High-Accuracy Positioning in 5G-NR: Is carrier phase the answer?

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ABSTRACT

With the constant evolution of 5G new radio (NR), it is anticipated that positioning will be a fundamental feature demanded by most commercial applications. Location based services will demand tighten requirement with respect to positioning accuracy and latency. Recently, carrier phase-based positioning has gained a momentum to be a prime candidate for high-accuracy positioning in 5G-NR future releases. This paper presents a brief insight of the latest discussions and techniques utilizing carrier phase for positioning in future 5G-NR releases.

I. INTRODUCTION

The 5th Generation (5G) was designed to tackle three main applications, namely; massive machine type communication (MTC), enhanced mobile broadband (eMBB), and ultra-reliable low latency communications (URLLC). With the ubiquity of cellular communication, the connectivity paradigm is constantly evolving to tackle emerging use-cases of technologies such as the Internet of Things, autonomous vehicles and robots, and industrial controls. To tackle these uses cases, 5G is evolving to provide positioning services in areas where Global Navigation Satellite System (GNSS) signals are too weak, e.g. urban canyon, indoor environment, and tunnels. Due to this reason, the 3rd Partnership Project (3GPP) has introduced dedicated 5G new radio (NR) positioning support from Release-16 [1], [2] and is continuing to enhance these techniques as 5G-NR evolves.

The wireless positioning techniques can be categorized into two branches, namely; non-range-based technique [3], [4] and range-based technique [5]. The non-range-based technique relies on the fingerprints database of the wireless propagation environment or the connectivity between the wireless nodes. The range-based techniques have various methods including time of arrival (ToA), time difference of arrival (TDoA), angle of arrival (AoA) and angle of departure (AoD). A summary these method is shown in Fig. 1.

![Localization Techniques](image)

Fig. 1. Localization Techniques

This paper aims to give an insight into the latest high-accuracy positioning developments, specifically related to carrier phase-based positioning in 5G-NR.

II. HIGH-ACCURACY POSITIONING

The desired accuracy for positioning system depends on the use cases. The standardization bodies such as 3GPP analyze these use cases and define the requirements for positioning methods to be developed. The accuracy of the positioning system is enhanced for every new release. In the case of Release-16, the positioning system for commercial use case should have a horizontal accuracy of 3 m. Later, 3GPP further increased the accuracy to 20 cm in Release-17. Following the trend, future releases will have to handle a much higher level of accuracy requirements.

For high-accuracy positioning, precise range measurements are required. The accuracy of the positioning system depends on the bandwidth of the system and the resolution capabilities of the devices. For high-accuracy positioning, the measurements are based on the carrier phase and code phase Table I. In the code phase, the received signal is correlated with a different shifted versions of the transmitted pseudo-random noise (PRN) code. The PRN code which gives the maximum correlation is used to calculate the ToA for positioning. The accuracy of the code phase depends on each chip length and may not be accurate enough for use in 5G-NR.

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Typical Accuracy</th>
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<tbody>
<tr>
<td>Code Phase</td>
<td>Unambiguous</td>
<td>Low Accuracy</td>
<td>approx. 0.5 m</td>
</tr>
<tr>
<td>Carrier Phase</td>
<td>High Accuracy</td>
<td>Ambiguous</td>
<td>approx. 0.5 mm</td>
</tr>
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</table>

The other method for high-accuracy is the carrier phase. In the carrier phase, the detected phase of the carrier is used to get the ranging estimate. To get an accurate estimate of the position of the receiver, it has to estimate the fractional and integer part of the signal. At the receiver, the phase lock loop (PLL) can accurately capture the fractional part of the signal. The integer part is hard to capture and it translates into integer ambiguity. The integer ambiguity needs to be
precisely resolved. The following section briefly gives the latest techniques proposed to be used in 3GPP 5G-NR next releases.

III. CARRIER PHASE-BASED POSITIONING

The use of carrier phase-based positioning has been in use in GNSS. The GNSS has proven to be accurate for outdoor applications. The accuracy of GNSS deteriorates in urban canyon and indoor use cases. As an alternative, 5G-NR Release-16 and on-words have to introduce dedicated ranging signals to help achieve high accuracy positioning.

