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Navigation using Positioning Reference Signal in 6G Non -Terresterials-Newtorks (NTN)

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***Abstract*—6G NTN Non-Terrestrial Network is destined to revolutionize wireless communications and user wireless positioning. It promises not only higher throughput and broader frequency band operations but also enhanced services, including improved localization capabilities. It will also improve services, including enhanced localization services. While 6G systems will continue to evolve and serve different user markets, the 3GPPdefined NTN standard allows for the integration of non-terrestrial components into existing 5G systems, thereby expanding service coverage to underserved or unserved areas. Since Release 15, 3GPP has been defining and standardizing positioning solutions for terrestrial 5G networks to meet various requirements. Positioning signals, standardized by 3GPP, are already used in terrestrial 5G communication networks. With the introduction of non-terrestrial 5G communication networks in Release 17, 3GPP is now focusing on 6G cellular networks under Release 20. This paper reviews the state of 5G positioning and localization, highlights existing challenges, and proposes a signal derived from terrestrial networks for future localization in 6G NTN networks.**

Keywords—6G NTN, Navigation, Positioning, PRS, GNSS, satellites, 3GPP.

I. INTRODUCTION

Since the introduction of 5G positioning, non-terrestrial network (NTN)-based positioning has attracted significant interest due to its wide range of applications, including emergency services, lawful interception, and charging and tariff services. NTN is defined as a network that includes nonterresterial flying objects such as High Altitude Platform System (HAPS) air to groud networks and satellite communication network. Furthermore, there is growing interest in integrating satellite networks with 6G NTN, which offers advantages such as service continuity, scalability, and availability, all of which will help 5G systems meet their demanding use cases. Therfore, the analysis of navigation performance using 6G NTN communication is a very promising complementary alternative to Global Navigation Satellite System (GNSS). This paper will tackle localization and navigation using positioning reference signal in the future 6G satellites networks.

II. LOCALIZATION AND POSITIONING IN STANDARIZATION

A. Navigation and positioning objectives

Positioning of UE is critical for the operation of 6G NTN. Since the introduction of 3GPP Rel.17, NTN has attracted considerable interest due to many applications, including in emergency services. In the context of 6G, NTN design must account for precise positioning, utilizing single or multiple Low Earth Orbit (LEO) satellites for location and verification in scenarios where Global Navigation Satellite System (GNSS) signals are weak or unavailable In the context of 6G, NTN design shall consider explicit positioning using single or multiple LEO-satellites for location and verification purposes in scenarios where Global Navigation Satellite Systems (GNSS) signals be weak or unavailable. To this end, there are various positioning methods based on delay and Doppler measurements, e.g. TOA, TDOA, RTT or two-way TOA, and frequency-difference-of-arrival (FDOA) will be discussed. The choice of positioning method depends on the specific requirements of the system and the available resources. For example, delay-based methods such as TOA and RTT require high bandwidth to achieve high resolution. In addition, RTT requires bidirectional signalling, while TDOA requires downlink signalling, but features a worse dilution of precision (DOP). Ultimately, the accuracy of the positioning method depends on the system's specifications, and in some cases, it may be necessary to develop a new reference signal to achieve high navigation and positioning accuracy, particularly for critical use cases like emergency services[3] .

The actual 5G positioning procedure is that the UE has to search for a wideband Positioning Reference Signal within a certain research window in time. Considering the distance between the TRPs (Transmission Radio Point) in NTN, large relative distance will lead to larger search window spanning various sub-frames. For the UE, searching for a wideband signal during a long period of time can be energy consuming[4]. As these terrestrial signals cannot be directly applied in a non-terrestrial setting - they would no longer meet positioning accuracy requirements - they need to be adapted. This section looks at the feasibility and impact of adapting positioning signals from terrestrial networks to non-terrestrial networks.

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The aim of the study is to evaluate the possibility of using the PRS in the 6G NTN context for LEO constellations equipped with future payloads capable of providing a user link in the FR2 band . The PRS was developed for terrestrial users and gNBs, and its use in an NTN context is not currently specified by 3GPP standards. However, it is already being studied, as will be discussed in the next section.

