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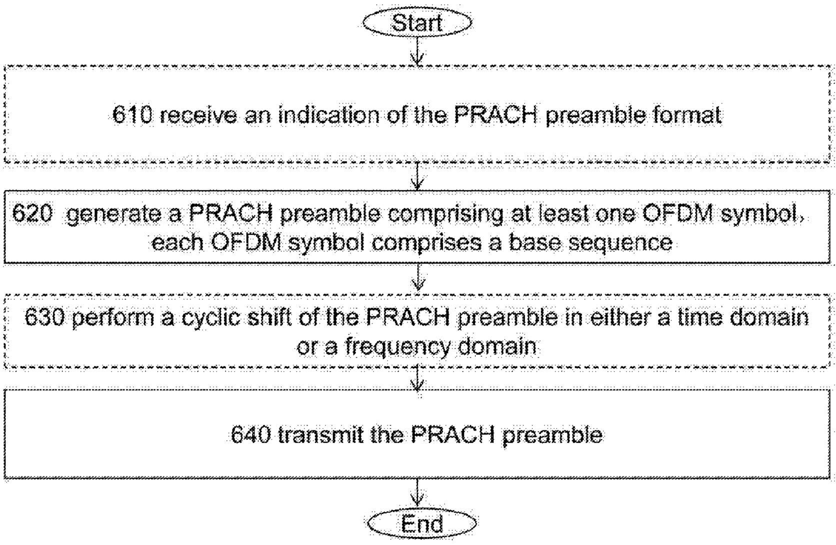

Fig. 6

(57) Abstract: Methods and apparatus are provided for random access. The U E generates a physical random access channel, PRACH, preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length; The UE transmits the PRACH preamble. The BS detects a PRACH preamble in m number of fast Fourier transform, FFT, windows, wherein m is an integer, and m times a length of the CP is no less than a length of one OFDM symbol.

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METHODS AND APPARATUSES FOR RANDOM-ACCESS

Technical Field

Embodiments of the present disclosure generally relate to random-access (RA).

Background

A random-access (RA) procedure is initiated by a user equipment (UE) to establish a communication link between the UE and a base station (gNB 1100).

5th Generation (5G) New Radio (NR) is the name chosen by Third Generation Partnership Project (3GPP) defining the global 5G telecommunications standard for the specification of a new 5G wireless air interface. 3G and 4G communications standards such as current Long Term Evolution (LTE)/LTE advanced standards were directed to connecting people. Instead, 5G/NR will connect everything and provide a unifying connectivity fabric for the next decade and beyond. 5G/NR may bring about a suite of families such as enhanced Mobile Broadband, massive Machine Type Communications, and Ultra-Reliable and Low Latency Communications (URLLC). URLLC is defined as one of the key target scenarios to be supported by 5G/NR and should provide low latency communications and high reliability (e.g. URLLC reliability requirement for one transmission of a packet is $1\text{-}10^{-5}$ for X bytes (e.g., 20 bytes) with a user plane latency of 1ms) and high reliability. Thus, concepts from current LTE/LTE advanced standards such as physical uplink control channel (PUCCH) for License Assisted Access (LAA) and enhanced LAA may be further improved upon to provide low latency and high reliability communications and thus further improve link performance.

The heterogeneous services in 5G

One main target of the 5G standard is the support a multitude of different services each with very different requirements. Those services include Enhanced Mobile Broadband (E-MBB) for high data transmission, Ultra-Reliable Low Latency Communication (URLLC) for devices requiring low latency and high link reliability and Massive Machine-Type Communication (M-MTC) to support a large number of low-power devices over a very long range.

With those different services in mind, the 5G standard should allow sufficient flexibility to support those various requirements efficiently at the same time.

The embodiments herein are related to the physical random-access channel (PRACH) to provide enough flexibility to support the heterogeneous services.

In the course of the standardisation efforts for 5G, the following agreements on the RA channel (RACH) have been reached:

For single/multi-beam operation,

- For multiple/repeated RACH preamble transmissions, consider only Option 1, option 2 and option 4, see Figure 2a.
- Option 1: cyclic prefix (CP) is inserted at the beginning of the consecutive multiple/repeated RACH OFDM symbols, CP/GT between RACH symbols is omitted and GT is reserved at the end of the consecutive multiple/repeated RACH symbols
- Option 2/4: The same/different RACH sequences with CP is used and GT is reserved at the end of the consecutive multiple/repeated RACH sequences
- For supporting various coverage and forward compatibility, flexibility in the length of CP/GT and the number of repeated RACH preambles and RACH symbols is supported
- Note: specific use of these three options may depend on RACH subcarrier spacing and TRP beam correspondence
- Note: Option 2 uses the same sequence in all symbols combined with an orthogonal cover code. Option 4 may use same or different sequences in all symbols.

Basic structures of a PRACH preamble

A PRACH preamble may be also referred to as RACH preamble, RA preamble or preamble. 3GPP has agreed on to use at least the basic PRACH preamble structure “Option 1” depicted in Figure 2a without precluding others. In this structure, the same PRACH sequence *S* is transmitted every OFDM symbol, which has the advantages to reduce the receiver complexity and to allow for a timing estimation of up to one OFDM symbol length.

