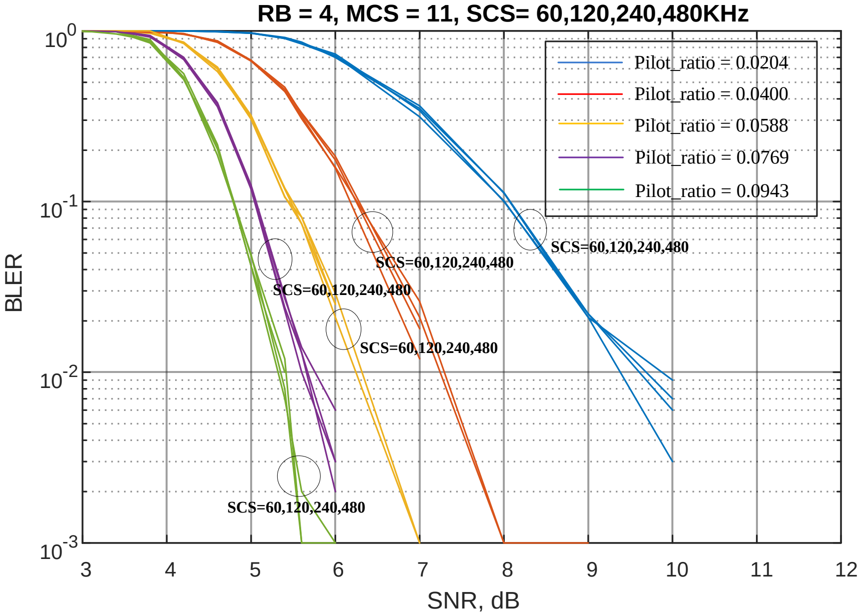

Fig.4. RB=4, MCS=11, SCS=60, 120, 240, 480KHz

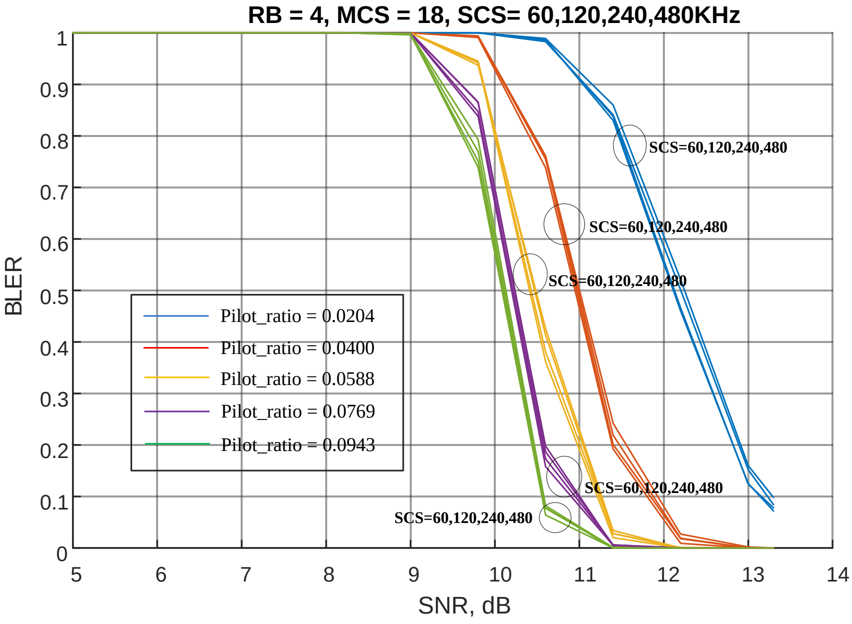

Fig.5. RB=4, MCS=18, SCS=60, 120, 240, 480KHz

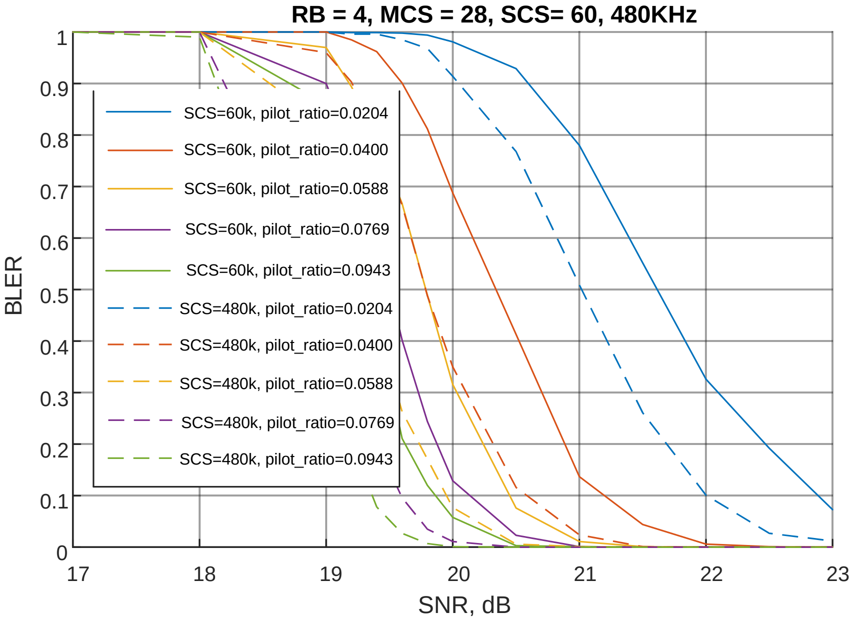

Fig.6. RB=4, MCS=28, SCS=60, 480KHz

It can be observed from figures 3 - 6 that when RB = 4 and MCS = 1, 11, 18, 28, there is about 0.2-0.5 dB SNR gain for 120KHz, 240KHz and 480KHz SCS cases compared to the 60KHz case. As the pilot ratio increases, the performance improves as well. This is because the CPE is more accurately estimated by using more PN RS and therefore after CPE compensation, the performance improves.

– *32 RB case*：

When MSC=1, similar results as that of 4RB case can be seen from figure 7 when RB = 32. Furthermore, similar phenomenon can be obtained for MCS = 10, 11, 17, 18 cases and the results are omitted for simplicity.

For example, as can be seen from figure 8, for MCS = 28 case, there is about 0.8dB SNR gain when 480KHz SCS is adopted compared to the 60KHz SCS case.

