

Source: CMCC
Title: Phase-tracking reference signal for DFT-s-OFDM systems
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1. Introduction

In the last RAN1#88bis meeting, the following working assumption on phase-tracking reference signal (PT-RS) for DFT-s-OFDM has been achieved [1]:

Working assumption:

- Uplink PTRS for DFT-s-OFDM waveform is supported.
 - Presence of PTRS for DFT-s-OFDM is UE-specifically configurable
 - FFS: Pattern/density of PTRS for DFT-s-OFDM is UE-specifically configurable or not

In RAN1#87 ad hoc meeting, the following agreements have been achieved regarding the PT-RS for DFT-s-OFDM in the uplink [2]:

Agreements:

- NR considers frequency offset and PN compensation for DFT-s-OFDM
 - FFS the exact method (e.g. pre-DFT /post-DFT insertion of PT-RS, blind detection, DM-RS)
 - Consider receiver complexity, PAPR, modulation order to be supported, etc

In this contribution, PT-RS design for UL DFT-s-OFDM in high-frequency systems is investigated.

2. Considerations of PT-RS for NR uplink DFT-s-OFDM in high-frequency systems

● On the need of PT-RS for DFT-s-OFDM

As shown in Fig.1, DFT-s-OFDM is essentially a DFT-precoded OFDM scheme and is known to have smaller PAPR than CP-OFDM [3]. However, similar to CP-OFDM, DFT-s-OFDM is also sensitive to phase noise and carrier frequency offset (due to imperfect TX and RX RF front-ends), both of which will cause ICI [4]. Phase noise occurs in frequency synthesizer in both the receiver and transmitter, which breaks orthogonality. Carrier frequency offset is generated by difference of frequency oscillator and Doppler effect.

In LTE, the uplink modulation scheme for up to 256QAM is supported. In 5G NR, it is believed that at least the same capability should be supported. High modulation schemes such as 64QAM and 256QAM are very sensitive to phase noise especially in high frequency systems, for both CP-OFDM and DFT-s-OFDM. Therefore, it is suggested that PT-RS is needed in NR uplink for compensation of phase noise at least for high modulation scheme. For low-order modulation scheme such as QPSK, PT-RS may not be needed, i.e., UL DMRS could be sufficient for phase noise compensation.

In summary, it is suggested that on-demand PT-RS should be supported for NR uplink. Whether PT-RS is needed, and the time-and-frequency-domains density should be related to the phase noise level (i.e., phase noise model) and/or MCS and/or subcarrier spacing and/or scheduled resource block and/or waveform and/or UE category, etc.