Option 1 is based on repeating the same PRACH sequence (or PRACH OFDM symbol) without cyclic prefix (CP) between the repetitions, such that one PRACH

OFDM symbol acts as a cyclic prefix for the next PRACH OFDM symbol. Option 2/4 has CP inserted for each OFDM symbol. Option 2 has the same sequence in all OFDM symbols modulated with orthogonal cover code while Option 4 has same or different sequences S0-S12 for the repetitions. More details can be found in 3GPP R1-1702127.

In all options, the sequence consists of multiple OFDM symbols. The number of OFDM symbols is determined by the PRACH format.

Different PRACH formats for Option 1

PRACH format may also be referred to as RA preamble format, preamble format or format. A random-access preamble format comprises one or multiple random access preamble(s), a random-access preamble comprises a preamble sequence, and a preamble sequence comprises one or multiple PRACH OFDM symbol(s). The preamble sequence may also be referred to as a PRACH preamble sequence, a PRACH sequence, or a sequence.

A set of PRACH formats 0-5 has been proposed for the Option 1. The PRACH formats 0-5 have different lengths of the PRACH preamble such that they can be used for different coverage situations or for different beamforming techniques, see Figure 2b. Each format includes a PRACH burst comprising one or multiple PRACH OFDM symbols and a guard time (GT). The PRACH burst length ensures that the sequence is robust enough for the gNB 1100 to detect and the GT ensures it can tolerate the maximum latency. A slot is used as time unit on the horizontal axis with 14 PUSCH OFDM symbols in each slot but this number can differ.

Assuming 15kHz sub-carrier spacing, format 0 with ¼ OFDM symbol GT can support a coverage distance of up to 2.5 km while Format 5, with 3 OFDM symbols GT, can support a cell radius of up to 30 km. If larger distances need to be supported, new formats with larger GT would be defined.

Although Figure 2b shows multiple formats for Option1 but following the same principle, by varying sub-carrier, CP length, number of OFDM symbols etc, multiple formats may be prepared for other PRACH options, e.g., Option 2 and Option 4.

Summary

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

According to an aspect, there is provided a method performed by a user equipment, UE for performing a random access to a base station, BS, in a telecommunication network. The UE generates a physical random access channel, PRACH, preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length; The UE transmits the PRACH preamble.

According to further aspects of the invention there is provided a UE apparatus including a processor, a storage unit and a communications interface, where the processor unit, storage unit, and communications interface are configured to perform the method(s) as described.

According to further aspects of the invention there is provided a method performed by a base station, BS, in a telecommunication network for detecting a random access from a user equipment, UE. The BS receives a physical random access channel, PRACH, preamble. The PRACH preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length.

According to further aspects of the invention there is provided a method performed by a base station, BS, in a telecommunication network for detecting a random access from a user equipment, UE. The BS detects a PRACH preamble in m number of receive fast Fourier transform, FFT, windows, wherein m is an integer, and m times a length of the CP is no less than a length of one OFDM symbol. Optionally, a starting point of a ith FFT window is the starting point in time of a (i-1)th FFT window plus a time period, which is less than or equal to the length of the CP, wherein i is an integer, and $1 \leq i \leq m$.

According to further aspects of the invention there is provided a BS apparatus including a processor, a storage unit and a communications interface, where the processor unit, storage unit, and communications interface are configured to perform the method(s) as described.

The methods described herein may be performed by software in machine readable form on a tangible storage medium or computer readable medium e.g. in the form of a computer program comprising computer program code means adapted to perform all the steps of any of the methods described herein when the program is run on a computing device, BS or UE and where the computer program may be embodied on a computer readable medium. Examples of tangible (or non-transitory) storage media include disks, thumb drives, memory cards etc. and do not include propagated signals. The software can be suitable for execution on a parallel processor or a serial processor such that the method steps may be carried out in any suitable order, or simultaneously. For example, another other aspect of the invention there is provided a computer readable medium comprising a computer program, program code or instructions stored thereon, which when executed on a processor, causes the processor to perform a the methods as described herein.

In a further aspect of the invention there is provided a computer readable medium comprising a computer program, program code or instructions stored thereon, which when executed on a processor, causes the processor to perform the methods described or as described herein.

This acknowledges that firmware and software can be valuable, separately tradable commodities. It is intended to encompass software, which runs on or controls “dumb” or standard hardware, to carry out the desired functions. It is also intended to encompass software which “describes” or defines the configuration of hardware, such as HDL (hardware description language) software, as is used for designing silicon chips, or for configuring universal programmable chips, to carry out desired functions.

In a further aspect of the invention there is provided a telecommunication system comprising at least one of the UE as described herein, and/or at least one of the BS apparatus as described herein.

The preferred features may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the invention.