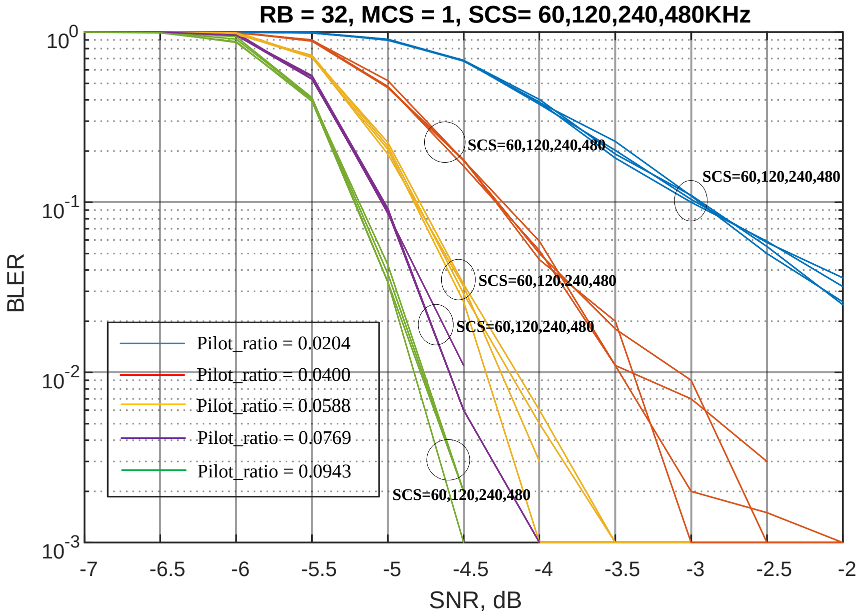

Fig.7. RB=32, MCS=1, SCS=60, 120, 240, 480KHz

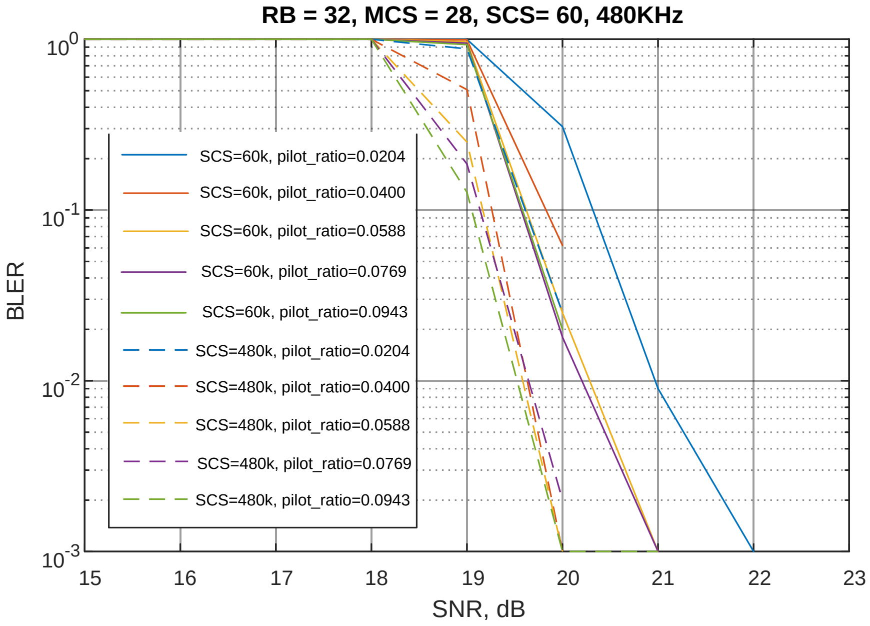

Fig.8. RB=32, MCS=28, SCS=60, 480KHz

– ***64 RB case:***

Finally, when MSC=1, similar results as that of 4RB and 32RB cases can be seen from figure 9 when RB = 64. Furthermore, similar results can be observed for MCS = 10, 11, 17, 18 cases and the results are omitted for simplicity. For example, as can be seen from figure 10, for MCS = 28 case, there is still about 0.5dB SNR gain when 480KHz SCS is adopted compared to the 60KHz SCS case.