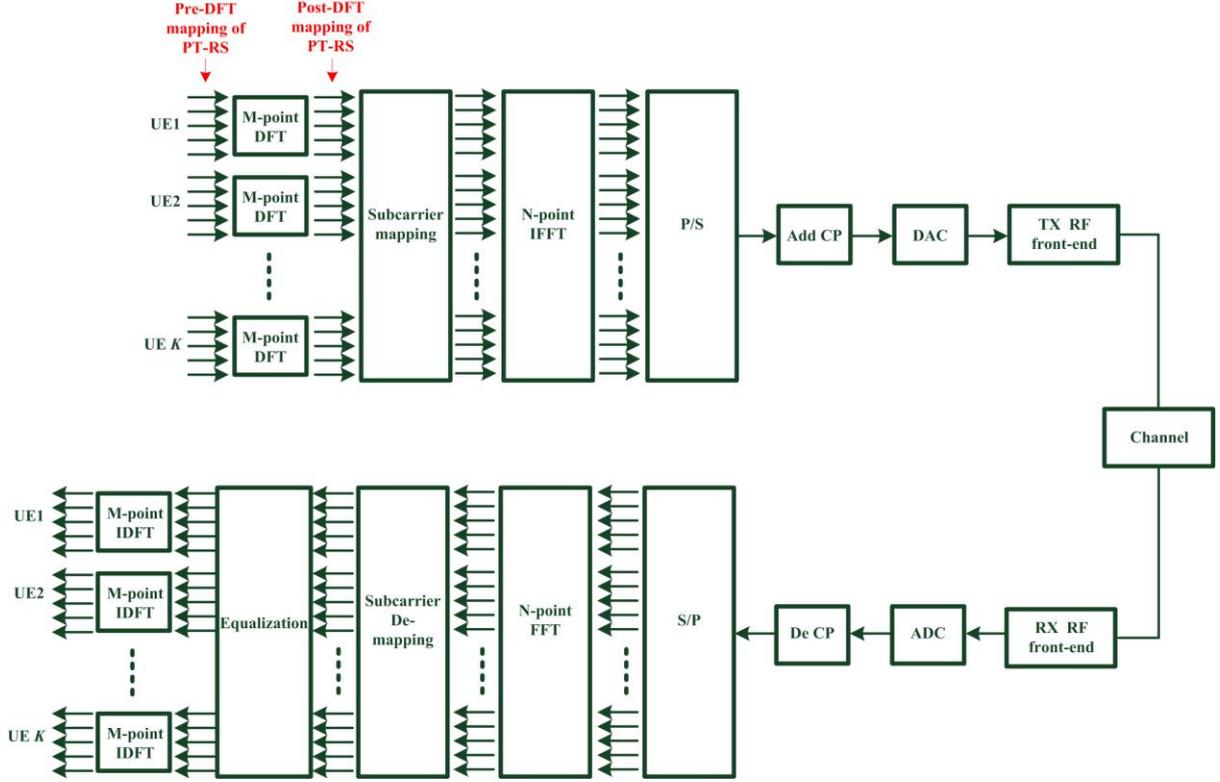


Fig. 1. DFT-s-OFDM system

- **Proposal 1:** For NR uplink DFT-s-OFDM systems, it is suggested that on-demand PT-RS should be supported. Whether PT-RS is needed, and the time-and-frequency-domains density should be related to the phase noise level (i.e., phase noise model) and/or MCS and/or subcarrier spacing and/or scheduled resource block and/or waveform and/or UE category, etc.

● Pre-DFT or Post-DFT mapping of PT-RS in DFT-s-OFDM

The effect of phase noise on DFT-s-OFDM, after the N-point FFT at the receiver and for the k^{th} subcarrier, can be expressed as:

$$R_k = X_k H_k J_0 + \sum_{\substack{l=0 \\ l \neq k}}^{N-1} X_l H_l J_{k-l} + Z_k = C_k + I_k + Z_k \quad (1)$$

The expression (1) is in fact the same as the effect of phase noise on CP-OFDM, except that in CP-OFDM X_k is directly the modulated constellation symbol whereas in DFT-s-OFDM X_k is M-point DFT spread symbol ($M < N$). As can be observed that, the common phase error (CPE), J_0 , also occurs in DFT-s-OFDM. The purpose of PT-RS is to estimate this CPE.

From the view point of estimation, CPE can be estimated before the M-point IDFT (i.e., Post-DFT mapping of PT-RS at the transmitter) or after the M-point IDFT (i.e., Pre-DFT mapping at the transmitter) at the receiver in Fig. 1. The pros and cons of pre-DFT and post-DFT mapping of PT-RS are summarized as follows, respectively:

- ✧ Pre-DFT mapping of PT-RS:
 - Pros: Low PAPR
 - Cons: Data is mixed with PT-RS after DFT spreading, which complicates the equalization

because phase noise estimation must be accomplished after the M-point IDFT, and therefore joint channel and phase noise estimation cannot be done only after the N-point FFT at the receiver.

✧ Post-DFT mapping of PT-RS:

- Pros: In accordance with CP-OFDM design, allowing for the same uplink processing for both CP-OFDM and DFT-s-OFDM, which means that data and RS are FDM before the N-point IFFT at the transmitter, and for the receiver all necessary estimation and compensation processes can be accomplished only after the N-point FFT.
- Cons: High PAPR

The main reason that DFT-s-OFDM is adopted as the uplink air-interface technique over CP-OFDM in LTE is because of its low PAPR which relieves the problem of high power back-off requirement prevalent in CP-OFDM systems. And it is for the same reason that DFT-s-OFDM should be adopted as the uplink air-interface technique in 5G NR.

In 5G NR, especially for high-frequency systems over 6 GHz, the transmit power is much more limited than its low-frequency counterpart below 6 GHz because of the Current Collapse Effect in high-frequency components [5]. Therefore, PAPR of NR uplink should be made as low as possible to maximize the uplink transmit power of NR high-frequency systems, in order to extend its power-limited coverage.

In summary, considering that low PAPR is the main objective that all uplink designs should be complied with and strive to achieve, especially for high-frequency systems, pre-DFT mapping of PT-RS is preferred in NR uplink high-frequency systems.

- **Proposal 2:** Pre-DFT mapping of PT-RS is preferred for uplink DFT-s-OFDM in NR high-frequency systems.

● **Multi-user mapping for DFT-s-OFDM systems in the presence of phase noise**

Subcarriers can be allocated to multi-users in various ways. In NR, there are two possible allocation schemes, i.e., interleaved and localized. As shown in Fig.2, for interleaved subcarrier mapping, the subcarriers for each user are mapped equally-spaced apart, whereas for localized subcarrier mapping the subcarriers for each user are assigned to contiguous frequency bands. It is known that interleaved DFT-s-OFDM outperforms localized counterpart under ideal conditions by exploiting frequency diversity. However, in the presence of phase noise, quite opposite result will occur.