Brief Description of the Drawings

Further details, aspects and embodiments will be described, by way of example only, with reference to the drawings. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. Like reference numerals have been included in the respective drawings to ease understanding.

Figure 1 is a schematic overview of a telecommunication network according to some embodiments.

Figure 2a illustrates basic structures of PRACH preamble according to some embodiments.

Figure 2b illustrates proposed PRACH formats according to some embodiments.

Figure 3 illustrates some example PRACH preambles in a PRACH preamble set according to some embodiments.

Figure 4 illustrates a BS receives PRACH with beam sweeping according to some embodiments.

Figure 5 shows a TA ambiguity problem as solved by some embodiments herein.

Figure 6 is a simplified flow chart illustrating an exemplary method performed by a UE according to some embodiments.

Figures 7a-7b are simplified block diagrams illustrating an exemplary UE apparatus according to some embodiments.

Figure 8 illustrates CP and PRACH Sequence Lengths according to some embodiments.

Figure 9 illustrates a BS places multiple receive FFT windows shifted by CP according to some embodiments.

Figure 10 is a simplified flow chart illustrating an exemplary method performed by a BS according to some embodiments.

Figures 11a-11b are simplified block diagrams illustrating an exemplary BS apparatus according to some embodiments.

Detailed Description

Those skilled in the art will recognize and appreciate that the specifics of the examples described are merely illustrative of some embodiments and that the teachings set forth herein are applicable in a variety of alternative settings.

This innovative solution proposes a novel PRACH sequence based upon multiple base sequences. The PRACH sequence consists of multiple OFDM symbols. In each PRACH OFDM symbol it may use a different base sequence. These base sequences may be transmitted in frequency domain (following the well-known CP-OFDM technique) or in time domain (following the well-known SC-FDMA technique). Cyclic shifts may be applied to these base sequences in time domain or in frequency domain to further increase the number of PRACH preambles and hence increase the PRACH capacity. The PRACH preamble inserts cyclic-prefix (CP) for each sub-sequence. According to some embodiments, multiple PRACH preambles from multiple base sequences may be obtained to get a specific level of identifiability (uniqueness) with a certain number of OFDM symbols. This feature enables the successful detection of PRACH preamble (and UL synchronization) even when base station receives a fraction of the PRACH preamble. According to some embodiments, it is further proposed a receiving method where PRACH can be successfully detected even if uplink receive timing delay (delay spread plus round trip time) is much more than the length of the CP.

The base sequence may also be referred to as a sub-sequence, particularly when a PRACH preamble is referred to as a PRACH preamble sequence.

In some embodiments, ZC sequence is used just as an example of a base sequence, the skilled person will appreciated that they are not limited to ZC sequence, and the same scheme also applies to all sub-sequences.

The embodiments may have the following effects:

- Sequence Design for Increased PRACH capacity: New sequence allows a large increase in the PRACH capacity.

- *Sequence Design for No time ambiguity with Beam-Sweeping:* according to some embodiments, where PRACH preambles are designed for a certain level of identifiability or uniqueness, beam-sweeping time ambiguity problem which arises with Option 1 (same sequence repeated in each symbol) will disappear completely.

- *Sequence Design for Improved PRACH latency:* The PRACH sequences can be formed from combinations of multiple ZC sequences such that they are identifiable even upon a reception of a number of, not all, PRACH OFDM symbols in the PRACH preamble. This can be used to reduce the PRACH latency.

- *Handling of uplink PRACH delays larger than CP length:*

  - Successful PRACH Detection: The gNB can use the proposed receiving method to successfully detect the PRACH preambles even when the Received PRACH has a delay (delay spread + Round Trip Time) larger than the CP length.

  - Preamble Format Unification: As with this solution, the gNB is able to detect the PRACH from UEs located at larger distances than absorbable by the CP, the preamble formats can be the same between medium to large cells in terms of CP.

  - Energy Efficient PRACH Preambles: As some embodiments herein allows successful detection of PRACH preambles with smaller cyclic prefixes than round trip times, less energy gets wasted in CP making the RACH preambles more energy efficient.

Referring now to Figure 1, an example of part of a telecommunication system operating in accordance with at least some embodiments herein is illustrated schematically. The telecommunication system comprises a base station (BS) 100 and a UE 700. The telecommunication network may comprise multiple BS 1100 and multiple UEs.

Normally, when the UE 700 wants to access a radio access network, the UE 700 may establish a reliable communication link between the UE 700 and the BS 1100 by initiating a random-access (RA) procedure. In certain cases, BS may command the UE using DL resources to initiate an UL RA procedure.

Examples of the telecommunication that may be used in certain embodiments of the described apparatus, methods and systems may be at least one communication network or combination thereof including, but not limited to, communications networks based on wireless, cellular or satellite technologies such as mobile networks, Global

System for Mobile Communications (GSM), GPRS networks, Wideband Code Division Multiple Access (W-CDMA), CDMA2000 or Long Term Evolution (LTE)/LTE Advanced networks or any 2nd, 3rd, 4th or 5th Generation and beyond type communication networks and the like.

