# Positioning Reference Signal design for positioning via 5G

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**Abstract**

5G-NR New Radio (5G-NR) is destined to revolutionize the wireless communications as well as user wireless positioning. 5G-NR will be able to offer not only higher throughput and higher available frequency bands of operation, but also improved services, including enhanced Location Based Services. 5G systems will continue to use the Positioning Reference Signals (PRS) employed now in 4G systems, in order to enable positioning with non-synchronized Base Stations (BS) with an increased performance compared to 4G positioning. PRS are used to measure the delays of the downlink transmissions by correlating the received signal from the base station with a local replica in the receiver. In this paper, different PRS allocations within the 5G frame are analysed and compared in order to find if the PRS distribution affects the positioning performance, and, if this happens, which the best distribution is.

## 1 Introduction

Positioning using cellular networks such as 3G/UMTS (Universal Mobile Telecommunications System) or 4G/LTE (Long Term Evolution) has been already widely studied in literature [1]–[4]. However, the meter- or tens-of-meter-level accuracy provided by these systems has proven not to be enough for some applications, such as safety critical applications, autonomous driving, or aircraft positioning, where cm-level accuracy is needed [5]. One of the main targets in the design of the 5G New Radio (5G-NR) signals is to be able to improve the positioning capabilities offered by the previous systems. Studies such as [6], [7] show indeed that accuracy below 1 m can be reached using 5G. To achieve such accuracy, 5G-NR standard will include dedicated data and pilots (PRS or Positioning Reference Signal) for such a purpose. In addition, 5G-NR will most likely operate at higher frequencies than the current 4G systems, i.e., in the range of mm-Waves. This will allow using higher bandwidths and, in consequence, a higher number of dedicated resources for positioning will be available. PRS allocation within the DL (Downlink) frame is not yet completely defined in the 5G standards, although some proposed alternatives can be found in [8]–[10]. In this paper we analyse some of the proposed PRS allocations, by comparing the achieved positioning performance at different frequencies of operation. The goal is to find out if a certain PRS distribution can provide better positioning accuracy than other PRS distributions.

## 2 5G New Radio Downlink Transmission Schemes

5G-NR transmissions are more flexible than their predecessor technologies. 5G-NR signals can be transmitted using different numerology, which is summarized in Table 1. The numerology is parameterized using an index parameter $\mu$. In Table 1, $\Delta_f$ stands for sub-carrier spacing, $T_S$ for symbol duration, $T_{CP}$ for the Cyclic Prefix (CP) duration, $N_{Slot}^{Frame}$ for the number of slots per frame, and $T_{Slot}$ for the slot duration. The available Frequency Ranges (FR) for 5G-NR are also flexible. FR ranges can be divided in two, namely FR1 for frequencies below 6 GHz and FR2 for frequencies above 24 GHz. FR1 transmissions can use the parameters corresponding to $\mu$ equal to 0, 1, or 2, while FR2 transmissions can use the parameters corresponding to $\mu$ 2, 3 or 4. In this paper we have considered the frequencies 5 GHz, 28 GHz and 78 GHz, belonging to FR1, FR2, and FR2, respectively.

Table 1: Supported flexible transmission numerology in 5G-NR

| $\mu$ | $\Delta_f$ **(kHz)** | **FR1** | **FR2** | $T_S$ ($\mu s$) | $T_{CP}$ ($\mu s$) | $T_S + T_{CP}$ ($\mu s$) | $N_{Slot}^{Frame}$ | $T_{Slot}$ **(ms)** |
|---|---|---|---|---|---|---|---|---|
| 0 | 15 | ✓ | x | 66.67 | 4.69 | 71.35 | 10 | 1 |
| 1 | 30 | ✓ | x | 33.33 | 2.34 | 35.68 | 20 | 0.5 |
| 2 | 60 | ✓ | ✓ | 16.67 | 1.17 | 17.84 | 40 | 0.25 |
| 3 | 120 | x | ✓ | 8.33 | 0.57 | 8.92 | 80 | 0.125 |
| 4 | 240 | x | ✓ | 4.17 | 0.29 | 4.46 | 160 | 0.0625 |

