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(72) Inventor(s):
Mythri Hunukumbure
Yinan Qi

(73) Proprietor(s):
Samsung Electronics Co., Ltd.
(Incorporated in the Republic of Korea)
129, Samsung-ro, Yeongtong-gu, Suwon-si,
Gyeonggi-do, 443-742, Republic of Korea

(74) Agent and/or Address for Service:
HGF Limited
Document Handling - HGF - (York), 1 City Walk,
LEEDS, LS11 9DX, United Kingdom

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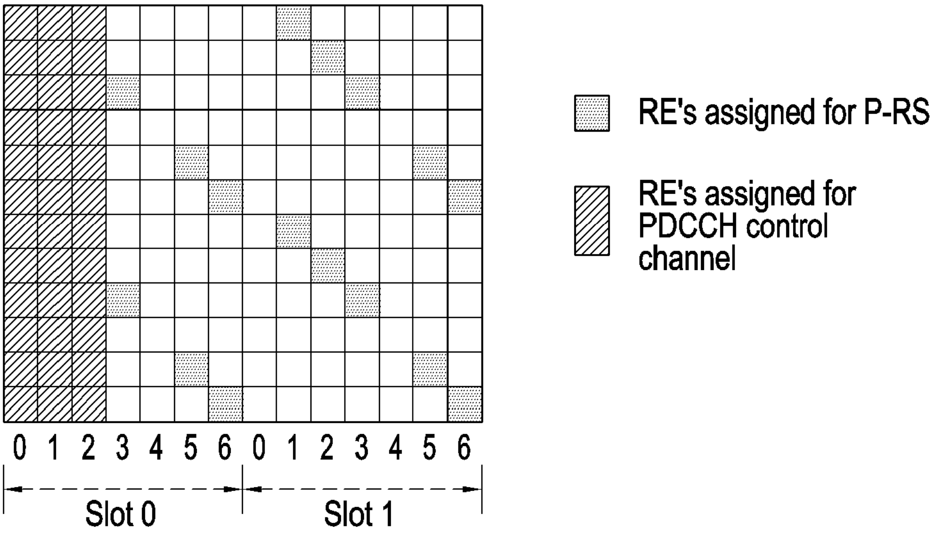
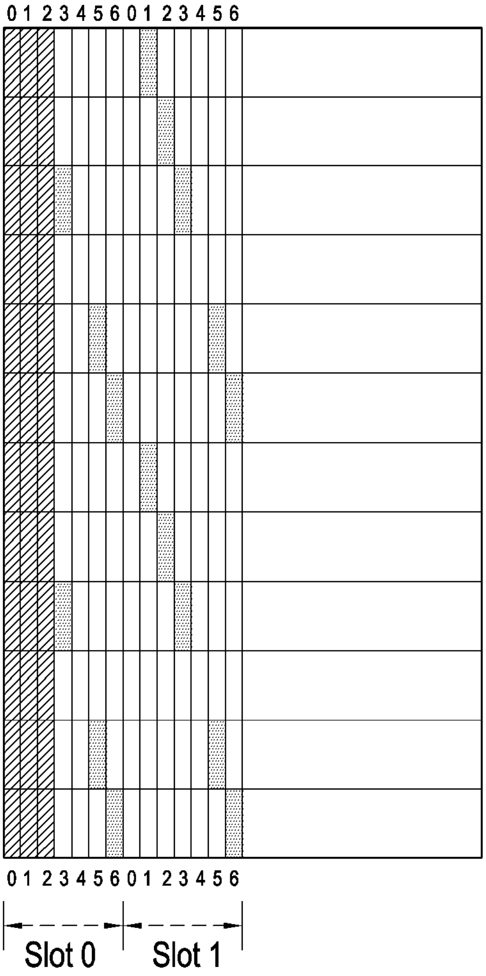
13 05 20