The UE 700 may be an automotive part with wireless communication capability mounted in a vehicle, a wearable device with wireless communication capability, a mobile terminal, or a wireless terminal, a mobile phone, a computer such as e.g. a laptop, a Personal Digital Assistants PDAs or a tablet computer, sometimes referred to as a surf plate, with wireless capability, or any other radio network units capable to communicate over a radio link in a wireless communications network. Please note that the term UE 700 used in this document also covers other wireless devices such as device-to-device (D2D) devices, Machine to machine (M2M) devices, even though they do not have any user. The wearable device, which is also referred to as wearable communication device, or electronic wearable portable device. The term wearable device refers to electronic technologies or computers that are incorporated into items of clothing and accessories, which can be worn on the body of a user to collect data. Generally, the wearable device has some form of communications capability and will allow a server and the wearer access to collect the data.

The base station (BS) 1100 is operable in a Radio Access Network (RAN) and serving a cell. The base station 1100 may be, e.g. a Radio Base Station (RBS), which sometimes may be referred to as e.g. “gNB”, “eNB”, “eNodeB”, “NodeB”, “B node”, gNodeB or BTS (Base Transceiver Station), depending on the technology and terminology used. The base stations may be of different classes such as e.g. macro eNodeB, home eNodeB or Pico base station, based on transmission power and thereby also cell size.

Example of embodiments of a method performed by a UE 700 performing a random access to a base station, BS, in a telecommunication network will now be described with reference to **Figure 6**. Actions that are optional are presented in dashed boxes. The method may comprise the following actions, which actions may be taken in any suitable order.

Action 610

The UE 700 may receive an indication of the PRACH configuration from the BS. The PRACH preamble will be transmitted by the UE 700 according to a PRACH configuration.

The indication of PRACH configuration, i.e., PRACH parameters, may comprise at least one of: PRACH preamble format, one or more cyclic shifts, and the time frequency resource where UEs will transmit the PRACH preambles, and a (explicit or implicit) set of base sequences. The indication of the set of base sequences may comprise at least one of: a length of the base sequence, a size of the base set, and each base sequences in the base set. See more details in Action 1010.

The base sequences in the base sequence set may be in a form of a rootSequenceIndex, and then the UE generates a base sequence, e.g., a Zaddoff Chu sequence, using the rootSequenceIndex.

3GPP would define a mapping where each base sequence indicator (a simple integer, for example) may represent the set of roots which corresponds to that. Upon receiving this indicator, all the UEs in a cell know which set of root sequences (or bases sequences) has been selected by base station for PRACH transmission.

Action 620

The UE 700 generates a physical random access channel, PRACH, preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol. Each OFDM symbol comprises a base sequence, and optionally a cyclic prefix, CP. The base sequence is from a base sequence set, which comprises one or more base sequences of a same length.

All base sequences in the set have a same length. The base sequence may be a Zadoff-Chu (ZC) sequence, an M sequence, a pseudo-noise (PN) sequence or any other sequence with desired auto- and cross correlation properties.

The base sequence in each OFDM symbol can be either the same or different.

According to an embodiment, each base sequence in the PRACH preamble is unique. In other words, each base sequence in a PRACH preamble set, which comprises all possible PRACH preambles can be generated from the base set allowed in a cell where the BS is serving is unique. It is unique within the cell where the BS is serving, i.e., where the UE is locating. However it is not necessary to be unique in all cells of telecommunication network. That’s to say, the same base sequence may be selected by UEs in two different cells.

According to another embodiment, every n number of consecutive base sequences in the PRACH preamble is unique, wherein n is an integer, and n≥2. In other words, every n number of consecutive base sequences in the PRACH preamble set is unique. It is unique within the cell the BS is serving, i.e., where the UE is locating. Considering all cells of telecommunication network, it may be also unique, but not necessary. The value of n is any integer which can uniquely distinguish the PRACH preamble only on the n number of OFDM symbol, e.g., 1 or 2, etc.

According to another embodiment, each base sequence in the base sequence set is unique in all cells of the telecommunication network. In other words, one base sequence is only comprised in one base sequence set, not repeated in any other base sequence set in other cells of the telecommunication network. A device in a core network may determine such a unique set for all cells served by BSs, and then inform the BSs of them, respectively.

Action 630

It is optional. According to an embodiment, the UE 700 performs a cyclic shift of the PRACH preamble in either a time domain or a frequency domain according to the PRACH configuration. When Action 630 is performed, a cyclic shifted PRACH preamble is transmitted in Action 640.

Performing a cyclic shift of the PRACH preamble means performing the same cyclic shift of all the sub-sequences in the PRACH preamble. Performing a cyclic shift of the PRACH preamble comprises one or more cyclic shifts in order to generate one or more cyclic shifted PRACH preamble. The indication of the cyclic shift may be received from the BS as part of PRACH configuration. The cyclic shifted PRACH preamble is as good as the PRACH preamble before cyclic shift applied. By performing the cyclic shift, the allowed set of PRACH preambles for the users in the cell becomes large.