B. NTN deployment and associated standarisation positioning activities

NTN has been introduced in Release 17 through various communications channels, from IoT to 5G communications. However, for Releases 17 and 18, the use of GNSS was considered mandatory for the user. In [9], the current assumption of 3GPP normative work is that the UE shall be capable of GNSS positioning to determine the location for obtaining 5G services via satellite access, which excludes the possibility of providing 5G services to UEs without GNSS receiver or unable to determine the location with GNSS receiver. Nevertheless, according to the specification document [10], the use of satellites in a 5G system is based on the following requirements:" « A UE supporting satellite access shall be able to provide or assist in providing its location to the 5G network. A 5G system with satellite access shall be able to determine a UE's location in order to provide service (e.g. route traffic, support emergency calls) in accordance with the governing national or regional regulatory requirements applicable to that UE.

III. POSITIONIG REFRENCE SIGNAL (PRS)

A. Physical Structure of (PRS)

PRS sequences are pseudo-random sequences that have good autocorrelation proprieties and small cross-correlation to ensure accurate timing measurements. PRS signals are sent in at least one symbol and one sub-carrier frame. The pseudo-random sequence used is a Gold sequence of length 31 [5]. The signal is modelised as:

$$r(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big) \quad (1)$$

Where C is

$$c_{\text{init}} = \left(2^{22}\left\lfloor \frac{n_{\text{ID,seq}}^{\text{PRS}}}{1024}\right\rfloor + 2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)\left(2\left(n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024\right) + 1\right) + \left(n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024\right)\right) \bmod 2^{31}$$

$$m = 0, 1, \ldots$$
$$k = mK_{\text{comb}}^{\text{PRS}} + \left(\left(k_{\text{offset}}^{\text{PRS}} + k'\right) \bmod K_{\text{comb}}^{\text{PRS}}\right)$$
$$l = l_{\text{start}}^{\text{PRS}}, l_{\text{start}}^{\text{PRS}} + 1, \ldots, l_{\text{start}}^{\text{PRS}} + L_{\text{PRS}} - 1\text{s}$$

In the standardisation for 5G TN, the bandwidth can be divided among a maximum of 3300 subcarriers. The effective number of subcarriers is defined by the subcarrier spacing (SCS), with possible values listed in Table 1 (note that, according to [5], SCS values greater than 120 kHz cannot be used for the PRS. From a temporal perspective, data transmission is organized into 10 ms frames. Each frame is divided into 10 subframes of 1 ms. Each subframe is further divided into a certain number of slots, with each slot containing 14 OFDM symbols. The number of slots per subframe is a function of the SCS. Indeed, the principle of OFDM is to ensure orthogonality between the subcarriers by transmitting data blocks with a duration of 1/SCS. Thus, for an SCS of 15 kHz, there will be 1 slot per subframe i.e., 14 OFDM symbols for an SCS of 30 kHz, 2 slots per subframe i.e., 28 OFDM symbols, and so on.

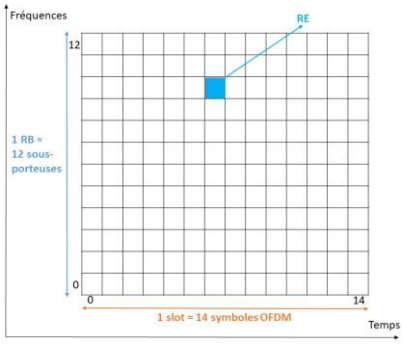

Fig. 1. PRS Resources Elements Allocation [5]

PRS supports four comb forms, namely Comb 2/4/6/12, in the frequency domain, and four symbol number configurations, i.e., Symbol 2/4/6/12, in the time domain. PRS supports the time-domain patterns with the RE offset KPRS offset = 0, where NA indicates that the mapping mode is not supported. Therefore, the two-dimensional time-frequency.

The comb structure of PRS is to control the interference of PRS signals transmitted by multiple transmitters.

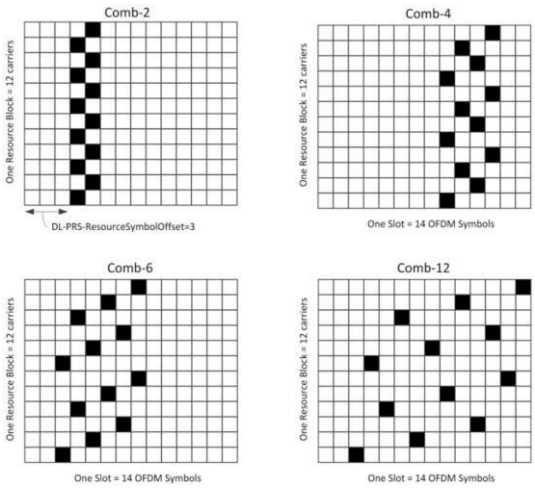

Fig. 2. Examples of time-frequency configuration of PRS symbol [24]

