3GPP TSG RAN WG1 NR Ad-Hoc Meeting **R1-1700438**
Spokane, USA, 16th - 20th January 2017

Source: **CMCC**
Title: **Phase-Tracking Reference Signal Design for High-Frequency Systems**
Agenda Item: **5.1.2.3.3**
Document for: **Discussion and Decision**

1. Introduction

In RAN1#87 meeting, the following agreements on phase-tracking reference signal (PT-RS) have been achieved (R1-1613553 [1]):

Agreements:

- RS for Phase tracking is denoted as PT-RS
  - FFS: Naming of RS
- PT-RS supports the following for CP-OFDM:
  - Time-domain density of mapped on every other symbol and/or every symbol and/or every 4-th symbol
    - FFS: Whether/how to down-select the time-domain density
    - Note: Other time-domain densities of PT-RS are not precluded
  - At least for UL
    - The presence of PT-RS is UE-specifically configured
      - FFS: Whether implicit and/or explicit UE-specific configuration is supported
    - PT-RS is confined in the scheduled time/frequency duration for a UE
  - FFS: UE-specific and/or non-UE-specific and/or cell-specific for DL
- The following are to be studied for PT-RS:
  - Number of PT-RS ports to be supported
  - Use of precoding
  - QCL relationship with other RS, e.g., DM-RS
  - Details on frequency domain pattern(s) and/or variable frequency domain densities
  - Whether PT-RS is necessary for DFT-s-OFDM waveform
  - Sharing of time/frequency resource between PT-RS among UEs and/or among layers of a single UE
  - Additional usage for estimating residual frequency offset and/or high-speed channel
  - Possible method(s) to improve phase estimation performance from PT-RS
    - E.g., using ZP/NZP PT-RS to reduce interference
  - Details of UE-specific configuration, e.g., associated with the scheduled MCS and/or BW, the number of scheduled layers, or use dedicated signaling
  - Others are not precluded

In this contribution, the time and frequency domain density for PT-RS is firstly investigated. Furthermore, frequency domain pattern for PT-RS is studied. Finally, some considerations on PT-RS design for different local oscillator (LO) configurations in high-frequency systems are given.

2. Time and frequency domain density for PT-RS

In order to investigate the PT-RS pattern in time and frequency domain, i.e., the density or spacing of PT-RS in both time and frequency domain, extensive simulations considering different traffic RBs, MCSs, SCSs and density of PT-RS in both time and frequency domain according to the following table 1 are conducted.

Table 1: Simulation Parameters

Carrier frequency	30GHz
Waveform	OFDM
Phase noise (PN) model	Proposed PN model in [2]
PT-RS time domain density	Every symbol, every other symbol, every 4-th symbol, every 9-th symbol
PN interpolation scheme in time domain	Linear interpolation
PT-RS frequency domain density	[0.0204,0.0400,0.0588,0.0769,0.0943]
PN compensation scheme in frequency domain	Only compensate CPE
TX/RX number	1 TX/1 RX
FFT size	2048
# of Traffic resource blocks (RBs)	4, 32, 64
Modulation and coding scheme (MCS) cases in LTE	QPSK：MCS 1 64QAM： MCS 28
Subcarrier spacing (SCS)	60, 480KHz
Channel coding	LTE Turbo, 1/3 rate
Channel model	AWGN

- **Investigation on PT-RS time domain density**

In this subsection, in order to only consider the effect of interpolation error in time domain on the system performance, the ideal CPE estimation is adopted. Whereas in the next subsection, CPE is estimated by using PT-RS in order to investigate the frequency domain density.

Figures 1-3 show the time domain interpolation results for the MCS=1, SCS=60 KHz and RB=4 case. It can be seen that compared to the continuous case (i.e., PT-RS is mapped on every symbol and no interpolation is needed), there is barely no performance loss when PT-RS is mapped on every other symbol or every 4-th symbol or even every 9-th symbol case. This is due to the fact that low-order MCS scheme such as QPSK is robust against phase noise compared to high-order MCS scheme such as 64QAM.