Action 640

The UE transmits the PRACH preamble. Transmitting the PRACH preamble may be referred to as transmitting (640) a PRACH, a PRACH signal, or a preamble.

The base sequences which make data part of OFDM symbols may be transmitted in a time domain, e.g., as in Single-carrier FDMA (SC-FDMA) manner, or in a frequency domain, e.g., as in CP-OFDM manner. More specifically, there may be two possibilities how the base sequence makes a data part of one OFDM symbol.

One way is that base sequence transmission is performed in frequency domain, like conventional CP-OFDM manner. The base sequence is placed on PRACH allocated frequency sub-carriers, which may be assigned by the BS. Then IFFT is performed by the UE on this frequency placed base sequence to obtain the data part of the OFDM symbol. The other way is that base sequence transmission is performed in time domain, like in SC-FDMA manner: the UE would first do an FFT to convert the base sequence from time domain to frequency domain. Then these frequency domain coefficients (i.e., the FFT of base sequence) would be mapped on a time frequency grid corresponding to a PRACH frequency resource, which may be assigned by the BS. Then IFFT is performed by the UE on this frequency placed FFT-base-sequence to obtain the data part of the OFDM symbol. A fraction of the data part of the OFDM symbol is used as cyclic prefix (CP) for both cases.

According to some embodiment, a sum of a delay spread and a round trip delay of the UE is larger than the length of the CP of the PRACH symbols. This solution has the advantage of acquiring UL synchronization even in case of wherein a sum of a delay spread and a round trip delay larger than one OFDM symbol (use case for large cells). This solution has the advantage of acquiring UL synchronization also in case of beam sweeping at gNB side. Additionally, as a technical advantage, acquiring fast UL synchronization in case of low latency UE (e.g. URLLC) is also enabled. According to some embodiment, fast UL synchronization is achievable from a single PRACH symbol.

Figure 7a illustrates various components of an exemplary computing-based device 700 which may be implemented to include the functionality of the transmitting a PRACH as described, by way of example only, with respect to an UE 700 as described with reference to Figure 1.

The computing-based device 700 comprises one or more processors 702 which may be microprocessors, controllers or any other suitable type of processors for processing computer executable instructions to control the operation of the device in order to perform measurements, receive measurement reports, schedule and/or allocate communication resources as described in the process(es) and method(s) as described herein.

In some examples, for example where a system on a chip architecture is used, the processors 702 may include one or more fixed function blocks (also referred to as accelerators) which implement the methods and/or processes as described herein in hardware (rather than software or firmware).

Platform software and/or computer executable instructions comprising an operating system 704A or any other suitable platform software may be provided at the computing-based device to enable application software to be executed on the device. Depending on the functionality and capabilities of the computing device 700 and application of the computing device, software and/or computer executable instructions may include the functionality of perform measurements, receive measurement reports, determine communication resources and/or the functionality of the UE 700 according to the embodiments herein as described according to the embodiments herein.

The software and/or computer executable instructions may be provided using any computer-readable media that is accessible by computing based device 700. Computer-readable media may include, for example, computer storage media such as memory 704 and communications media. Computer storage media, such as memory 704, includes volatile and non-volatile, removable and non-removable media implemented in any method or technology. A data store 704A of the memory 704 is configured for storage of information such as computer readable instructions, data structures, program modules or other data, S.

Computer storage media may include, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transmission medium that can be used to store information for access by a computing device. In contrast, communication media may embody computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave, or other transport mechanism. As defined herein, computer storage media does not include communication media. Although the computer storage media (memory 704) is shown within the computing-based device 700 it will be appreciated that the storage may be distributed or located remotely and accessed via a network or other communication link (e.g. using communication interface 706).

The computing-based device 700 may also optionally or if desired comprises an input/output controller 710 arranged to output display information to a display device 712 which may be separate from or integral to the computing-based device 700. The display information may provide a graphical user interface. The input/output controller 710 is also arranged to receive and process input from one or more devices, such as a user input device 714 (e.g. a mouse or a keyboard). This user input may be used to set scheduling for measurement reports, or for allocating communication resources, or to set which communications resources are of a first type and/or of a second type etc. In an embodiment the display device 712 may also act as the user input device 714 if it is a touch sensitive display device. The input/output controller 710 may also output data to devices other than the display device, e.g. other computing devices via communication interface 706, any other communication interface, or a locally connected printing device/computing devices etc.

Figure 7b illustrates a scheme of an UE 700 as described with reference to Figure 1 and according to another embodiment. The UE 700 comprises a receiving module 781, a generating module 782, a cyclic shifting module 783, and a transmitting module 784, which are configured to perform the Actions 610-640, respectively.

Now the method will be described from a BS 1100 perspective. Example embodiments of method performed by a BS 1100 in a telecommunication network for detecting a random access from a User Equipment, UE will now be described with reference to a flowchart depicted in Figure 10. The method comprises the following actions, which actions may be taken in any suitable order. Actions that are optional are presented in dashed boxes.