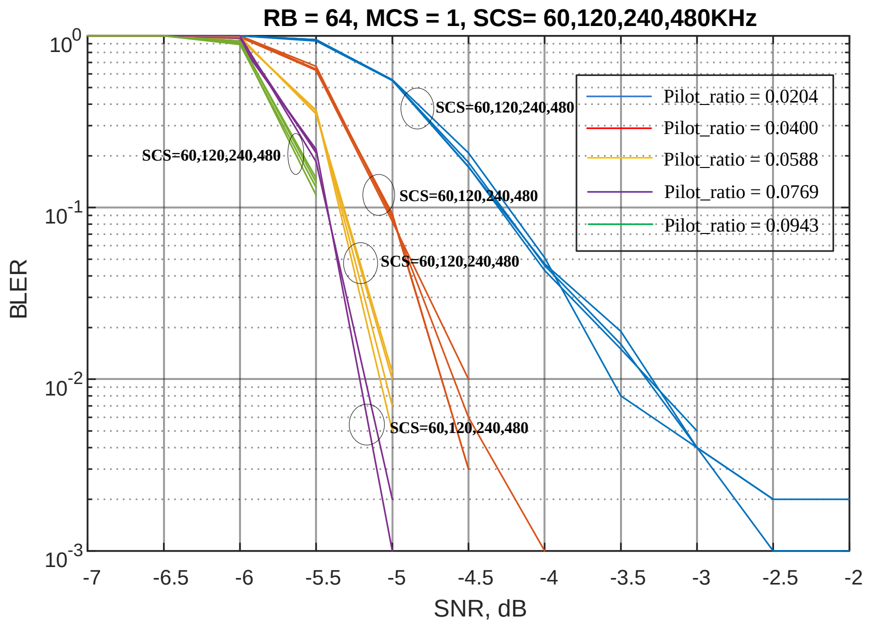

Fig.9. RB=64, MCS=1, SCS=60, 120, 240, 480KHz

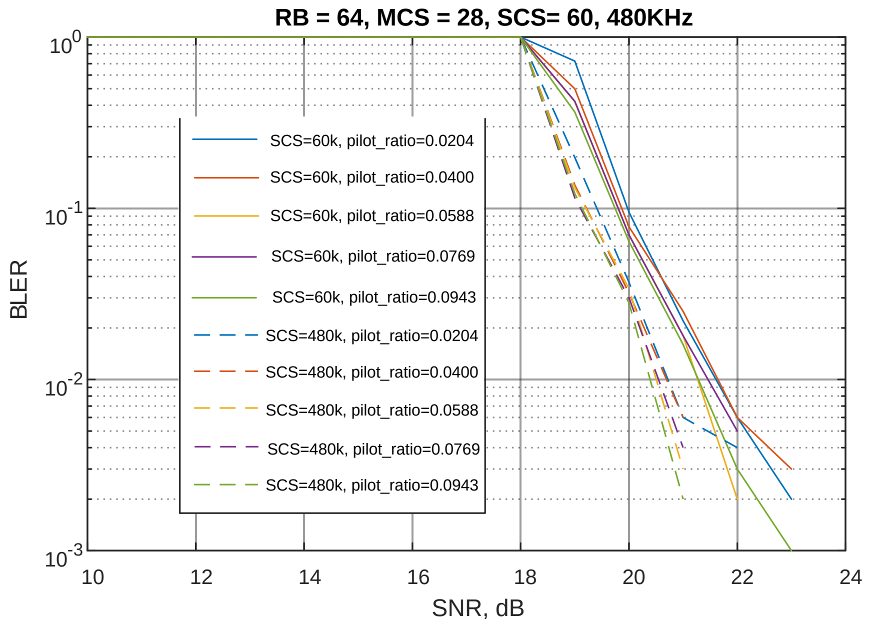

Fig.10. RB=64, MCS=28, SCS=60, 480KHz

- ***Observation 1:*** *As can be observed from figures 3 - 10, there is about 0.2dB – 0.8dB SNR gain for 120 KHz, 240KHz and 480KHz SCS cases compared to the 60KHz SCS case, especially when high MCS, e.g., MSC=28, is adopted.*

- ***Proposal 2:*** *SCS Larger than 60KHz should be supported if high MCS is to be supported in NR high frequency systems.*

■ Comparison of different PN RS within traffic RBs

From figures 11 and 12 it can be observed that for a fixed pilot ratio, different RB sizes have different performances. For example, the performance of “32RB, Pilot ratio = 0.0204” case is better than that of all pilot ratios for 4RB case. Another example is that the performance of “64RB, Pilot ratio = 0.0204” case is almost the same as that of the “32RB, Pilot ratio = 0.0400” case. Similar results can also be observed from figures 12 and 13 for high MCS case. This indicates that in order to achieve the same performance, the density or spacing of PN RS in frequency domain *needs not* to be fixed as traffic RB changes. The density should be able to be flexibly configured within each UE’s scheduled bandwidth.

- ***Observation 2:** For a given BLER target, the needed pilot ratio is smaller for larger number of RBs.*
- ***Proposal 3:** The density or spacing of PN RS in frequency domain needs not to be fixed as traffic RB changes. The density should be able to be flexibly configured within each UE’s scheduled bandwidth. The detailed density is FFS.*
- ***Proposal 4:** Whether PN RS should be specifically designed and mapped independent of DMRS and CSI-RS, depends on the density of DMRS and/or CSI-RS in both time and frequency domains could or could not satisfy the requirement of phase noise tracking. If the DMRS and/or CSI-RS cannot satisfy the requirement, additional RS for phase noise tracking should be defined.*

From figures 11 - 12 it can be also seen that for QPSK case (i.e., MCS=1), the effect of ICI can be nearly neglected and therefore no matter how many RBs are adopted, the “error floor” phenomenon will not occur. However, for 64QAM case (i.e., MCS=28), it can be seen from figures 12 - 13 that the effect of “error floor” gradually starts to occur as RB increases for the reason that more subcarriers are presented to contribute to the ICI, which has more detrimental effect on higher modulation orders. Finally, it can be observed that larger SCS indeed helps to alleviate the effect of ICI and therefore can lower the error floor.