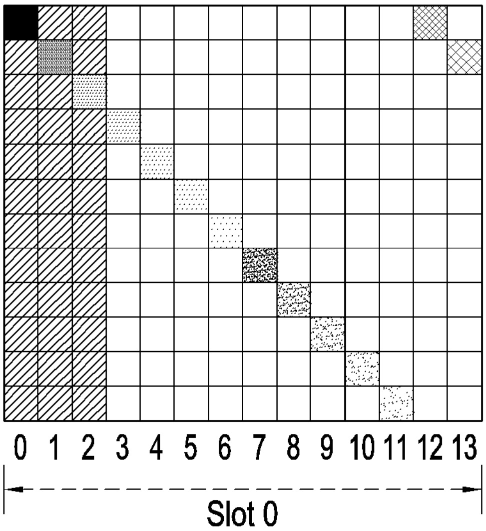


(a) LTE-sub-carrier spacing = 15 kHz

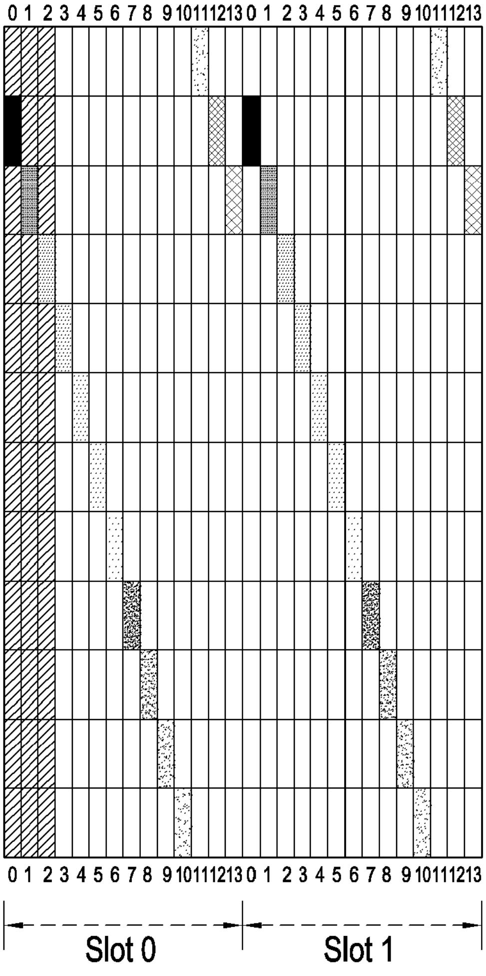


(b) 5G-NR option-sub-carrier spacing = 30 kHz

FIG.1

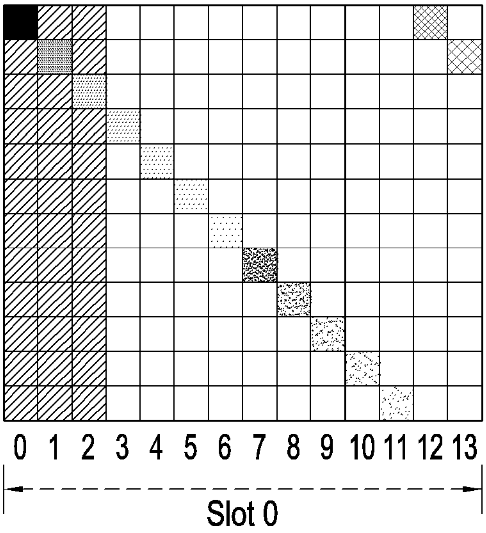


(a) PRS pattern for cell with SCS = 15 kHz

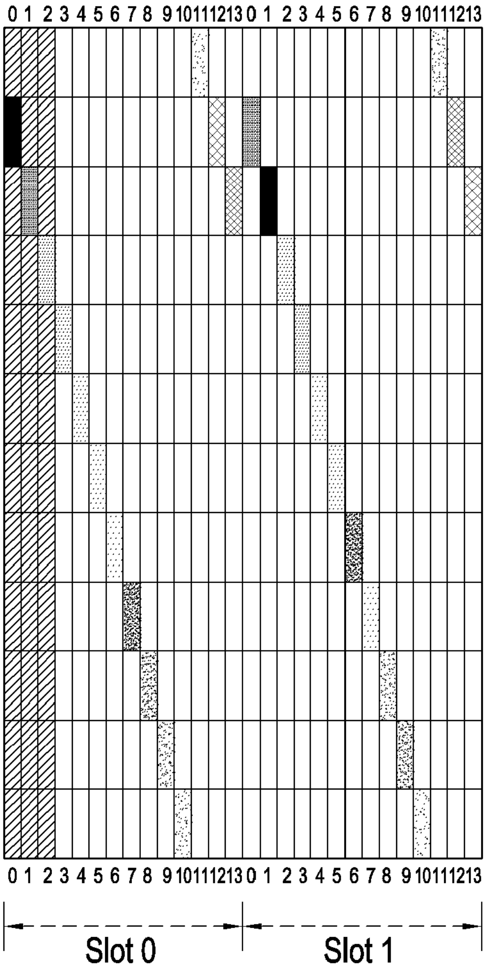


(b) PRS pattern for cell with SCS = 30 kHz

FIG.2



(a) PRS pattern for cell with SCS = 15 kHz



(b) PRS pattern for cell with SCS = 30 kHz

FIG.3

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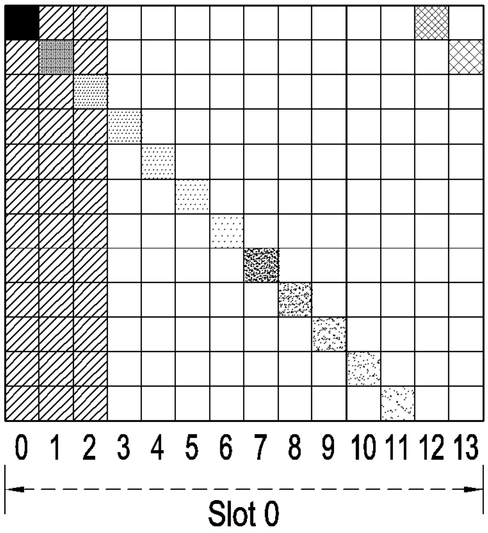
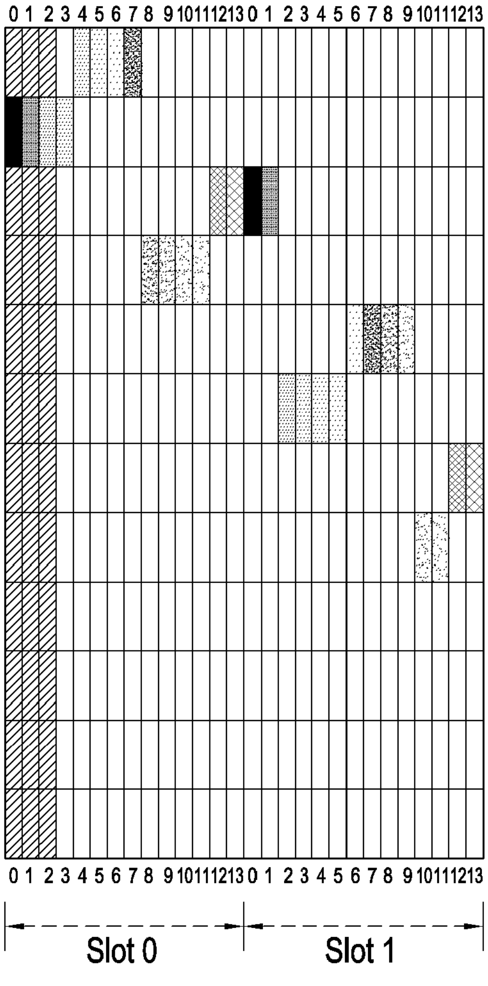


(a) PRS pattern for cell with SCS = 15 kHz



(b) PRS pattern for cell with SCS = 30 kHz

FIG.4

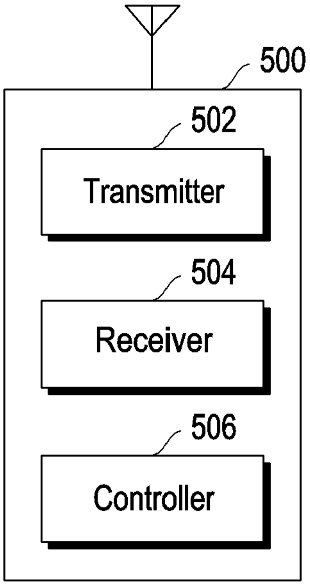

500
502
Transmitter
504
Receiver
506
Controller

FIG.5

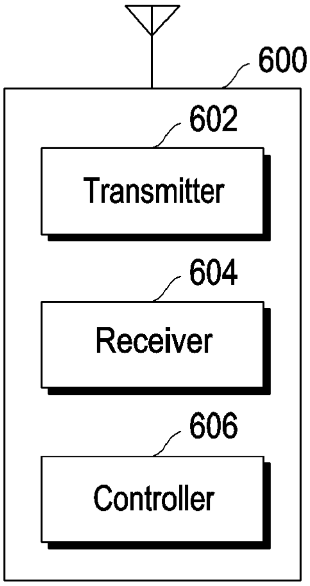

600
602
Transmitter
604
Receiver
606
Controller

FIG.6

METHODS, APPARATUS, AND SYSTEMS FOR TRANSMITTING AND RECEIVING POSITIONING REFERENCE SIGNALS IN 5G NEW RADIO NETWORKS

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates to methods, apparatus, and systems for transmitting and receiving positioning reference signals in 5G New Radio (NR) wireless communications networks.