## 3 Scenario Layout and Positioning Based on Positioning Reference Signals

The analysed scenario is depicted in Fig. 1. It consists of a set of 10 Base Stations (BS) and a single static receiver (Rx), both with omni-directional antennas. The BS are assumed to be distributed uniformly in a certain area surrounding the receiver, with a inter-Bs separation of 100 m. The BS height is uniformly distributed between 0 and 3 m. Regarding the channel model, QuaDRiGa [11] has been used as a simulation framework. The specific channel model it's been the 3GPP 38.901 (Indoor with Line of Sight (LoS) [12]. Line of Sight (LoS) is considered during the transmission. In addition, a path loss proportional to the 3D distance between BS-receiver and shadowing with an shadowing standard deviation of 3 dB is considered.

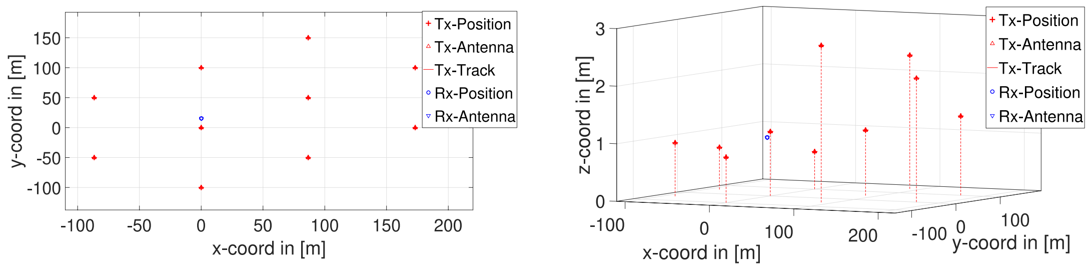


Fig. 1: Illustration of the deployed scenario: 2D layout (left) and 3D layout (Right) with 10 BS and 1 static receiver.

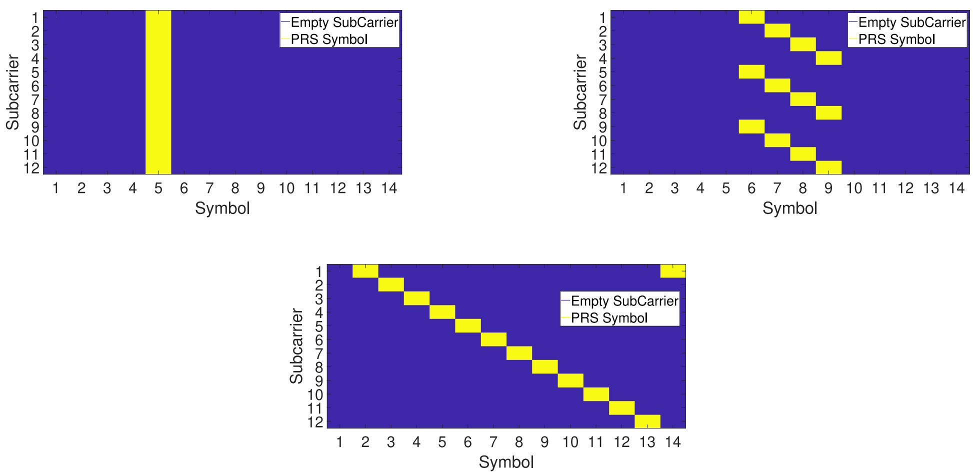


Fig. 2: PRS allocation used during the simulations. Top-left, top-right and bottom plots corresponds to comb 1, comb 4 and comb 12, respectively.