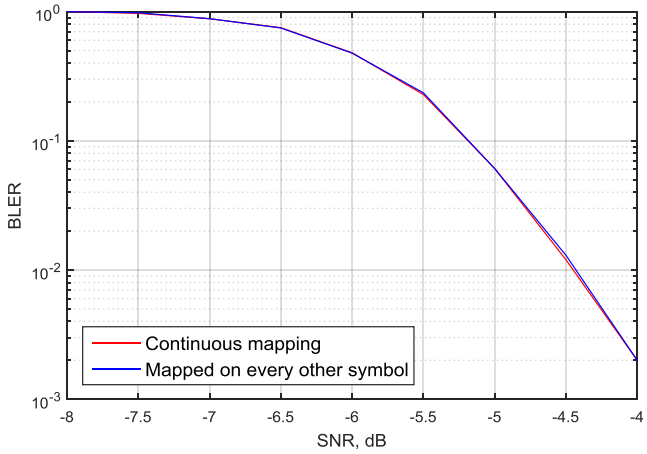

Fig.1. Comparison of continuous mapping and mapped on every other symbol in time domain

(MCS=1, SCS=60 KHz and RB=4)

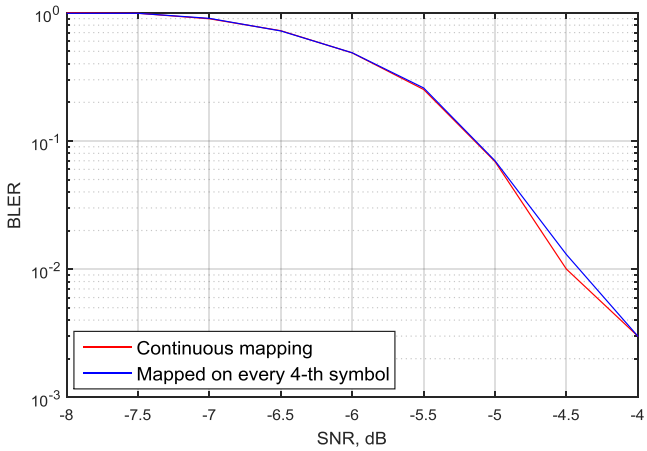

Fig.2. Comparison of continuous mapping and mapped on every 4-th symbol in time domain

(MCS=1, SCS=60 KHz and RB=4)

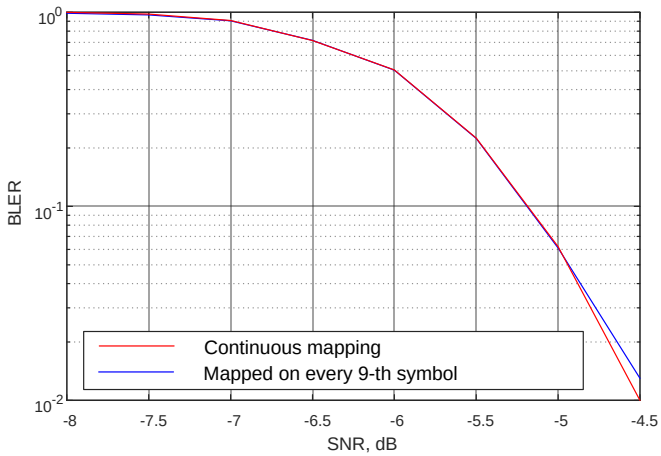

Fig.3. Comparison of continuous mapping and mapped on every 9-th symbol in time domain

(MCS=1, SCS=60 KHz and RB=4)

Figures 4-6 show the time domain interpolation results for the MCS=28, SCS=60 KHz and RB=64 case. It can be seen from these figures that obvious performance loss can be observed compared to figures 1-3. When PT-RS mapped on every other symbol case is adopted, there is about 1.5dB SNR loss compared to the continuous case. When PT-RS mapped on every 4-th symbol case is adopted, there is about 4.5dB SNR loss compared to the continuous case and furthermore, the error-floor phenomenon is observed in this case. Finally, even further SNR loss (more than 5dB) can be observed when PT-RS mapped on every 9-th symbol case is adopted, and the error-floor phenomenon is very obvious in this case.