Action 1010

The BS 1100 may transmit an indication of the PRACH configuration to the UE 700, e.g., as part of the downlink system information.

This indication of PRACH configuration may comprise at least one of: a PRACH preamble format, a PRACH time and frequency resource, one or more cyclic shifts allowed by the BS, and a (explicit or implicit) set of base sequences. The indication of the set of base sequences may comprise at least one of: a length of the base sequence, a size of the base set, and each base sequences in the base set. The PRACH preamble is prepared from the base set according to the preamble format and selected randomly among all possible preambles which are allowed in this cell according to the PRACH configuration. As all of the parameters related to PRACH configuration may be broadcasted as a part of the system information in the downlink, UEs when they get attached to the network, they are able to decode this information. For a multitude of use cases, for example initial access, connection re-establishment, handover, downlink/uplink data arrival or positioning purpose, UEs may initiate the RACH procedure by transmitting PRACH preamble according to the PRACH configuration.

Action 1020

The BS 1100 receives a physical random access channel, PRACH, preamble.

The PRACH preamble may comprise at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, and optionally a cyclic prefix, CP, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length.

Action 1030

The BS 1100 may detect the PRACH preamble in m number of fast Fourier transform, FFT, windows, wherein m is an integer, and m times a length of the CP is no less than a length of one OFDM symbol.

It is noted that Action 1030 is not limited to any specific PRACH preamble format.

A FFT window may be also referred to as a receive window, a receive FFT window or a window in short. According some embodiments, a starting point of a ith FFT window is the starting point in time of a (i-1)th FFT window plus a time period, which is less than or equal to the length of the CP, wherein i is an integer, and $1 \le i \le m$.

In general, the starting point of the CP of the received PRACH may fall in the FFT window. The FFT window in which a starting point of the CP of the received PRACH preamble is contained will provide the best correlation result.

The Length of one OFDM symbol comprises the data (sub-sequence) part plus the length of the cyclic prefix when the CP is included.

According some embodiments, CP*m may be no less than the length of the OFDM symbol length. In other words, CP*m may be at least be equal to the length of the OFDM symbol length, examples are given below.

Example 1:

CP=0.25ms, data part (D) = 0.75ms: OFDM_symbol_length= 0.25+0.75 = 1ms

Assuming m=3 gives 3*CP=0.75 < OFDM. m=3 will not work.

Assuming m=4 gives 4*CP=1 = OFDM, so m=4 works.

Example 2:

CP=0.3 ms, data part (D) = 0.7 ms: OFDM_symbol_length= 0.3+0.7 = 1 ms

Assuming m=3 gives 3*CP=0.9 < OFDM, so m=3 will not work.

Assuming m=4 gives 4*CP=1.2 > OFDM, m=4 works.

Figure 11a illustrates various components of an exemplary computing-based device 1100 which may be implemented to include the functionality of the transmitting a PRACH as described, by way of example only, with respect to a BS 1100 as described with reference to Figure 1.

The computing-based device 1100 comprises one or more processors 1102 which may be microprocessors, controllers or any other suitable type of processors for processing computer executable instructions to control the operation of the device in order to perform measurements, receive measurement reports, schedule and/or allocate communication resources as described in the process(es) and method(s) as described herein.

In some examples, for example where a system on a chip architecture is used, the processors 1102 may include one or more fixed function blocks (also referred to as accelerators) which implement the methods and/or processes as described herein in hardware (rather than software or firmware).

Platform software and/or computer executable instructions comprising an operating system 1104A or any other suitable platform software may be provided at the computing-based device to enable application software to be executed on the device. Depending on the functionality and capabilities of the computing device

1100 and application of the computing device, software and/or computer executable instructions may include the functionality of perform measurements, receive measurement reports, determine communication resources and/or the functionality of the BS 1100 according to the embodiments herein as described according to the embodiments herein.

The software and/or computer executable instructions may be provided using any computer-readable media that is accessible by computing based device 1100. Computer-readable media may include, for example, computer storage media such as memory 1104 and communications media. Computer storage media, such as memory 1104, includes volatile and non-volatile, removable and non-removable media implemented in any method or technology. A data store 1104A of the memory 1104 is configured for storage of information such as computer readable instructions, data structures, program modules or other data, S.

Computer storage media may include, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transmission medium that can be used to store information for access by a computing device. In contrast, communication media may embody computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave, or other transport mechanism. As defined herein, computer storage media does not include communication media. Although the computer storage media (memory 1104) is shown within the computing-based device 1100 it will be appreciated that the storage may be distributed or located remotely and accessed via a network or other communication link (e.g. using communication interface 1106).

The computing-based device 1100 may also optionally or if desired comprises an input/output controller 1110 arranged to output display information to a display device 1112 which may be separate from or integral to the computing-based device 1100. The display information may provide a graphical user interface. The input/output controller 1110 is also arranged to receive and process input from one or more devices, such as a user input device 1114 (e.g. a mouse or a keyboard). This user input may be used to set scheduling for measurement reports, or for allocating communication resources, or to set which communications resources are of a first type and/or of a second type etc. In an embodiment the display device 1112 may also act as the user input device 1114 if it is a touch sensitive display device. The input/output controller 1110 may also output data to devices other than the display device, e.g. other computing devices via communication interface 1106, any other communication interface, or a locally connected printing device/computing devices etc.