In 3GPP meeting number#101 [6], the use of the carrier phase positioning reference signal (C-PRS) is proposed. The C-PRS supports the ME to obtain the carrier phase measurements. The C-PRS can be a pure sinusoidal signal which can be pre-configured or pre-defined frequency. To avoid interference, the C-PRS would be cell-dependent. The advantage of C-PRS is has a very small bandwidth. Moreover, the sub-carrier spacing (SCS) between the C-PRS from different cells is very small. In addition to this, it has no overhead as the transmission of the C-PRS can be done at the edge of the carrier. The accuracy achieved by the carrier phase is in the cm range but it has several challenges. These challenges include timing misalignment, integer ambiguity, and synchronization between BS and ME. These challenges and their proposed solution are summarized in Table II.

<table>
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<tr>
<th>Challenges</th>
<th>Proposed Solution</th>
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<tr>
<td>Timing Misalignment</td>
<td>Adopting a continuous waveform for CP-OFDM.</td>
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<tr>
<td>Integer Ambiguity</td>
<td>Selecting a long wavelength for sub-carriers in 5G-NR.</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Modifying the BS architecture to support Master-Slave carrier phase synchronization.</td>
</tr>
</tbody>
</table>

In a recent 3GPP meeting number#104 [7], the challenges mentioned above are tackled. One of the possible solutions for timing misalignment, integer ambiguity, and synchronization is to use a continuous PRS sequence. Since in 5G-NR, the ME is synchronized with the serving BS only. Due to the radio propagation aliments, the BS signal may arrive with a delay to the ME. Due to this, the phase information may be distorted, resulting in estimation error. To avoid the phase estimate errors, the use of a continuous waveform is proposed. In cyclic prefix orthogonal frequency division multiplexing (CP-OFDM), a portion of the tail of the symbol is used as a CP. Due to this, the waveform is not continuous. By rotating the data by the length of the CP interval, the waveform can be made continuous. This will remove any misalignment resulting in perfect synchronization.

The integer ambiguity is another issue that needs to be addressed when using carrier phase positioning. The carrier phase can be extracted by a PLL. To get an accurate estimate of the true distance difference, the hidden number of the wave must be resolved. One of the possible ways to resolve the integer ambiguity is to use a frequency that results in a very long wavelength. For example, for the FR1 band and 30 KHz SCS, the length of one symbol is 10 km. Assuming 4096 FFT, the wavelength of the OFDM sub-carrier is from 3 m to 9 km subject to the sub-carrier number. When the sub-carrier of long wavelengths, such as one corresponding to 9 km, is used the ME position can be determined just by using the phase difference. Provided the distance between two BS is less than 9 km [7]. This results in a coarse estimate of the position due to poor angular resolution. To improve the angular resolution, the sub-carrier of a shorter wavelengths are used to refine the angular resolution. The integer ambiguity can be resolved by \( \left\lfloor \frac{\theta}{2\pi} \times (\text{subc}_1/\text{subc}_2) \right\rfloor \), where \( \theta \) is the angular phase difference, \( \text{subc}_1 \) is the wavelength measured using the longer sub-carrier and \( \text{subc}_2 \) is the wavelength measured using the shorter sub-carrier. Applying this procedure iteratively can achieve cm grade accuracy.

The BS synchronization also plays a very crucial role in obtaining a high accuracy positioning estimate. The BS should be precisely synchronized in sub-nanosecond variance or less than 1 carrier wavelength, to achieve cm grade accuracy. For this, 3GPP has proposed to change the BS architecture to attain precise clock synchronization. The BS will share their C-PRS with each other so that they can fine-tune the offset to better facilitate the positioning [7].

IV. CONCLUSION

This paper reviewed some of the proposed carrier phase-based positioning techniques to be included in the future revision of 5G-NR. Carrier phase-based positioning techniques can attain sub-meter and even cm grade accuracy. It has been used in GNSS, but lately has been introduced in 5G-NR for high accuracy positioning. As urbanization is increasing, need for accurate positioning techniques are required based on the current trend carrier phase positioning is a prime candidate to achieve cm grade accuracy.

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