IV. Theoretical Analysis and Ranging using PRS in Terresterail Network

Taking Comb=4 with 4 symbols as an example, the PRS mapped the OFDM signal model. In a time slot, PRS occupies OFDM symbols in the time domain, N subcarriers in the frequency domain, and the number of subcarriers carrying. PRS is $N_j(N/K_{PRScomb})$, where J is the set of subcarriers carrying PRS. T_s is the total duration of the OFDM symbol which satisfies $T_s = T_{CP} + T.\Delta f = \frac{1}{T}$ is the frequency spacing of subcarriers, f_k is the frequency of the k-th subcarriers that carry PRS symbol.$Rect\ (t/Ts)$ is the rectangular function which is equal to 1. With the PRS equally spaced in the frequency domain, the frequency of the Subcarriers carrying PRS symbols fk satisfy the following equations as the equation to be limited.

N_j - point inverse fast Fourier transform (IFFFT) [6] is :

$$IFFT(((S_g)_{k,m}) = \frac{1}{m_a N_j} \sum_{k=0}^{m_a N_j - 1} e^{-j2\pi K_{comb}^{PRS}\ \Delta fk \frac{2R_r}{c}} \times e^{j2\pi lk / m_a N_j} \quad (2)$$

Performed on the PRS, which is inserted at equal intervals in the frequency domain. IFFT is performed on the m-th column of the $(S_g)_{k,m}$.

$$\Delta fk \frac{2R_r}{c} \times e^{j2\pi lk / N} \sum_{k=0}^{N_j - 1} e^{-j2\pi K_{comb}^{PRS}} \quad (3)$$

$$r(l) = IFFT((S_g)_{k,m})$$

$$l \in \{0,1,\dots Nj-1\}$$

where IFFT $(\cdot)$ is an inverse fast Fourier transform operation. l i is the index of the (i^{th}) result of point IFFT. The peak occurs when the two exponential terms in (2) cancel each other. With the index of the peak of the column m $ind_{sg,m}$ The estimated Range is :

$$\widehat{R_r} = \frac{\hat{d}}{2N_j K_{comb}^{PRS} \Delta f} \quad (4)$$

For the OFDM waveform modulated by PRS sequence, one time slot accounts for up to 12 symbols. The SNR is 5 dB. The rest of simulation parameters are shown in Table 3.

measurement result is shown in Fig. 2, where the theoretical value of range resolution is = 4.88 m. Since the peak index of column IFFT in Fig. 2 is 11 and the count starts from 1 in the simulation, the value of $_{indSg,m}$ is 10.

With 1000 times Monte Carlo simulations, the RMSE of range estimation is 1.17 m. When introducing the fractional factor, the RMSE is reduced to 0.33 m.

From the results of range estimation, the ranging accuracy is significantly improved and reached the centimeter level in terrestrial context (TN) .

V. Application Of The PRS to Non-Terrestrial Networks

The PRS service and support for non-terrestrial networks have been studied and implemented simultaneously in releases 16 and 17. This makes it possible to now explore the application of PRS within an NTN network.

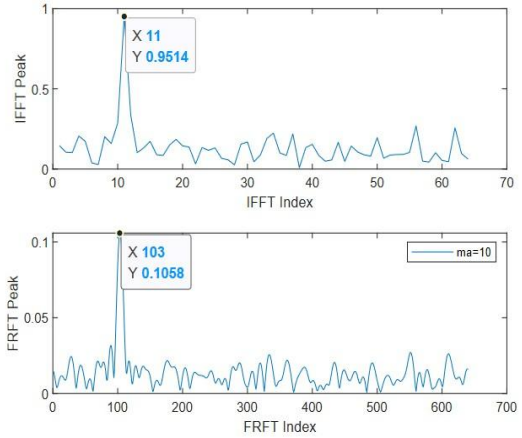

Fig. 3. Simulated IFFT correlation peak when the target is at 50 m

Table 1: Simulation parameters and Results

Symbol	Parameter	Value
fc GHz	carrier frequency	24
Δf (KHz)	frequnecy spacing of subcarriers	120
Ts us	Total duration of OFDM Symbol	8.92
N	Number of subcarriers	256
KPRS_comb	Comb size PRS	4/2/
N_J ($N/K\_comb\^PRS$)	Number of subcarriers carrying PRS	64/128
R_r (m)	range of target	50
v (m/s)	velocity of target	15
Theoretical value of Range	**Equation**	value
ΔR (m)	$= c/2N\Delta f$	4,8828125
Estimated Range (R_r) (m)	Index_peak_autocorrelation*c/($2N\Delta f$)	48,828125
Estimated Range with fractional	Index_peak_autocorrelation*c/(2*ma*$N\Delta f$)	49,8046875
Factor m_{a} =10		
Position Erreur (m)	Range of target-Estimated range	1,171875
Position error _ fractional Factor	Range of target -Estimated_range_ma	0,1953125