Figure 11b illustrates a scheme of a BS 1100 as described with reference to Figure 1 and according to another embodiment. The BS 1100 comprises a transmitting module 1181, a receiving module 1182, and a detecting module 1183, which are configured to perform the Actions 1010-1030, respectively.

More detailed embodiments of the telecommunication system will now be described.

Sequences and PRACH Preambles

In this proposal PRACH preambles are generated from a set of base sequences (or sub-sequences). These sub-sequences have the same length. One example of this base set is the set of ZC sequences of a certain length L, with this set comprising up to (L-1) ZC sequences corresponding to all possible roots 1 to L-1. Some further selection may be applied to this base set to choose certain roots with specific properties like better cross correlations with each other and/or better power spectrum characteristics such as cubic metric.

PRACH Preamble set:

Each single PRACH preamble consists of multiple sub-sequences (which can be the same or different), taken from the base set. Each PRACH preamble consists of N PRACH OFDM symbols, each OFDM symbol with its data (sub-sequence) and cyclic prefix (CP). Thus, the proposed PRACH preamble construction falls under the Option 4 of 3GPP PRACH discussions. The data part of OFDM symbol is a sub-sequence from the base set. According to an embodiment, the base sequence is used in the frequency domain, and then after inverse fast Fourier transform (IFFT), a cyclic prefix is added in the time domain. Another way to construct preambles is to use the base sequence in time domain, perform FFT operation to convert it in frequency domain, use these frequency coefficients on RACH frequency resources, perform IFFT and transmit after adding CP.

A PRACH preamble set comprises all possible preambles which are in a length of N OFDM symbols and are constructed by making all possible combinations of sub-sequence taken from the base set. Then the PRACH preamble set is extended by generating multiple cyclic shifts of each distinct preamble formed in the previous step. In this case, a single cyclic shift is applied to the whole preamble, meaning that all sub-sequences are shifted with this specific integer cyclic shift. These cyclic shifts can be applied to the base sequences either in time domain or in frequency domain. In Figure 3, only some PRACH preamble examples in a PRACH preamble set have been shown, where the PRACH preambles has a length N=4 OFDM symbols.

Suppose a, b, c, d denote base sequences of the same length L, e.g., ZC sequences of length L, with different roots. x^y donates a base sequence x with a cyclic shift y, for instance, a^i denotes the base sequence a with a cyclic shift "i". GT denotes the guard time. Seq donates a base sequence.

PRACH Capacity and Selection of "SUITABLE" PRACH Preambles

Unconstrained PRACH Capacity:

If the base set of ZC sequences is selected with the length (L) of 139 complex symbols, the base set may have L-1 (138) sequences of different roots from 1 to 138. If we assume that all roots are used and restrict that only 10 cyclic shifts can be applied to these sequences, the capacity of Option 1 would be (138 sequences) * (10 cyclic shifts) = 1380. For the proposed scheme with such a base set, and for the case if PRACH preamble has 4 OFDM symbols (N=4), the available PRACH preambles are [(L-1)^N sequences] * (10 cyclic shifts) = (138)^4 * 10 = 362,673,9360. This capacity increases exponentially with the number of PRACH OFDM symbols for the proposed scheme. This capacity increase is a major advantage of this proposal over Option1 and Option 2.

ZC Roots:

ZC sequences show better cross-correlation properties among different roots if the difference of these roots is relative prime with respect to the length of the ZC sequence (L). Similarly, power spectrum characteristics of some roots may be better than others. Thus, the number of sub-sequences which should preferably be used for the above computation (both Option 1 and the proposed scheme) could be less than L-1.

Different Cyclic Shifts:

As PRACH preambles are used to get the UL synchronization for the UEs, not all possible cyclic shifts can be used. Depending upon the cell size, channel conditions and network scenarios, only a subset of cyclic shifts can be applied. For precise PRACH capacity calculation, this factor also might be taken into account. Reduction of capacity due to restriction on usage of cyclic shifts applies to capacity of Option 1, Option 2 and the proposed PRACH sequences in the same way.

PRACH Preamble Selection:

If PRACH preambles are formed without any constraint on how many different sub-sequences constitute a PRACH preamble, and different PRACH preambles differ from each other on how many OFDM symbols, PRACH capacity becomes huge but there are two important disadvantages:

- The complexity of the PRACH detection at gNB could be enormous.
- There could be different PRACH preambles which are same for most part but differ with each other on one or few OFDM symbols, resulting in increased miss-detection and false-alarm probabilities.