BACKGROUND OF THE DISCLOSURE

[0002] Wireless or mobile (cellular) communications networks in which a mobile terminal (UE, such as a mobile handset) communicates via a radio link with a network of base stations, or other wireless access points or nodes, have undergone rapid development through a number of generations. The 3rd Generation Partnership Project (3GPP) design, specify and standardise technologies for mobile wireless communication networks. Fourth Generation (4G) systems are now widely deployed.

[0003] 3GPP standards for 4G systems include an Evolved Packet Core (EPC) and an Enhanced-UTRAN (E-UTRAN: an Enhanced Universal Terrestrial Radio Access Network). The E-UTRAN uses Long Term Evolution (LTE) radio technology. LTE is commonly used to refer to the whole system including both the EPC and the E-UTRAN, and LTE is used in this sense in the remainder of this document. LTE should also be taken to include LTE enhancements such as LTE Advanced and LTE Pro, which offer enhanced data rates compared to LTE.

[0004] The trend towards greater data throughput continues with 3GPP currently working to standardise Fifth Generation (5G) network technologies. As part of this, a new air interface is being developed, which may be referred to as 5G New Radio (5G NR) or simply NR. NR is designed to support the wide variety of services and use case scenarios envisaged for 5G networks, though builds upon established LTE technologies. One aspect of 5G NR is the provision of enhanced positioning techniques for determining the positions of both user equipment (UE) and 5G NR base stations (next generation Node Bs (gNBs)), where the position of UEs and gNBs is at least required for effective beamforming but also for the provision of location dependent services. Whilst Positioning Reference Signals (PRS) are utilised in LTE and LTE Advanced, the configuration of these PRS is required to be enhanced or new positioning signals defined if the advantages of position-dependent functionality in 5G NR are to be achieved. In particular, due to the adaptive/variable/scalable numerology of 5G NR networks, existing approaches to the transmission and/or reception of PRS may not be appropriate for all configurations of 5G NR networks.

BRIEF SUMMARY OF THE DISCLOSURE

[0005] It is an aim of certain examples of the present disclosure to address the issue of enabling the effective transmission and reception of positioning reference signals across the different possible network configurations in 5G New Radio (NR) systems, and in particular, the different configurations that may result from the scalable numerology of 5G NR networks.

[0006] According to a first aspect of the present disclosure there is provided a method for transmitting positioning reference signals, PRS, in a 5G New Radio, NR, communications network comprising a first base station configured to operate a first cell with a first OFDM subcarrier spacing, SCS, and a second base station configured to operate a second cell with a second OFDM SCS, the second SCS being higher than the first SCS, and wherein time resources of each cell are divided into subframes of a same predetermined duration and the subframes of the first and second cells are divided in time into one or more time slots based on their respective SCS, the method comprising transmitting, by the first base station within a subframe of the first cell, a first PRS pattern with a first repetition frequency, and transmitting, by the second base station within a corresponding subframe of the second cell, a second PRS pattern with a second repetition frequency, wherein the first repetition frequency is based on the number of time slots in a subframe of the first cell and the second repetition frequency is based on the number of slots in the subframe of the second cell. and the second PRS pattern is based on the first PRS pattern.

[0007] In one example, the PRS patterns may be repeated in every slot of the subframe and the repeated pattern can be an exact repetition, a cyclically swapped repetition (with the cycle based on the number of slots per subframe) or a continuation of a block diagonal pattern.

[0008] In an example of the present disclosure the first PRS pattern is transmitted in each time slot of the first cell, and the second PRS pattern is transmitted in each time slot of the second cell such that the first repetition frequency is equal to the number of time slots in a subframe of the first cell, and the second repetition frequency is equal to the number of time slots in a subframe of the second cell.

[0009] In an example of the present disclosure the first PRS pattern and the second PRS pattern are diagonal patterns with respect to the time slots of the first and second cells.

[0010] In an example of the present disclosure the first PRS pattern is the same as the second PRS pattern.

[0011] In an example of the present disclosure each time slot of the first cell and the second cell is divided in time into a predetermined number of symbols, and wherein transmitting the first and second PRS patterns includes transmitting at least part of the first and second PRS patterns in the first symbol of the first slot of the subframe of their respective cells.

[0012] In an example of the present disclosure the transmission of the second PRS pattern in the second cell is shifted by at least one subcarrier with respect to the transmission of the first PRS pattern in the first cell.

[0013] In an example of the present disclosure the second PRS pattern is a block diagonal form of the first PRS pattern, and each block of the second PRS pattern is shifted by at least one subcarrier with respect to the corresponding portion of the first PRS pattern.

[0014] According to a second aspect of the present disclosure there is provided a method for transmitting positioning reference signals, PRS, by a base station in a 5G New Radio, NR, communications network, the base station being configured to operate a first cell with an OFDM subcarrier spacing, SCS, and the time resources of the cell being divided into subframes and each subframes being divided in time into one or more time slots based on the SCS, the method comprising transmitting, by the base station within a subframe of the cell, a PRS pattern with a repetition frequency, wherein the repetition frequency is based on the number of time slots in the subframe

[0015] In an example of the present disclosure the PRS pattern is transmitted in each time slot of the subframe such that the repetition frequency is equal to the number of time slots in the subframe.

[0016] In an example of the present disclosure the PRS pattern is a diagonal pattern with respect to a time slot.

[0017] In an example of the present disclosure each time slot of the cell is divided into a predetermined number of symbols, and wherein transmitting the PRS pattern includes transmitting at least part of the PRS pattern in the first symbol of the first slot of the subframe.

[0018] In an example of the present disclosure at least part of the PRS pattern is transmitted in every symbol of each time slot.

[0019] According to a third aspect of the present disclosure there is provided a 5G New Radio, NR, communications network comprising a first base station configured to operate a first cell with a first OFDM subcarrier spacing, SCS, and a second base station configured to operate a second cell with a second OFDM SCS, the second SCS being higher than the first SCS and time resources of each cell being divided into subframes of a same predetermined duration, wherein the communication network is configured to perform the method of any of the first aspect and the related examples.

[0020] According to a fourth aspect of the present disclosure there is provided a method for receiving position reference signals by a terminal device in a 5G New Radio, NR, communications network comprising a first base station operating a first cell with a first OFDM subcarrier spacing, SCS, and a second base station operating a second cell with a second OFDM SCS, the second SCS being higher than the first SCS, and wherein time resources of each cell are divided into subframes of a same predetermined duration, the method comprising receiving, from the first base station within a subframe of the first cell, a first PRS pattern, and receiving, from the second base station within a subframe of the second cell, a second PRS pattern, wherein the second PRS pattern is based on the first PRS pattern.