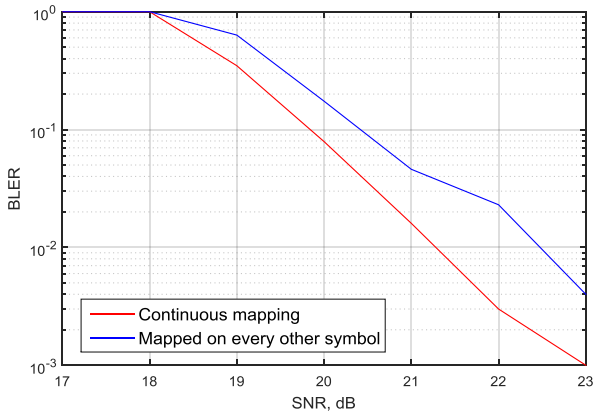

Fig.4. Comparison of continuous mapping and mapped on every other symbol in time domain (MCS=28, SCS=60 KHz and RB=64)

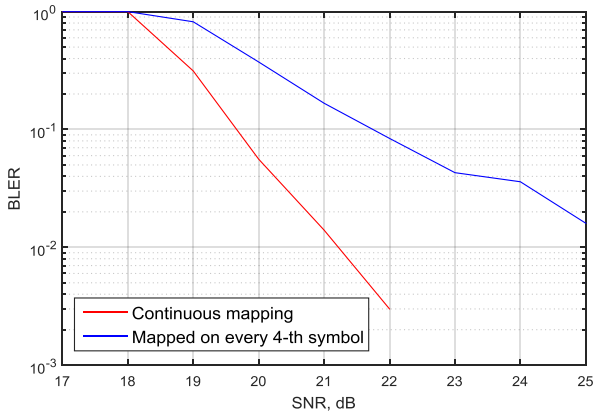

Fig.5. Comparison of continuous mapping and mapped on every 4-th symbol in time domain (MCS=28, SCS=60 KHz and RB=64)

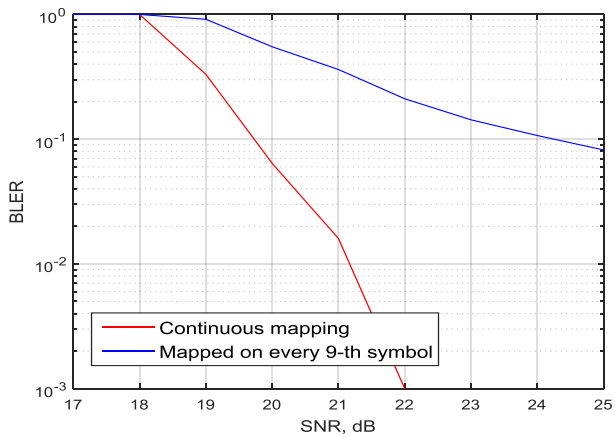

Fig.6. Comparison of continuous mapping and mapped on every 9-th symbol in time domain

(MCS=28, SCS=60 KHz and RB=64)

In summary, from figures 1- 6 it can be seen that the PT-RS density in time domain should be able to be flexibly configured. For example, low time-domain PT-RS density such as mapped on every other or every fourth symbol is enough to guarantee the performance of the low MCS case such as QPSK, whereas continuous PT-RS mapping is suggested for high MCS case such as 64QAM or higher.

● Investigation on PT-RS frequency domain density

In this subsection, different PT-RS density in the frequency domain is configured to estimated CPE. From figures 7 and 8 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" is better than that of all pilot ratios for 4RB case. Another example is that the performance of "64RB, Pilot ratio = 0.0204" is almost the same as that of the case "32RB, Pilot ratio = 0.0504". Similar results can also be observed from figures 9 and 10 for high MCS case. This indicates that in order to achieve the same performance, the density or spacing of PT-RS in frequency domain *needs not* to be fixed as traffic RB changes. The frequency domain density should be able to be flexibly configured within each UE's scheduled bandwidth.