This is a relatively new topic; even a recent publication such as [14] identifies with the potential to improve positioning service coverage, provided that signal design and beamforming are optimized. However, this subject has already been discussed in references [15], [16], [17], and [18].

[15] presents the results based on NR positioning as described in release 16. The satellite trajectories are

consistent with those of the 6G NTN network. The positioning method used is DLTDOA, the standard for PRS. The performance is evaluated in terms of horizontal positioning error, in order to assess the impact of the following factors :the channel bandwidth, the sampling frequency, the number of PRS symbols per slot, the number and altitude of satellites, the channel model, the satellite position error. The authors show the horizontal positioning errors are typically in the meter to decimeter range in most cases. However, several issues are not addressed: synchronization between satellites: It is assumed that the UE and satellites are synchronized with each other, acquisition of time-of-flight measurements. document does not specify the measurement model and does not provide the simulator code, only presenting positioning error CDFs. The positioning algorithm is also not specified. Unlike the following article, the single-LEO case is not studied.

VI. Application of The PRS to Non-Terrestrial Networks.

The constellation, as shown in Fig. 3, consists of 24 planes. The satellites are LEO satellites at an altitude of 600 km. The orbits are inclined by 53º with respect to the Equator while the orbital planes spacing is equal to 15º .

The simulations in this paper focus on a certain area on Earth. This area has the form of a circle, with a radius that is equal to 600 km, as depicted in Fig. 11. This area is covered by 9 satellites in two different orbits. The 9 satellites are divided into 5 satellites in the first orbit and 4 satellites in the second orbit. The first orbit is inclined by 2º, whereas the second orbit is inclined by 17º

In this simulation study, we consider the Walker constellation parameters as illustrated in the figure. We assume 4 satellites per plane, and the elevation study is conducted at an altitude of 600 km.

Fig.4. Consellation used in the simulation

VII. Simulations Results

In this section, we present results using 4 satellites at the same plane. First, the UE computes the cross correlation between the reference signal sent from the satellite and the signal received by the UE. The correlator used is a frequency domain correlator as it reduces the computation complexity in comparison with a time domain correlator. Then, the output from the correlator is the input to the peak detector. In the peak detector, the signal arrival region is firstly detected. Then, the noise floor is estimated.

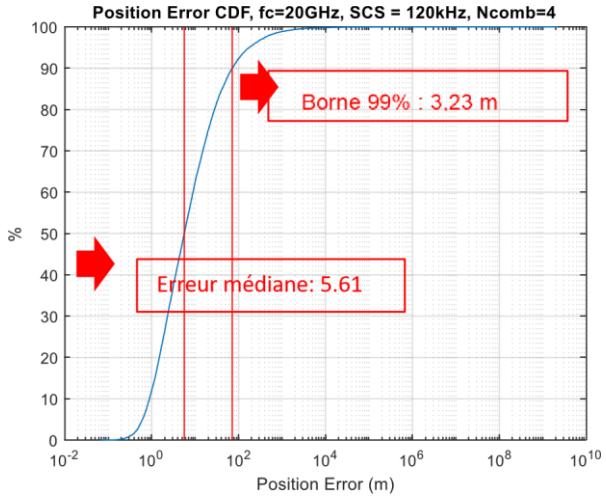

Fig.5. The simulation results

VIII. Conclusion

In this paper, we demonstrate the PRS, as a pilot signal in 5G mobile communication system, has the feasibility and superiority in 6G networks . We investigate the method of using

PRS for ranging and positioning in the future 6G, communication and positioning. We propose enhance method for increasing number of FFT points to increase bandwith of PRS signal to achive high accuracy. In this simulation we consider that the number of satellites in more enough to rise this accuracy. The challenges in the 6G constellations is to study the impact of number of satellites the dopller effect and the movement of UE. In the future work all these parameters will be investigated in deep to provid a key element for signal mapped in this future 6G constellations.

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