[0021] In an example of the present disclosure the receiving the first PRS and the second PRS includes sampling the first and second PRS signals at a sampling frequency corresponding to one of the first SCS or the second SCS.

[0022] In an example of the present disclosure the subframes of the first and second cells are divided in time into time slots based on their respective SCS, and wherein, when the sampling frequency corresponds to the first SCS, the receiving the second PRS comprises receiving a first portion of the second PRS in first time slot and a second portion of the second PRS in a second time slot.

[0023] In an example of the present disclosure the subframes of the first and second cells are divided in time into time slots based on their respective SCS and each time slot of the cell is divided into a plurality of symbols, and wherein receiving the first PRS pattern includes receiving at least part of the first PRS pattern in the a first symbol of the first slot of the subframe of the first cell, and receiving the second PRS pattern includes receiving at least part of the second PRS pattern in the a first symbol of the first slot of the subframe of the second cell.

[0024] According to a fifth aspect of the present disclosure there is provided a terminal device configured to perform the any of the method of the fourth aspect and the related examples.

[0025] According to an aspect of the present disclosure there is provided a computer readable storage medium having stored thereon computer executable instructions which when executed by a computer cause the computer to perform the above method.

[0026] Another aspect of the present disclosure provides a computer program comprising instructions arranged, when executed, to implement a method and/or apparatus in accordance with any one of the above-described aspects. A further aspect provides machine-readable storage storing such a program.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Embodiments of the present disclosure are further described hereinafter with reference to the accompanying drawings, in which:

[0028] Figure 1 illustrates the use of LTE positioning reference signals (PRS) in subframes with a 15kHz subcarrier spacing (SCS) and how the same pattern would appear if applied to 30kHz SCS in 5G NR;

[0029] Figure 2 illustrates the use of a proposed configuration of PRS in subframes in 5G NR with 15kHz and 30kHz SCS;

[0030] Figure 3 illustrates the use of a proposed configuration of PRS in subframes in 5G NR with 15kHz and 30kHz SCS;

[0031] Figure 4 illustrates the use of a proposed configuration of PRS in subframes in 5G NR with 15kHz and 30kHz SCS;

[0032] Figure 5 illustrates an example structure of a 5G NR gNB, and

[0033] Figure 6 illustrates an example structure of a 5G NR UE.

DETAILED DESCRIPTION

[0034] Examples in accordance with the present disclosure will now be described in the context of a 5G wireless communication network, and in particular a NR radio access network forming part of a 5G wireless communication network. It will be understood that the present disclosure is not limited to any particular radio access technology. That is, the use of and configuration of Positioning Reference Signals (PRS) or other signals used for position determination at either the UE (i.e. mobile terminal/terminal device) side or network side are equally applicable in other wireless communication systems where it is desirable to provide positioning techniques that operate across a range of network configurations, and to determine accurate positioning information of a UE and/or base stations such that improvements in system performance and new location dependent functionality can be provided. References to particular 3GPP constructs in certain examples should not be understood as limiting the ability of examples of the present disclosure to be applied to other wireless communication networks.

[0035] In 5G NR, and more generally LTE and LTE Advanced systems, approaches to position determination may be separated into three different categories: Radio Access Network (RAN)-dependent techniques, RAN-independent techniques and hybrid techniques, which utilise a combination of the two former techniques in order to complement their operation. RAN-dependent techniques are those that utilise information provided by or derived from signals of the RAN, for example, position information may be determined based on Cell-IDs, E-Cell IDs, Observed Time Difference of Arrival (OTDOA), Uplink Time Difference of Arrival (UTDOA), Angle of Departure (AoD), Angle of Arrival (AoA); and RAN-independent techniques are that utilise information and signals external to the RAN, for example GNSS, Bluetooth, WLAN, Terrestrial Beacon Systems (TBS). From these approaches, there is an effort to improve the capabilities and compatibility of the RAN-dependent techniques so as to provide improved position determination. In particular, improved approaches to the use of techniques based upon signal detection and analysis are sought, in other words techniques such as OTDOA, UTDOA, AoD, and AoA. Consequently, there is a requirement for enhancing the configurability of the reference signals used for the RAN-dependent positioning functionality in 5G NR systems.

[0036] In LTE and LTE Advanced, RAN-dependent position determination using techniques such as OTDOA, UTDOA, AoD, and AoA are dependent on the receipt of reference signals, or more precisely, Positioning Reference Signal(s) (PRS) in the downlink and Sounding Reference Signal(S) (SRS) in the uplink. These reference signals take the form of a pseudo random sequence QPSK signal that is generated based on parameters including one or more of physical layer cell identity, slot number, OFDM symbol number, cyclic prefix etc. PRS were introduced in 3GPP LTE Release 9 and therefore further details on PRS can be found in 3GPP TS 36.211 Release 9 version 9.1.0 (30/3/2010) . Uplink-based positioning was introduced in 3GPP LTE Release 11, where such positioning is based upon Sounding Reference Signals (SRS), further details on which can be found in 3GPP TS 36.211 Release 11 version 11.7.0 (23/3/2017).

[0037] In 5G NR it is envisaged that position functionality may be based on an evolved form of the PRS/SRS or a new form of reference signalling. In the following description, although downlink PRS (DL PRS) are predominantly referred to, the characteristics, configurations and implementation details of the various aspects of 5G NR position determination configurations are not limited to only PRS but are equally applicable to other forms of signals utilised for position determination such as Uplink PRS/SRS or other forms of position reference signalling.

Observed Time Difference of Arrival Positioning

[0038] As set out above, numerous different approaches may be used to determine the position of a UE in 5G systems. However, observed time difference of arrival (OTDOA) is likely to be commonly used in conjunction with downlink PRS. OTDOA of arrival operates by measuring the difference in arrival times between reference signals (e.g. downlink PRS) received from multiple transmissions points, which in the case of 5G NR will be gNBs. For example, the arrival time of reference signals from three gNBs will be measured and then a relative arrival time (i.e. observed time difference) will be calculated relative to one of the gNBs, such as the serving gNB for example. The relative arrival times are then transmitted to the serving gNB which can then calculate the position on of the UE based on upon the received measurements and its own location information using a hyperbolic multilateral algorithm. More precisely, taking t_1 to be the arrival time of the PRS signal from the gNB_1, t_2 to be the arrival time of the PRS signal from gNB_2 and t_3 to be the arrival time of the PRS signal from gNB_3 the UE calculates the observed time differences of arrival ($t_{2,1}=t_2-t_1$ and $t_{3,1}=t_3-t_1$) and transmits them to the serving gNB (e.g. gNB_1). These calculated values define two hyperbolas, the intersection of which provides the position of the UE. An equivalent procedure may also be performed in the uplink (i.e. UTDOA) based upon uplink reference signals transmitted by the UE to a serving gNB and at least two neighbouring gNBs.