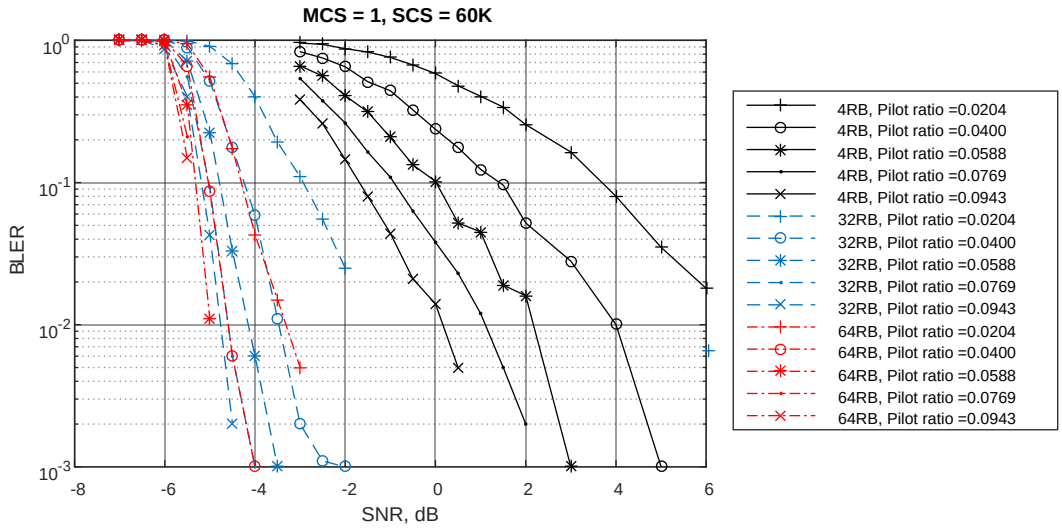

Fig.7. MCS = 1, SCS = 60K, different RBs and Pilot ratios

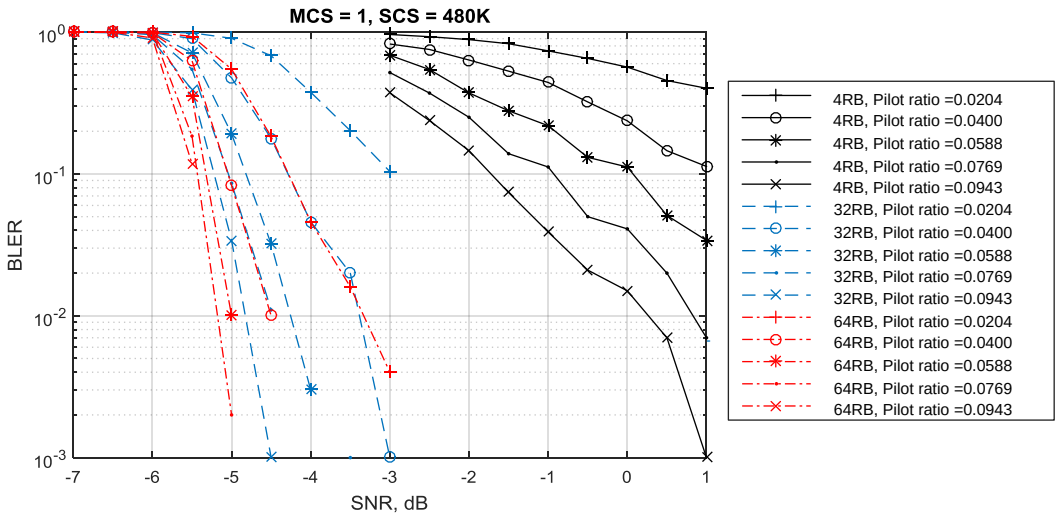

Fig.8. MCS = 1, SCS = 480K, different RBs and Pilot ratios

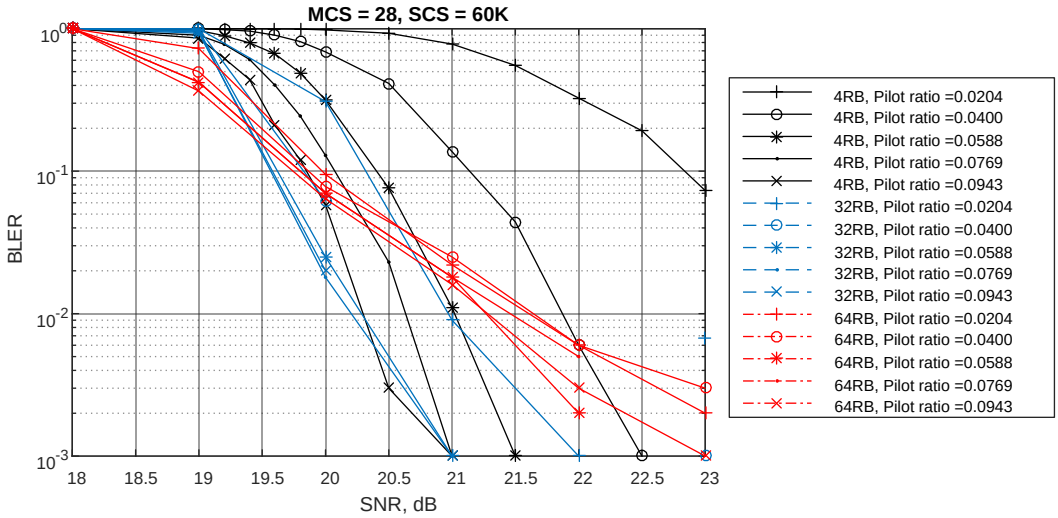

Fig.9. MCS = 28, SCS = 60K, different RBs and Pilot ratios

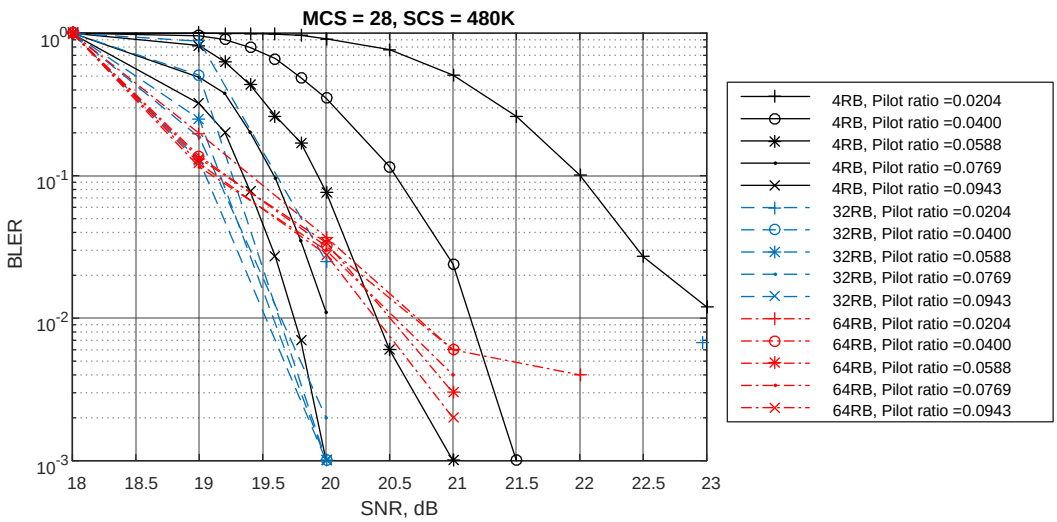

Fig.10. MCS = 28, SCS = 480K, different RBs and Pilot ratios

From figures 7 - 8 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 9 - 10 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.

- ***Proposal 1:*** *The PT-RS density in both time and frequency domains should be able to be flexibly configured. The time-and-frequency-domains density configuration for PT-RS is directly related to the phase noise level (i.e., phase noise model) and/or modulation and coding scheme and/or subcarrier spacing and/or scheduled resource block and/or waveform.*
    - *Larger phase noise level implies denser PT-RS*
    - *Higher MCS implies denser PT-RS*
    - *Larger SCS implies sparser PT-RS*
    - *Larger scheduled RBs implies sparser PT-RS*
    - *FFS the impact of PT-RS on DFT-S-OFDM waveform*

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3. Frequency domain patterns for PT-RS

The effect of PN on OFDM-based systems is its induced common phase error (CPE) and inter-carrier interference (ICI) [3]. The received signal on the *k*-th subcarrier affected by PN can be expressed by:

$$R_k = \underbrace{X_k H_k}_{\text{Channel frequency response}} \underbrace{J_0}_{\text{CPE}} + \underbrace{\sum_{l=0, l\neq k}^{N-1} X_l H_l J_{k-l}}_{\text{ICI}} + \eta_k \tag{1}$$

$$J_i = \frac{1}{N} \sum_{n=0}^{N-1} e^{j\phi_n} \, e^{-j2\pi ni/N} \tag{2}$$

It can be seen from equations (1) and (2) that the CPE is a constant within each OFDM symbol irrespective of the subcarrier index *k*. This is a significant difference from the channel frequency response. From equation (1) it can be observed that the channel frequency response is directly related to the subcarrier index *k*, which means that the channel frequency response is frequency selective. This feature of the wireless channel requires that DMRS or CSI-RS should be somehow equally placed across the whole scheduled bandwidth in the frequency domain in order to obtain some critical samples of channel frequency response, which are then used to interpolate the whole channel frequency response within that symbol.