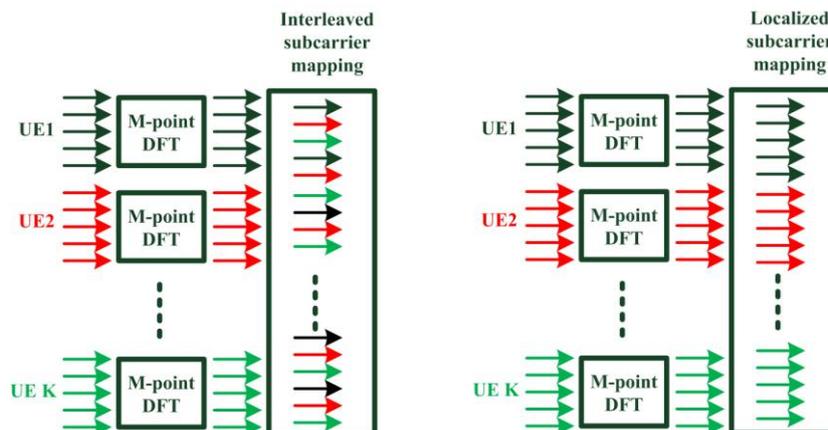


Fig. 2. Interleaved and localized mapping scheme

Assuming linear receiver, such as LMMSE, is adopted at the receiver. Then for a DFT-s-OFDM system in the presence of phase noise with multiple users, the received signal after equalization and M-point IDFT can be expressed as (for expressional simplicity, only the names for the according terms are given):

$$\begin{aligned}
 \text{The equalized data after M-point IDFT for UE } k &= \text{The originally transmitted data for UE } k \text{ rotated by CPE} \\
 &+ \text{The self interference caused by equalization} + \text{The self interference caused by phase noise} \\
 &+ \text{The multi-user interference caused by phase noise} + \text{AWGN}
 \end{aligned} \tag{2}$$

The performance difference between interleaved and localized mapping in DFT-s-OFDM arises primarily because of the difference in the variance of multi-user interference caused by phase noise in equation (2), as shown in Fig. 3. It can be seen that the variance for interleaved case of multi-user interference caused by phase noise dominates all other interferences. Therefore, the localized subcarrier mapping is more immune to phase noise and carrier frequency offset than the interleaved subcarrier mapping.

- **Proposal 3:** Localized mapping is preferred for multi-user uplink DFT-s-OFDM in NR high-frequency systems.

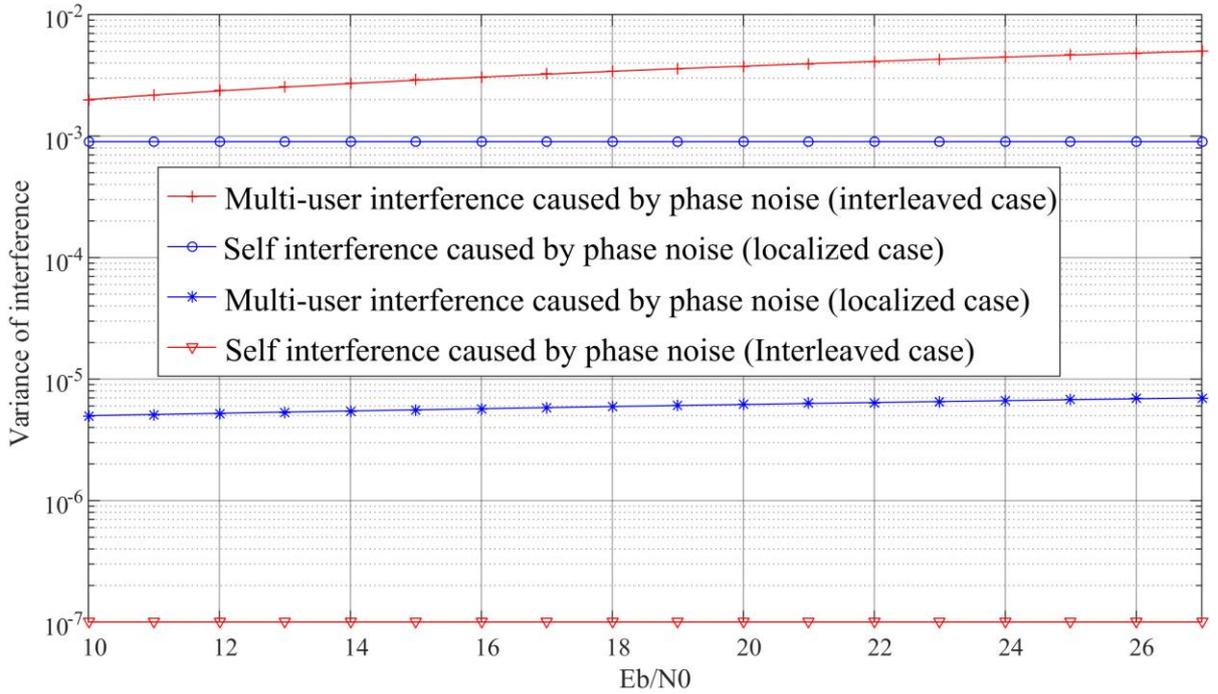


Fig. 3. The variance of multi-user and self interference for interleaved and localized subcarrier mapping