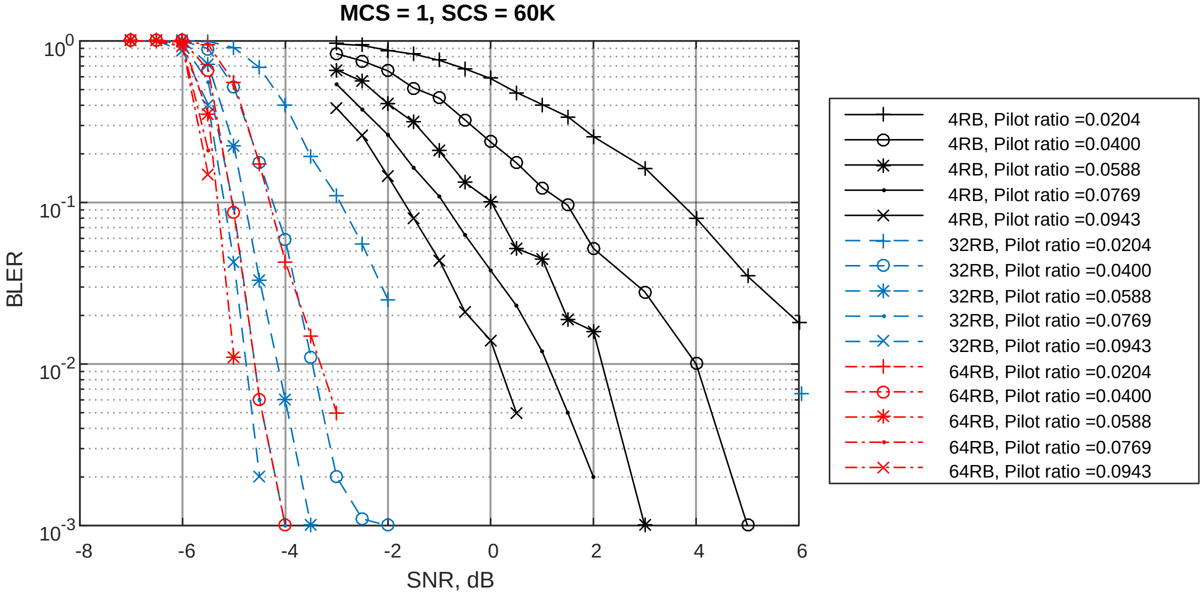

Fig.11. MCS = 1, SCS = 60K, different RBs and Pilot ratios

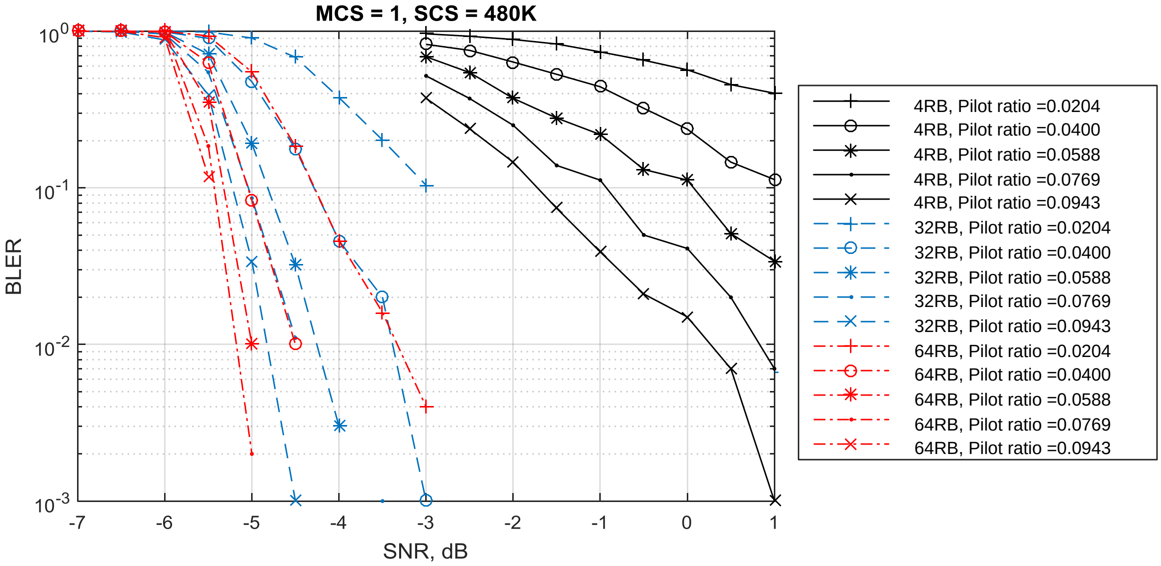

Fig.12. MCS = 1, SCS = 480K, different RBs and Pilot ratios

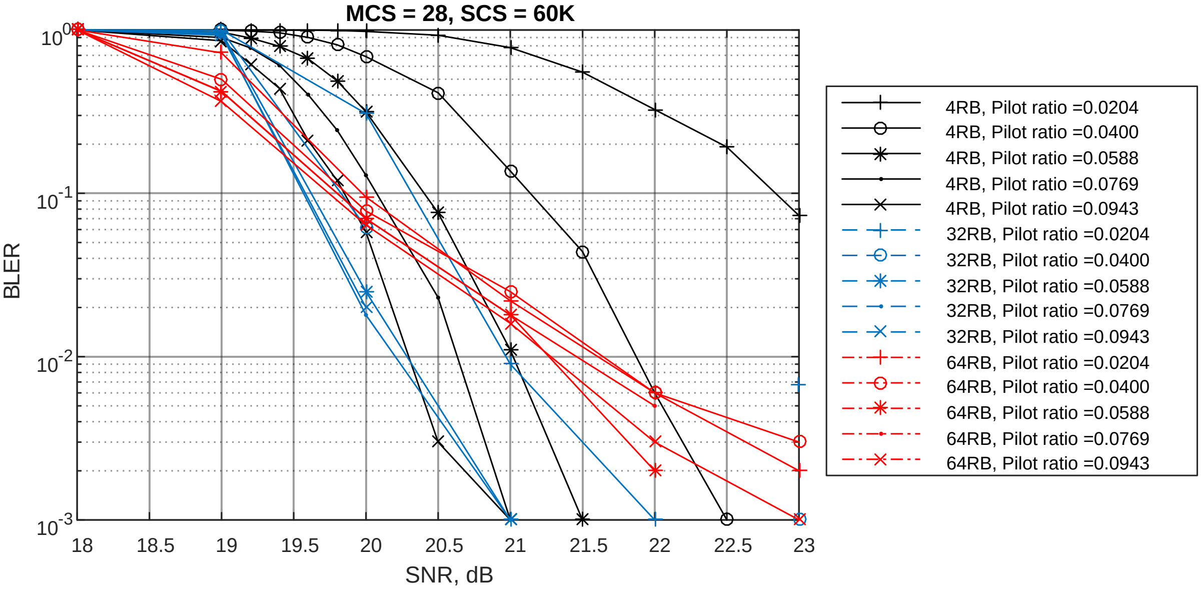

Fig.13. MCS = 28, SCS = 480K, different RBs and Pilot ratios

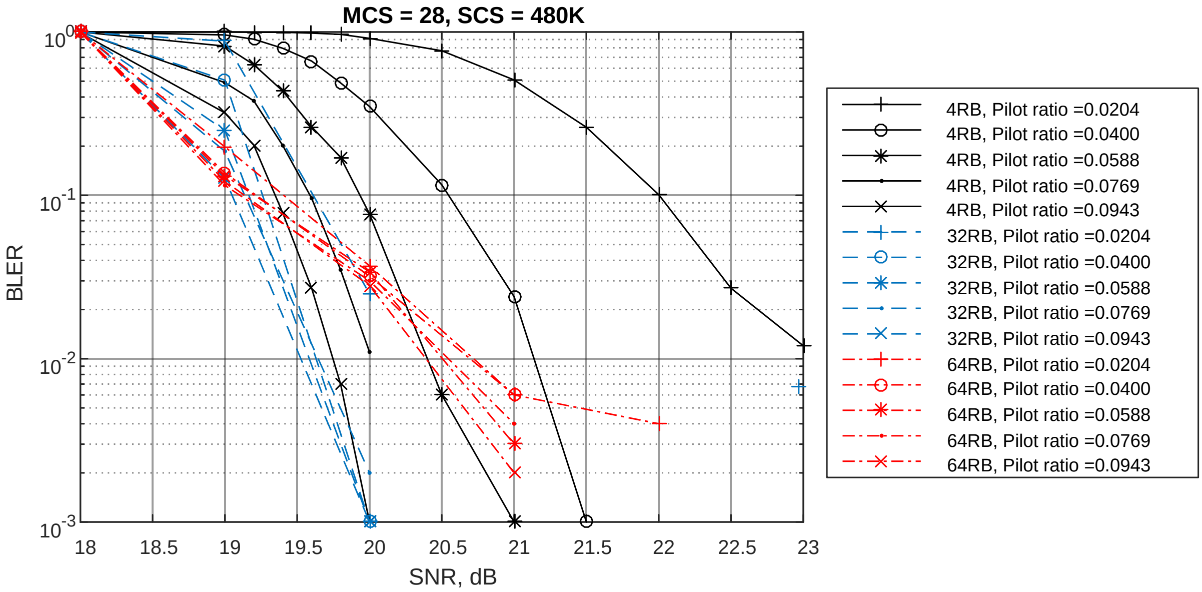

Fig.14. MCS = 28, SCS = 480K, different RBs and Pilot ratios

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4. Conclusions

In this contribution, CMCC’s views on phase noise reference signal design for high frequency systems are presented. The phase noise reference patterns in both time and frequency domains are analyzed. Through extensive simulation results, the following proposals are achieved:

- ***Proposal 1:*** *For NR high frequency systems, the PN RS should be continuous (i.e., on every OFDM symbol) in the time domain to track PN.*
- ***Observation 1:*** *As can be observed from figures 3 - 10, there is about 0.2dB – 0.8dB SNR gain for 120 KHz, 240KHz and 480KHz SCS cases compared to the 60KHz SCS case, especially when high MCS, e.g., MSC=28, is adopted.*