Due to the fact that the CPE is a constant within each OFDM symbol irrespective of the subcarrier index *k*, which means that the PT-RS is not required to be equally placed in the frequency domain as DMRS or CSI-RS whose function is to obtain the channel information, two frequency domain patterns for PT-RS are proposed as follows:

- **Frequency Domain Pattern 1: The PT-RS is placed in the middle of the scheduled bandwidth.**

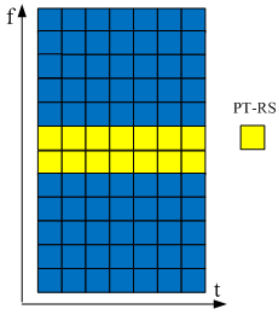


Fig.11. Proposed frequency domain pattern 1: the PT-RS is placed in the middle of the scheduled bandwidth (In this figure, PT-RS mapped continuously in the time domain is just adopted as an example. Non-continuous mapping in the time domain can be adopted as discussed in Section 2)

➢ This PT-RS pattern can protect PT-RS from other UE's interference.

- **Frequency Domain Pattern 2: The PT-RS is placed at the edge of the scheduled bandwidth.**

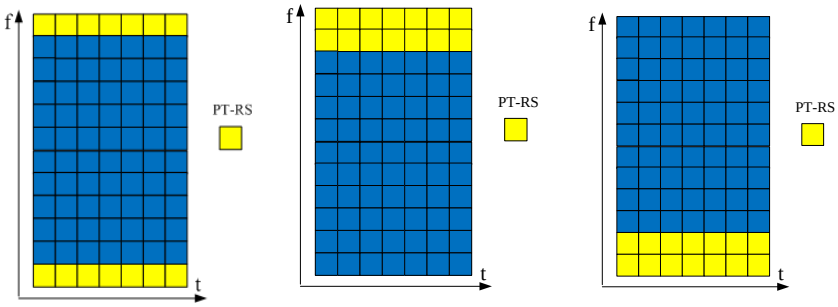
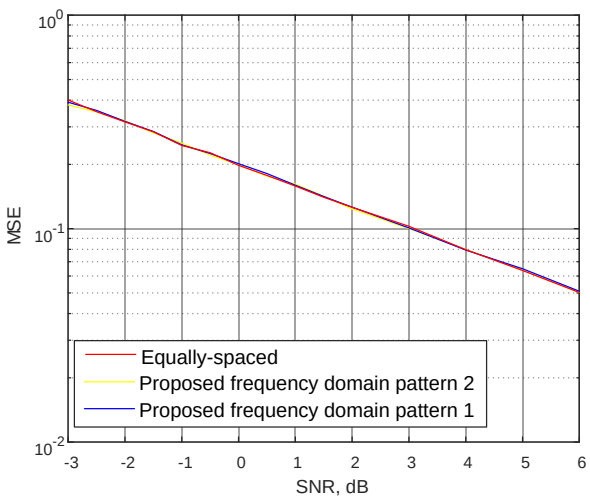


Fig.12. Proposed frequency domain pattern 2: the PT-RS is placed at the edge of the scheduled bandwidth (In this figure, PT-RS mapped continuously in the time domain is just adopted as an example. Non-continuous mapping in the time domain can be adopted as discussed in Section 2)

➢ This PT-RS pattern can protect data (i.e., RE is blue color) from other UE's interference.



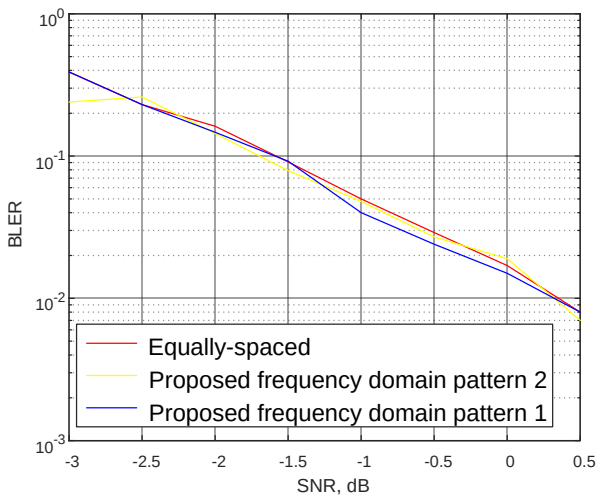


Fig.13. Comparison among equally-spaced, proposed pattern1 and proposed pattern 2 in frequency domain (MCS=1, SCS = 60KHz, RB=4)