5G NR Positioning

[0039] In addition to increasing the accuracy of position determination in 5G NR compared to LTE and LTE Advanced, there are also a number of further aspects that require consideration. For example, positioning techniques should preferably be able to function in both 5G NR frequency ranges of FR1 (450 to 6000MHz) and FR2 (>6GHz/24250 to 52600MHz), and be configurable so that they may operate over the many different network configurations that are envisaged in 5G NR systems. In particular, it is required that positioning techniques are compatible with the adaptable numerology of 5G NR system, which, among other things, includes varying OFDM subcarrier spacing (SCS) and a varying number of slots in a subframe. Furthermore, positioning techniques should operate at the minimum 5G NR bandwidth of 5 MHz but be scalable to higher bandwidths; they should be applicable to Internet of Things (IoT) devices, and also support voice and data devices; they should be efficient and low complexity for the various use cases whilst preferably using a common architecture where possible. Given these desired requirements, positioning techniques with a large degree of configurability and/or compatibility are required for 5G NR.

[0040] With respect to OFDM SCS in 5G NR, six different SCS are specified, as set out in Table 1 below

μ	**SCS ($\Delta f=2^{\mu}$x15kHz)**	**Cyclic Prefix**	**Frequency Band**
0	15kHZ	Normal	FR1
1	30kHZ	Normal	FR1
2	60kHZ	Normal, Extended	FR1, FR2
3	120kHZ	Normal	FR2
4	240kHZ	Normal	FR2
5	480kHZ	Normal	FR2

Table 1

[0041] As set out above, when performing position determination using OTDOA a UE is required to receive PRS from at least three different gNBs. Consequently, it is possible that two of more the gNBs that a UE is required to receive PRS from may be operating cells with different SCS. For example, depending on the devices operating in each of the cells operated by the gNBs, different SCS may be chosen. However, as is explained in more detail below, when operating in accordance with existing LTE PRS patterns, the PRS transmitted by gNBs operating with different SCS may not align in the time domain and there may also be an overlap in the subcarriers allocated with PRS in the each of the cells operated by the gNBs, thus causing problems when attempting to receive PRS signals from different cells at a UE.

[0042] With reference to Table 1, SCS can be scaled by factors of 2^{μ} in relation to the base SCS of 15kHz (which is the only SCS supported in LTE). A consequence of the increasing SCS is that the symbol duration is shortened by the same factor(s) of 2^{μ}. In 5G NR, one slot is defined as 14 symbols and for higher SCS, the duration of the slots will be shortened. However, a subframe is continued to be defined as a 1ms period, fitting in one slot in the 15kHz SCS. However, for the higher SCS, more slots (i.e. a factor of 2^{μ}) will fit into a sub-frame.

[0043] An LTE subframe (1ms duration) will always contain 2 slots and the PRS pattern for LTE is illustrated in Figure 1(a), where the time/frequency resources are shown on a resource element (RE) level (i.e. one subcarrier by one OFDM symbol) and two LTE slots i.e. a single physical resource block (PRB) , are shown. The PRS pattern is broadly diagonal across the 2 slots of the subframe and are not transmitted in the Physical Downlink Control Channel (PDCCH) allocated symbols of 0, 1 and 2 in slot 1. There are also gaps in the diagonal pattern to accommodate the cell specific reference signal (CRS) that are transmitted in LTE. Also, the subframes where the PRS patterns are included do not contain any data (no Physical Downlink Shared Channel (PDSCH) bits) so there will be no interference from PDSCH when receiving the PRS patterns from adjacent eNBs in the DL for the UEs.

[0044] In LTE, when a normal cyclic prefix is used, the PRS pattern is generated based on the following equation

$$k = 6\left(m + N_{RB}^{DL} - N_{RB}^{PRS}\right) + \left(6 - l + v_{shift}\right) \bmod 6$$

$$l = \begin{cases} 3,5,6 & \text{if } n_s \bmod 2 = 0 \\ 1,2,3,5,6 & \text{if } n_s \bmod 2 = 1 \text{ and (1 or 2 PBCH antenna ports)} \\ 2,3,5,6 & \text{if } n_s \bmod 2 = 1 \text{ and (4 PBCH antenna ports)} \end{cases}$$

$$m = 0,1,\ldots,2 \cdot N_{RB}^{PRS} - 1$$

$$m' = m + N_{RB}^{\max,DL} - N_{RB}^{PRS}$$

[0045] The parameter v_{shift} accounts for different eNBs and up to 6 eNBs can be accommodated, generating different diagonal patterns of PRS so the PRS from neighbouring eNBs do not interfere with one another.

[0046] It should also be noted that the observed timing difference accuracy will depend on the sampling rate, which in LTE is proportional to the 15kHz SCS. A common approach for timing detection is to obtain the received signal before the cyclic prefix (CP) removal in the OFDM receiver chain, and then correlate in the time domain with a locally generated PRS signal, sampled at the receiver clock rate. Although the received signal can be corrupted by interference from the other subcarriers in the same symbol and the CP, there will be the Gold sequence of the PRS embedded and the correlation will generate a peak to enable the determination of the timing offset.

[0047] Turning to 5G NR, when neighbouring gNBs operate multiple SCS in the same frequency range (FR1 or FR2), the UE may still employ the above (pre fast Fourier transform (FFT stage)) correlation technique to detect the timing difference. However, the UE will have to try with different PRS symbol durations and patterns, to find the actual sequence that will generate a correlation peak. Consequently, since such a repetitive correlation process using digital signal processing (DSP) is complex and thus has a relatively high power consumption, if the UE is a power constrained device (like a sensor device), this technique may not be suitable for preserving its battery life.

[0048] In an alternative approach , the CP is firstly removed, an FFT performed, and then the correlation process for the detected PRS signal using a local PRS copy in the frequency domain. When the PRS pattern is detected, the related local copy can be identified and the correct correlation can be generated with a single attempt. Also, since the detected signal is cleared of the CP and other subcarrier (non-PRS, in the same symbol) interference, this method may be more robust and can be used to detect PRS from distant cells, with low signal to interference plus noise ratio (SINR).

[0049] A practical scenario where this approach will be useful is when a sensor device is connected to a Marco cell utilizing 15kHz SCS and also having femto cells in the near vicinity, operating at a higher SCS (e.g. 30kHz or 60kHz). The sensor device may utilise the second method of correlation (post FFT, in the frequency domain) to estimate the timing offset. The below proposed PRS design solutions will be useful in such a scenario but are not limited to such a scenario.