- ***Proposal 2:*** *SCS Larger than 60KHz should be supported if high MCS is to be supported in NR high frequency systems.*
- ***Observation 2:*** *For a given BLER target, the needed pilot ratio is smaller for larger number of RBs.*
- ***Proposal 3:*** *The density or spacing of PN RS in frequency domain needs not to be fixed as traffic RB changes. The density should be able to be flexibly configured within each UE’s scheduled bandwidth. The detailed density is FFS.*
- ***Proposal 4:*** *Whether PN RS should be specifically designed and mapped independent of DMRS and CSI-RS, depends on the density of DMRS and/or CSI-RS in both time and frequency domains could or could not satisfy the requirement of phase noise tracking. If the DMRS and/or CSI-RS cannot satisfy the requirement, additional RS for phase noise tracking should be defined.*

5. References

[1] 3GPP, R1-168347, “WF on additional RS for NR”, LG Electronics, Samsung, NTT DOCOMO, RAN1#86, Aug. 2016.

[2] 3GPP, R1-1610524, “ WF on NR RS definition”, Huawei, HiSilicon, RAN1#86bis, Oct. 2016.

[3] 3GPP, R1-1610514, “WF on Reference Signal for Demodulation”, ZTE Corporation, ZTE Microelectronics, RAN1#86bis, Oct. 2016.

[4] 3GPP, R1-1610747, “WF on RS for Phase Tracking for CP-OFDM”, Huawei, HiSilicon, LG Electronics, Samsung, *et al.*, RAN1#86bis, Oct. 2016.

[5] 3GPP, R1-1610458, “WF on Waveform for NR Uplink”, Qualcomm, Orange, OPPO, *et al.*, RAN1#86bis, Oct. 2016.

[6] D. Petrovic *et al.*, “Effects of phase noise on OFDM systems with and without PLL: characterization and compensation”, IEEE Trans. Commun., 55(8), pp. 1607–1616, Aug. 2007.

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[8] 3GPP, R1-1612187, “Phase noise modeling and reduction”, CMCC., RAN1#87, Nov. 2016.

[9] S. Wu and Y. Bar-Ness, “OFDM systems in the presence of phase noise: consequences and solutions”, IEEE Trans. Signal Process., 52(11), pp. 1988-1996, Nov. 2004.