● UL MU-MIMO case

As shown in Fig. 4, each UE has its own local oscillator (LO), and the LOs among UEs are basically independent from each other. Therefore, the baseline for PT-RS design in UL-MIMO case is that there should be at least one PT-RS port for each UE if only a single LO is adopted in each UE. It is noted that each PTRS port aims to estimate the phase variation incurred by an independent LO of each UE. Since there is no correlation among these LOs, these PT-RS ports among UEs cannot share their information at the BS side.

Therefore, basically speaking, one PT-RS port's information cannot be used to help estimating or understanding any other PT-RS ports from the point of view of BS, even if BS can receive all these uplink PT-RS ports. In summary, since one PT-RS port is seen as interference to any other PT-RS ports, they should be orthogonal to avoid interference.

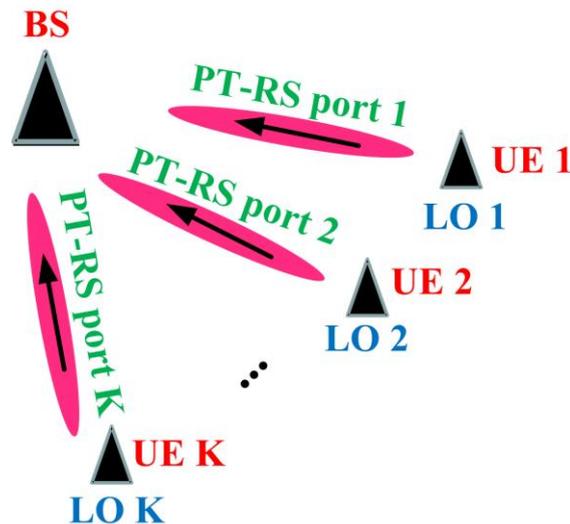


Fig. 4. UL MU-MIMO case

However, there may be some special cases that the orthogonal rule may be not complied with. For example, these scheduled UEs have difference channel quality and therefore, difference MCS level may be scheduled for each UE. For low MCS UEs who use BPSK or QPSK, PT-RS may not be needed or they can endure more interference level than high MCS UEs who use 64QAM or higher. Therefore, high MCS UE may use the corresponding REs for PT-RS of low MCS UE to transmit data to increase the throughput.

- **Proposal 4:** Support orthogonal PTRS ports multiplexing among UL MU-MIMO UEs. Non-orthogonal PTRS ports multiplexing among UL MU-MIMO UEs is FFS.

3. Conclusions

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

- **Proposal 1:** For the uplink DFT-s-OFDM systems, it is suggested that on-demand PT-RS should be supported. Whether PT-RS is needed, and the time-and-frequency-domains density should be related to the phase noise level (i.e., phase noise model) and/or MCS and/or subcarrier spacing and/or scheduled resource block and/or waveform and/or UE category, etc.
- **Proposal 2:** Pre-DFT mapping of PT-RS is preferred for uplink DFT-s-OFDM in NR high-frequency systems.
- **Proposal 3:** Localized mapping is preferred for multi-user uplink DFT-s-OFDM in NR high-frequency systems.
- **Proposal 4:** Support orthogonal PTRS ports multiplexing among UL MU-MIMO UEs. Non-orthogonal PTRS ports multiplexing among UL MU-MIMO UEs is FFS.

4. References

- [1] 3GPP, R1-1706328, “WF on PTRS for DFT-S-OFDM”, WF on PTRS for DFT-S-OFDM, etc., RAN WG1 Meeting #88bis, April 2017.
- [2] Chairman's Notes RAN1#87 ad hoc meeting, 3GPP TSG RAN WG1 Meeting #87, Spokane, USA, January 16th-20th, 2016.
- [3] Hyung G. Myung *et al.*, “Single carrier FDMA for uplink wireless transmission”, IEEE Trans. Veh. Tech. Mag., 1(3), pp. 30–38, Feb. 2006.
- [4] Basuki.E.Priyanto *et al.*, “Assessing and modeling the effect of RF impairments on UTRA LTE uplink performance”, IEEE Veh. Tech. Conf., pp. 1213–1217, Oct. 2007.
- [5] R.Vetury et al., “The impact of surface states on the DC and RF characteristics of AlGaIn/GaN HFETs”, IEEE Trans. Electron Devices, 48(3), pp. 560–566, Mar. 2001.