[0050] Figure 1(b) illustrates the use of the exact LTE PRS pattern in 5G NR when a SCS of 30kHz is used, such that Figure 1(a) and 1(b) illustrates the PRS patterns of neighbouring gNBs with different SCS in corresponding (i.e. aligned/synchronised) subframes when existing LTE PRS patterns are used in 5G NR. The existing PRS pattern is distributed in the same manner with respect to the 12 subcarriers and first 14 symbols, however, due to the increased SCS the 14 symbols are contained with the time period of 1 slot of the 15kHZ SCS.

[0051] As can be seen from Figures 1(a) and 1(b), alignment of the PRS between the subframes/cells with 15kHz and 30kHz SCS does not occur. For example, when the PRS starts on symbol 3 of slot 0 of the 30 kHz SCS cell (Figure 1(b)), PDCCH symbols are still being transmitted in the 15 kHz SCS cell, thus possibly causing interference in the reception of the PRS from the 30 kHz SCS cell. Furthermore, the gaps left for the CRS REs in LTE may also have a detrimental effect on the alignment of the PRS patterns in the two cells. Lastly, it should be noted that each symbol in Figure 1 will have a CP at the start (not shown) and having different numerologies can complicate the removal of the CP.

[0052] Consequently, there is a need for an approach to the provision of PRS in 5G NR systes that alleviates the problems that may occur when neighbouring gNBs operate their cells with different SCS and PRS are transmitted in corresponding (i.e. aligned) subframes.

[0053] In accordance with an example of the present disclosure, a first for addressing the aforementioned problems is to utilise a PRS pattern suitable for a 5G NR 15kHz SCS numerology, and then repeating the pattern with a SCS-based repetition frequency such that a pattern is repeated 2^{μ} times in the 2^{μ} slots within the selected subframe(s) for PRS, for higher 5G NR numerologies of 2^{μ}x15kHz SCS.

[0054] By virtue of this approach, UEs aware of the different SCS will be able to track the PRS and read/receive sufficient PRS required for the purposes of receiving a full PRS pattern and thus positioning within an applicable subframe. Furthermore, as is explained in more detail below, although UEs in each of the lower SCS and higher SCS cells will be running different sampling clocks/frequencies corresponding to their serving cell's SCS, the UEs in both cells will be able to read the PRS patterns of the neighbouring cells.

[0055] Figures 2(a) and 2(b) illustrate example PRS patterns for 15kHZ SCS and a 30kHz SCS, respectively in accordance with this example of the present disclosure. As can be seen, 5G NR numerologies will enforce 1 slot per sub-frame in the 15kHz SCS cell and 2 slots per subframe in the 30kHz SCS cell.

[0056] As can be seen, as part of the this first approach one or more of the following may be included: the PDCCH is punctured in order to accommodate PRS such that the PRS pattern can start from slot 0, symbol 0; symbol gaps previously used for the transmission of CRS in LTE have been removed and PRS transmitted in their place; the same PRS pattern is repeated in in all slots of the subframe; and lastly a block diagonal arrangement is used to avoid collisions of PRS transmitted by neighbouring gNBs. Furthermore, as can be see from Figures 2(a) and 2(b), due to the puncturing of the PDCCH and the removal of CRS, a part of the PRS pattern for each SCS is transmitted in every symbol within each slot.

[0057] As a result of the proposed approach to the PRS patterns, the PRS pattern fills all 14 symbols per slot (at a given subcarrier position), and will be repeated (with a given offset per cell) in the 2 slots of the 30kHz SCS. Furthermore, the problems associated with using existing LTE PRS patterns in neighbouring cells operating with different SCS are reduced. For example, considering a frequency reference point as the subcarrier at the top of each of Figures 2(a) and 1(b), the PRS patterns will be orthogonal and will not collide, even when the same PRS pattern is repeated for the 15kHz SCS cell on a second PRB in subcarriers below the 12 subcarriers not depicted in the Figure 2(a).

[0058] Although Figures 2(a) and 2(b) relate to a scenario with 2 gNBs operating with different SCS, the approach described with reference to these figures may be applied to 3 or more gNBs by varying the frequency (i.e. subcarrier) shift in PRS pattern between the gNBs in a similar manner to that set out for LTE PRS described above.

[0059] In addition to the alleviation of the aforementioned problems, the proposed approach enables a UE to efficiently receive PRS from neighbouring cells that have been transmitted using different SCS. For example, with reference to Figure 2(a) and (b), a UE that is connected to the 15kHz numerology gNB and has the gNB of 30kHz numerology as a neighbour will be running the sampling clock/frequency (f_s) based on 15kHz SCS, and therefore may easily receive the PRS transmitted by the 15kHz gNB using either of methods described above for example.

[0060] With respect to receiving the PRS transmitted by the gNB operating with a SCS of 30kHz, the UE can first receive the even symbols in the first slot of the neighbouring gNB PRS (in the subframe depictions of Figure 2 (b)) with readings from the first half of sampling instances per symbol (as defined for 15kHz SCS), and then the odd symbols of the second slot and finally combine them accordingly to generate the PRS sequence. To read the odd symbols of the 30kHz SCS PRS, the UE will switch to taking readings from the second half of sampling instances from symbol 7 (of its serving cells time grid) onwards. Consequently, for the 30 kHz SCS cell, this time period corresponds to its slot 1 and as the same PRS pattern is repeated here, the said UE will capture the missing odd numbered symbols. This approach may be applied to one or more neighbouring cells/gNBs operating at a higher SCS than the UE and that the UE requires a PRS from in order to perform position determination, where the selection of the specific cells and the order of reception of their respect PRS may be determined based on UE-specific parameters.

[0061] Given that it is proposed to repeat the PRS patterns several times in successive subframes, the UE can execute reading the PRS patterns of the serving cell and the neighbouring cell in adjacent subframes. Furthermore, when larger differences in SCS exist between neighbouring cells, a UE operating at a sampling frequency corresponding to the lower SCS, may receive a different part of the PRS of its neighbouring cell in each of the repeated transmissions of the PRS (i.e. in each slot) of the neighbouring cell and form the PRS pattern from these different parts.

[0062] As an alternative to this reception technique, the PRS pattern for the second slot (slot (1)) of the 30kHz SCS cell may have the even and odd PRS symbols swapped, as shown in Figure 3(b) by the shading of each PRS RE. This will enable the UE operating at the lower SCS (15kHz) UE to read the 30kHz SCS cell PRS symbols from sampling only the first half of its symbol durations and to read the PRS pattern. This may be advantageous since the CPs have to be removed and the CP of the first symbol is usually slightly longer than the remaining symbols in a slot, thus simplifying the CP detection and removal processes.