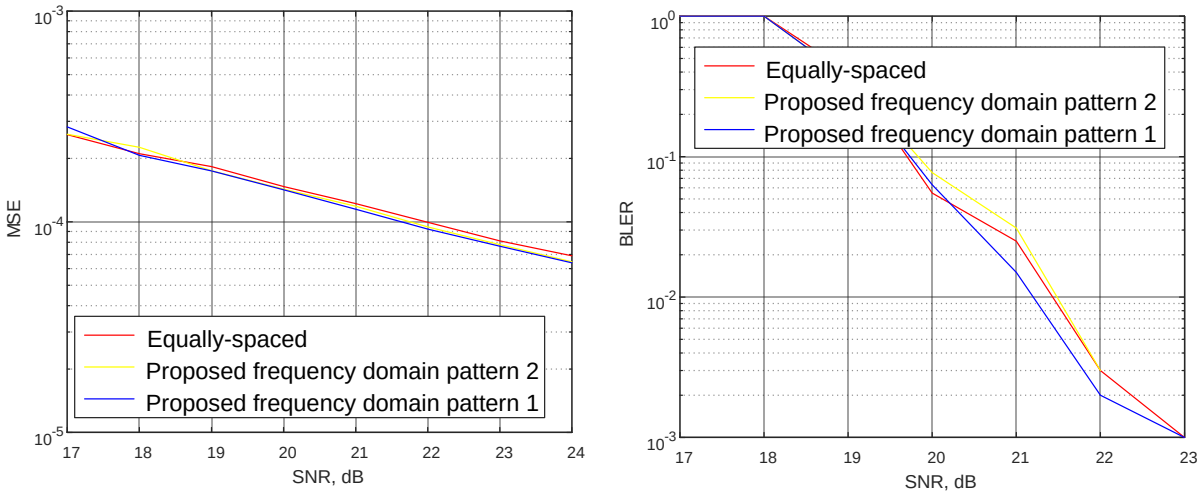


Fig.14. Comparison among equally-spaced, proposed pattern1 and proposed pattern 2 in frequency domain (MCS=28, SCS = 60KHz, RB=64)

Simulation results are given in figures 13 -14 to compare the performance of the proposed two frequency domain patterns with that of the regular equally-spaced pattern in the frequency domain for different system configurations. It can be seen that there is barely no performance differnece among these three patterns. Therefore, in order to protect PT-RS or data from other UE's interference, the PT-RS placed in the middle of the scheduled bandwidth or the PT-RS placed at the edge of the scheduled bandwidth should be considered as candidate scheme for PT-RS frequency domain pattern.

- ***Proposal 2*****:** *The two proposed frequency domain patterns for PT-RS, i.e., the PT-RS is placed in the middle of the scheduled bandwidth or the PT-RS is placed at the edge of the scheduled bandwidth, should be considered as candidate schemes for PT-RS frequency domain pattern.*

4. Considerations on PT-RS design for different local oscillator (LO) configurations in high-frequency systems

For high frequency systems, massive MIMO is adopted to perform beamforming in order to compensate for the higher path loss [4]. Hybrid RF/analog + digital beamforming instead of full digital beamforming is proposed in high frequency bands, both at the base station and UE side, as a promising and practical architecture for optimal tradeoff between cost and performance [5]. However, both hybrid and full digital architecture require multiple RF channels, and different LO configurations that are adopted to complete up/down frequency conversion in different scenarios may affect the PT-RS design.