The PRS sequences in 5G will most likely be based on Gold sequences, as in LTE. These

PRS sequences are pseudo-random sequences that have good auto-correlation properties and small cross-correlations to ensure accurate timing measurements. PRS signals are sent in at least one symbol and one sub-carrier of a frame during a certain number of consecutive slots. The PRS allocation within a frame does not have yet an standard, but different proposals have been made so far, where the one most likely to be finally used is the so-called comb structure with configurable resource blocks allocation [8]–[10]. PRS symbols are interleaved (with a cyclic shift) or distributed uniformly along the different sub-carriers composing the OFDM signal. This configurable resource block allocation can be really beneficial for efficiency and high-performance channel and position estimation. Depending on the network conditions, such as congestion or environment conditions, the network could provide a higher order or a lower order of comb structure, which means a higher or lower density of PRS in each slot. Fig. 2 shows three examples of PRS allocation within a slot, composed by 14 symbols and 3300 sub-carriers (just showing 12 sub-carriers for simplicity). All PRS allocations contain the same number of PRS symbols (3300 per slot), but they differently distributed in comb 1, comb 4, abd comb 12 cases. The yellow colour corresponds to a sub-carrier containing an PRS symbol and the blue colour corresponds to an empty sub-carrier. No data other than PRS symbols is considered during the transmission, since the objective is to analyse the different PRS combinations. In addition, each BS has its own clock, so the transmissions are performed asynchronously.

## 4 Results and Conclusions

The results for all the considered scenarios are summarized in Table 2, after carrying out 1000 Monte Carlo simulations, each transmitting 5 ms of signal from the BS to the receiver. Three different frequency bands are considered, and for each $\Delta_f$ and PRS distributions are different, thus we analyzed 18 different scenarios, as given in Table 2. The last column of Table 2 shows the estimated position accuracy in terms of Root Mean Square Error in meters.

Table 2: Positioning accuracy results.

| f (GHz) | $\Delta_f$ (kHz) | Comb N | RMSE(m) |
|---|---|---|---|
| 5 | 15 | 1 | 4.60 |
| 5 | 15 | 4 | 4.52 |
| 5 | 15 | 12 | 5.34 |
| 5 | 60 | 1 | 1.79 |
| 5 | 60 | 4 | 5.60 |
| 5 | 60 | 12 | 2.04 |
| 28 | 60 | 1 | 1.84 |
| 28 | 60 | 4 | 2.15 |
| 28 | 60 | 12 | 1.99 |
| 28 | 240 | 1 | 0.68 |
| 28 | 240 | 4 | 0.78 |
| 28 | 240 | 12 | 0.69 |
| 78 | 60 | 1 | 2.32 |
| 78 | 60 | 4 | 2.12 |
| 78 | 60 | 12 | 1.92 |
| 78 | 240 | 1 | 0.67 |
| 78 | 240 | 4 | 0.76 |
| 78 | 240 | 12 | 0.68 |

By comparing the results among the different considered scenarios we have observed the followings:

- The best positioning accuracy was achieved with highest frequency of operation (i.e., 78 GHz) and with the highest sub-carrier spacing $\Delta_f$ (i.e., 240 kHz). Obviously the higher the $\Delta_f$ is, a larger number of slots are transmitted during the same period of time, which include a higher number of PRS symbols. Thus, when the correlation with the local replica is performed, a higher gain is achieved and the transmission delay can be estimated more accurately.

- Using FR2 mm-Wave, which means operation frequencies higher than 24 GHz, and carrier sub-spacings $\Delta_f$ between 60 kHz and 240 kHz, the achievable positioning accuracy is indeed below 1m as targeted by many 5G services. However, using FR1 (i.e., operation frequencies lower than 6 GHz and $\Delta_f$ between 15 kHz and 60 kHz), the accuracy is above 1 m and below 6 m (in few cases, it is close to 1 m).
- There is not a clear pattern for PRS allocation distribution in order to achieve a more precise positioning. Most likely, the PRS distribution does not affect the overall gain, especially if the number of PRS symbols is constant.

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