[0063] In examples where the SCS spacing is higher than 30kHz, some advantages in terms of UE reception may be obtained by, where possible, cyclically shifting symbols of 2^{μ}-sized groups of PRS symbols such that a different symbol of each of the groups coincides with the beginning of the symbols of a cell operating with the lower SCS e.g. 15kHz. In some examples, the length of the PRS may vary e.g. (12 or 16 symbols), and therefore the specific rearrangement of the PRS symbols may also be dependent upon the length of the PRS, for example.

[0064] In the reverse scenario in which the UE connected to the 30kHz gNB and is required to receive PRS transmitted by a neighbouring gNB operating with a 15kHz SCS, the UE will be operating at a higher sampling speed due to the shorter symbol durations. In this case, when receiving the PRS of the 15kHz gNB, the UE will may read 2 instances of the same PRS value (in 2 symbol timings for the UE). Consequently, the UE can discard the second reading for each of the 2 symbol blocks. Although the UE will be operating at a higher sampling frequency, it will only be able to obtain the full PRS pattern at the end of the subframe period, while for its own PRS, the full pattern will be detected at half of this time i.e. the PRS of a gNB can be read in a minimum time of 1 slot of the gNB transmitting the PRS regardless of the SCS which the receiving UE is operating at.

[0065] It should be noted that the illustrated PRS patterns are merely examples, and that other designs providing the same advantages are possible, for example, those having diagonal patterns in the opposite direction or where a different rearrangement of the odd and even symbols is used in order to simply the reception process.

[0066] In particular, to achieve the interoperability of PRS between gNBs operating with different SCS, the slots should be filled with the PRS pattern from symbol 0 to symbol 13 without symbol gaps, and the same pattern should be repeated in every slot in the subframe. For example, whilst the described examples cover only a 2 times (2^{μ}, $\mu=1$) increase in the SCS (i.e. 15kHz and 30kHz), the proposed approach may be extended to any of the defined SCS in 5G NR (for both FR1 and FR2), where the repetition rate for the PRS pattern will be given by the number of slots (2^{μ}) per subframe.

[0067] In this more general case, UEs may receive the full PRS of neighbouring cells operating with different SCS using an approach similar to that described above with reference to Figures 2(a) and 2(b). For example, if a UE is operating with a SCS of 15kHz and a neighbouring cell is operating with a SCS of 60kHz and the PRS pattern is similar to that of Figures 2(a) and 2(b), the UE may receive the PRS of the 60kHz cell by reading one in every 4 (2^{μ}, $\mu=2$) symbols based upon a starting symbol offset by the slot number in each slot, and then combining the read symbols to form the full PRS pattern at the end of the subframe.

[0068] In accordance with another example of the present disclosure, in second approach to enabling the provision of aligned and/or non-colliding PRS between gNBs operating with different SCS, the PRS pattern may have a block pattern in the higher SCS gNB. This approach is illustrated in Figures 4(a) and 4(b).

[0069] As can been see from Figures 4(a) and 4(b), such a pattern ensures that there will be no collisions in the subcarrier positions in the frequency domain, even when the lower SCS PRS pattern is repeated in another PRB below the currently depicted PRB.

[0070] For example, in the PRS pattern of Figure 4(b), the first 4 symbols of the 15kHz SCS diagonal pattern is provided as a horizontal pattern in the 30kHz SCS cell and avoids the first 30kHz subcarrier (i.e. 2 subcarriers of the 15kHz SCS) so as not to collide with the PRS of the 15kHz cell transmitted in the first two symbols. More generally, the block diagonal pattern avoids the subcarriers of the lower SCS cell occupied by the PRS at specific symbols (i.e. where collisions are possible) by providing a horizontal pattern in the higher SCS on a subcarrier below or above the occupied frequency of the lower SCS pattern.

[0071] As for the patterns illustrated in Figures 2(a) an 2(b) the UE operating in the cell with the lower SCS may and thus with a lower sampling frequency may receive the complete PRS of the higher SCS cell by receiving even symbols in slot 0 and odd symbols in slot 1, by utilising the other approaches set out with respect to Figures 2(a) and 2(b).

[0072] In accordance with another example of the present disclosure, a third approach to enabling the provision on non-colliding PRS between gNBs operating with different SCS may be to maintain the existing LTE PRS patterns but when two patterns are colliding due to different PRS density/pattern and/or numerology and/or frame structure settings, one of the pattern can be punctured or shifted in time/frequency domain by K symbols/subcarriers to avoid the collision. This may be achieved via cooperation between neighbouring gNBs.

[0073] In accordance with another example of the present disclosure, the first and second approaches may be implemented jointly, or separately as the needs dictate. For example, if PRS muting (i.e. periodically not transmitting a PRS symbol/pattern where one would normally be transmitted), which is also a feature in LTE, is enacted, the higher SCS neighbour cell PRS can be muted when the lower SCS service cell PRS is active (and vice versa) and this will eliminate any collisions in the frequency domain.

[0074] For all the preceding approaches, although the PRS pattern have been illustrated as having a diagonal pattern in another direction in the PRB, for example they may also have an anti-diagonal pattern.

[0075] Furthermore, although the foregoing approaches have been set out for downlink PRS, they may also be applied to uplink PRS in order to reduce the likelihood of colliding uplink PRS transmitted by UEs in both a single cell and neighbouring cells. In some examples in which uplink PRS are being transmitted, a gNB may be required to perform the detection of different UE's PRS, where the UEs are operating with different SCS.

UE and gNB Operation

[0076] Figures 5 and 6 described below illustrate the general operation of a UE and a gNB when implementing positioning functionality based on the any of the above-described configurations.

[0077] Figure 5 provides a schematic diagram of the structure of a gNB 500 which is arranged to operate in accordance with the examples described above. The gNB 200 includes a transmitter 502 arranged to transmit signals to a UE; a receiver 504 arranged to receive signals from a UE; and a controller 506 arranged to control the transmitter and receiver and to perform processing such as in accordance with the above described methods, and also to communicate with the core network.

[0078] Figure 6 provides a schematic diagram of the structure of a UE 600 which is arranged to operate in accordance with the examples of the present disclosure described above. The UE 600 includes a transmitter 602 arranged to transmit signals to one or more gNBs; a receiver 604 arranged to receive signals from one or more gNBs; and a controller 606 arranged to control the transmitter and receiver and to perform processing in accordance with the above described methods.

[0079] Although in Figures 5 and 6 the transmitter, receiver, and controller have been illustrated as separate elements, any single element or plurality of elements which provide equivalent functionality may be used to implement the examples of the present disclosure described above.