There are generally three LO configurations for high-frequency systems:

i) A single high-frequency LO signal is generated centrally and distribute it throughout all the RF channels/antenna elements/panels;

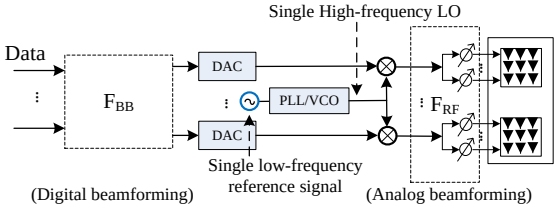


Fig.15. LO configuration i)

ii) All the RF channels/antenna elements/panels share one single low-frequency reference signal and separate PLLs + VCOs are used to independently generated high-frequency LO signals for each RF channel/antenna elements/panels;

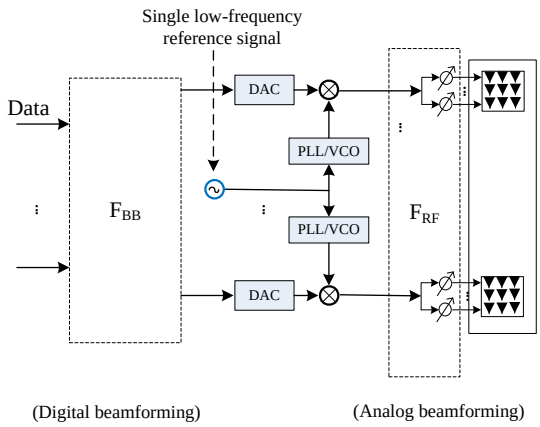


Fig.16. LO configuration ii)

iii) Each RF channel/antenna element/panel uses its own low-frequency reference signal + PLL + VCO to generate its own high-frequency LO signal.

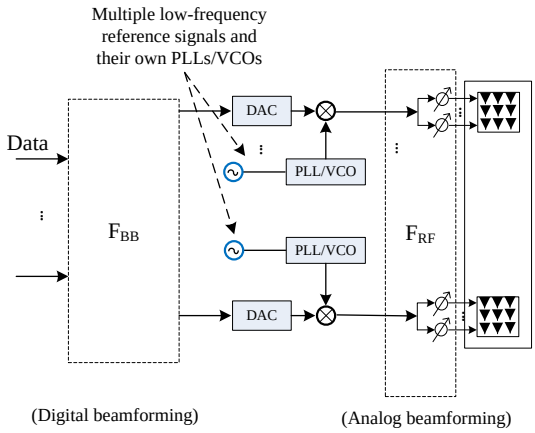


Fig.17. LO configuration iii)

Different phase noise characteristics may appear for the above LO configurations. For example, there may exist some kind of correlations among phase noise in different beams for the above case ii) LO configuration, which may be used to devise genie phase noise estimation and compensation schemes. Consequently, different PT-RS design may be configured for different LO configurations to take advantages of such phase noise characteristics.

- ***Proposal 3:*** *Further Investigate whether different LO configurations that are adopted for high frequency systems in different scenarios may affect the PT-RS design.*

5. Conclusions

In this contribution, CMCC's consideration of PT-RS design for high frequency systems is presented. The following proposals are achieved:

- ***Proposal 1:*** *The PT-RS density in both time and frequency domains should be able to be flexibly configured. The time-and-frequency-domains density configuration for PT-RS is directly related to the phase noise level (i.e., phase noise model) and/or modulation and coding scheme and/or subcarrier spacing and/or scheduled resource block and/or waveform.*
    - *Larger phase noise level implies denser PT-RS*
    - *Higher MCS implies denser PT-RS*
    - *Larger SCS implies sparser PT-RS*
    - *Larger scheduled RBs implies sparser PT-RS*
    - *FFS the impact of PT-RS on DFT-S-OFDM waveform*
- ***Proposal 2*****:** *The two proposed frequency domain patterns for PT-RS, i.e., the PT-RS is placed in the middle of the scheduled bandwidth or the PT-RS is placed at the edge of the scheduled bandwidth, should be considered as candidate schemes for PT-RS frequency domain pattern.*
- ***Proposal 3:*** *Further Investigate whether different LO configurations that are adopted for high frequency systems in different scenarios may affect the PT-RS design.*

6. References

[1] 3GPP, R1-1613553, "WF on RS for Phase Tracking", Huawei, HiSilicon, Intel, National Instruments, etc., RAN1#87, Nov. 2016.

[2] 3GPP, R1-1612187, "Phase Noise Modeling and Reduction", CMCC, RAN1#87, Nov. 2016.

[3] 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.

[4] TR38.913, "Study on scenarios and requirements for next generation access technologies (Release 14)", V0.3.0, Mar. 2016.

[5] R1-164893, "Hybrid beamforming for massive MIMO", CMCC, RAN1#85, May 2016.