[0080] Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0081] Features, integers or characteristics described in conjunction with a particular aspect, embodiment or example of the present disclosure are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The disclosure is not restricted to the details of any foregoing embodiments. Examples of the present disclosure extend to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0082] The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

[0083] The various embodiments of the present disclosure may also be implemented via computer executable instructions stored on a computer readable storage medium, such that when executed cause a computer to operate in accordance with any other the aforementioned embodiments.

[0084] The above embodiments are to be understood as illustrative examples of the present disclosure. Further embodiments are envisaged. It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the embodiments, or any combination of any other of the embodiments. Furthermore, equivalents and modifications not described above may also be used without departing from the scope of the invention, which is defined in the accompanying claims.

CLAIMS:

1. A method for transmitting positioning reference signals, PRS, in a 5G New Radio, NR, communications network comprising a first base station configured to operate a first cell with a first OFDM subcarrier spacing, SCS, and a second base station configured to operate a second cell with a second OFDM SCS, the second SCS being higher than the first SCS, and wherein time resources of each cell are divided into subframes of a same predetermined duration and the subframes of the first and second cells are divided in time into one or more time slots based on their respective SCS, the method comprising

transmitting, by the first base station within a subframe of the first cell, a first PRS pattern with a first repetition frequency, and

transmitting, by the second base station within a corresponding subframe of the second cell, a second PRS pattern with a second repetition frequency,

wherein the second repetition frequency is higher than the first repetition frequency by a same factor as the second SCS is higher than the first SCS, and wherein the second PRS pattern corresponds to the first PRS pattern.

2. The method of claim 1, wherein the first PRS pattern is transmitted in each time slot of the first cell, and the second PRS pattern is transmitted in each time slot of the second cell such that the first repetition frequency is equal to the number of time slots in a subframe of the first cell, and the second repetition frequency is equal to the number of time slots in a subframe of the second cell.

3. The method of claim 2, wherein the first PRS pattern and the second PRS pattern are diagonal patterns with respect to the time slots of the first and second cells.

4. The method of any of claims 1 to 3, wherein the first PRS pattern is the same as the second PRS pattern.

5. The method of any preceding claim, wherein each time slot of the first cell and the second cell is divided in time into a predetermined number of symbols, and wherein transmitting the first and second PRS patterns includes transmitting at least part of the first and second PRS patterns in the first symbol of the first slot of the subframe of their respective cells.

6. The method of any preceding claim, wherein the transmission of the second PRS pattern in the second cell is shifted by at least one subcarrier with respect to the transmission of the first PRS pattern in the first cell.

7. The method of claim 1, wherein the second PRS pattern is a block diagonal form of the first PRS pattern, and each block of the second PRS pattern is shifted by at least one subcarrier with respect to the corresponding portion of the first PRS pattern.

8. A method for transmitting positioning reference signals, PRS, by a base station in a 5G New Radio, NR, communications network, the base station being configured to operate a cell with an OFDM subcarrier spacing, SCS, and the time resources of the cell being divided into subframes and each subframes being divided in time into one or more time slots based on the SCS, the method comprising

transmitting, by the base station within a subframe of the cell, a PRS pattern with a repetition frequency,

wherein, when the base station is operating with a first SCS, the base station transmits the PRS pattern with a first repetition frequency, and when the base station is operating with a second SCS, the base station transmits the PRS pattern with a second repetition frequency, and

wherein the second repetition frequency is higher than the first repetition frequency by a same factor as the second SCS is higher than the first SCS.

9. The method of any of claim 8, wherein the PRS pattern is transmitted in each time slot of the subframe such that the repetition frequency is equal to the number of time slots in the subframe.

10. The method of claim 9, wherein the PRS pattern is a diagonal pattern with respect to a time slot.

11. The method of claim 10, wherein each time slot of the cell is divided into a predetermined number of symbols, and wherein transmitting the PRS pattern includes transmitting at least part of the PRS pattern in the first symbol of the first slot of the subframe.

12. The method of claim 11, wherein at least part of the PRS pattern is transmitted in every symbol of each time slot.

13. A base station in a 5G New Radio, NR, communications network, the base station being configured to operate a first cell with an OFDM subcarrier spacing, SCS, and time resources of the cell being divided into subframes, wherein the base station is configured to perform the method of any of claims 8 to 12.

14. A 5G New Radio, NR, communications network comprising a first base station configured to operate a first cell with a first OFDM subcarrier spacing, SCS, and a second base station configured to operate a second cell with a second OFDM SCS, the second SCS being higher than the first SCS and time resources of each cell being divided into subframes of a same predetermined duration, wherein the communication network is configured to perform the method of any of claims 1 to 7.

15. A method for receiving position reference signals by a terminal device in a 5G New Radio, NR, communications network comprising a first base station operating a first cell with a first OFDM subcarrier spacing, SCS, and a second base station operating a second cell with a second OFDM SCS, the second SCS being higher than the first SCS, and wherein time resources of each cell are divided into subframes of a same predetermined duration, the method comprising

receiving, from the first base station within a subframe of the first cell, a first PRS pattern, and

receiving, from the second base station within a corresponding subframe of the second cell, a second PRS pattern,

wherein the first PRS pattern is transmitted within the subframe with a first repetition frequency and the second PRS pattern is transmitted within the corresponding subframe with a second repetition frequency,

wherein the second repetition frequency is higher than the first repetition frequency by a same factor as the second SCS is higher than the first SCS, and

wherein the second PRS pattern corresponds to the first PRS pattern.

16. The method of claim 15, wherein the receiving the first PRS and the second PRS includes sampling the first and second PRS signals at a sampling frequency corresponding to one of the first SCS or the second SCS.

17. The method of claim 16, wherein the subframes of the first and second cells are divided in time into time slots based on their respective SCS, and wherein, when the sampling frequency corresponds to the first SCS, the receiving the second PRS comprises

receiving a first portion of the second PRS in first time slot and a second portion of the second PRS in a second time slot.

18. The method of any of claims 15 to 17, wherein the subframes of the first and second cells are divided in time into time slots based on their respective SCS and each time slot of the cell is divided into a plurality of symbols, and wherein receiving the first PRS pattern includes receiving at least part of the first PRS pattern in the a first symbol of the first slot of the subframe of the first cell, and receiving the second PRS pattern includes receiving at least part of the second PRS pattern in the a first symbol of the first slot of the subframe of the second cell.

19. A terminal device configured to perform the method of any of claims 15 to 18.

20. A computer readable storage medium having stored thereon computer executable instructions which when executed by a computer cause the computer to perform the method of any one of claims 1 to 12 and 15 to 19.