Selected PRACH Preambles with Limited Detection Complexity

To keep the PRACH detection complexity at gNB within reasonable limits, it could be important to limit the use of PRACH preambles in each cell constructed from a base sequence set comprising a small number of distinct sub-sequences and prefer the cyclic shifted versions of these sequences as much as possible. Cyclic shifted versions have not only the advantage of reduced complexity detection at gNB but also enjoy better cross-correlation properties. In case of ZC sequences, cyclic shifted versions of the same root sequence are orthogonal. Thus PRACH preambles which are cyclic shifted versions of each other would be orthogonal to each other.

As an example, if PRACH preamble consists of N=4 OFDM symbols, but it is restricted such that each cell uses only 2 sub-sequences to construct available preamble set, that is to say that the set of the base sequences has only two base sequences, the number of available preambles (without cyclic shift) becomes

2*2*2*2 = 2^4 = 16. The preamble set can be further extended (step 2 of Preamble construction) by creating cyclic shifted preambles for each preamble formed in step 1. If sub-sequences are ZC sequences of length L= 139 complex symbols and every 13th cyclic shift can be used (i.e., 10 possible cyclic shifts), the set of available PRACH preambles has size 2^N * (10) = 2^4 * (10) = 160.

If 3 different sub-sequences constitute a PRACH preamble set in each cell, the number of available PRACH preambles becomes 3^N * (10) = 3^4 * (10) = 810.

In one possible strategy, a device in the core network can choose to assign different sets of base sequences to neighbouring cells. In case, 3 distinct sub-sequences are assigned to each cell, the number of independent sets is (L-1)/3 = 138/3 = 46. Thus 46 neighbouring cells can be allocated the preambles where PRACH preambles (even the sub-sequences) of each cell are completely unique, which means it is unique in all cells.

The BS may send the PRACH configuration to be used in a cell as part of the downlink system information.

Selected PRACH Preambles with “Better” Identifiability

Although the use of all permutations of distinct sub-sequences may allow a major increase in the PRACH capacity, many of the resulting PRACH preambles will only differ for a small fraction of PRACH duration. This may result in increased miss-detection and false alarm. The other issue is with identifiability of PRACH preambles which could be extremely important for scenarios when gNB is not able to receive the complete PRACH preamble. This would be a typical use case for beam-sweeping scenarios. Allowing all permutations of sub-sequences may make a correct PRACH detection impossible without receiving the complete PRACH preamble.

To have better identifiability among different PRACH preambles even when fewer PRACH OFDM symbols are received, it would be important to restrict the usage of PRACH preambles in each cell such that they are “unique” within those many PRACH OFDM symbols, which are a part, not the whole, of the PRACH preamble.

Uniqueness within 1 OFDM Symbol:

If it is desired that two PRACH preambles are identifiable even if a single PRACH OFDM symbol is received at gNB, each OFDM symbol of each PRACH preamble is unique. Thus, the preamble set for each cell may be such that no sub-sequence is repeated not only in one preamble but also in the set of available preambles, i.e., each constituent sub-sequence appears only once. Thus, for N=4 length PRACH preamble, 4 distinct sub-sequences may be employed in each preamble. Example of two such preambles would be "abcd" and "efgh" (CP not mentioned here for sake of simplicity). Step 2 of preamble construction would allow generating further sequences with the cyclic shifts applied to these two PRACH sequences.

Uniqueness within 2 OFDM Symbols:

If it is desired to have PRACH preambles which can be uniquely identified upon reception of 2 PRACH OFDM symbols, allowed PRACH preamble set may be such that every 2 OFDM symbols for all preambles in this allowed preamble set are unique. Further to have correct time identifiability upon reception of 2 OFDM symbols in each preamble, each preamble may be unique within itself for each set of 2 OFDM symbols. As an example, a 4 OFDM symbol length preamble consisting of "aaab" does not satisfy this requirement as the OFDM symbol (1, 2) and OFDM symbol (2, 3) are same and would not let gNB identify the correct timing.

Suppose we have a set of ZC sub-sequences of L=139 complex symbols ("a", "b", "c", "d"), we can construct a set of 5 PRACH preambles which are unique for any 2 OFDM symbols (CP is not shown below):

"aaba", "acad", "bbcb", "bdcc", "cdda"

Thus, reception of any 2 OFDM symbols would allow gNB to distinctly identify which part of which preamble it has received. So, it can identify the PRACH preamble and resolve completely the timing of the sender UE.

These 5 sequences can then be extended with allowed cyclic shifts to get a sufficient number of preambles available in each cell. If 13 cyclic shifts are allowed (every 10^{th} cyclic shift for length 139), gNB would get 13*5 = 65 possible preambles which is quite a reasonable number (more than LTE PRACH allocation of 64 preambles per cell) to keep the probability of 2 users choosing the same preamble for PRACH transmission reasonably low. The cyclic shifted versions of the same preamble may be prioritized as much as possible as they allow orthogonality thanks to ZC properties.

Although it is difficult to come up with a closed form analytical formula (equation) which can provide directly the preambles with a desired level of identifiability/uniqueness, a simple computer program can easily build such preambles from a base set.

Time Ambiguity (TA) Resolution in Beam Sweeping Scenarios

PRACH receiving with beam sweeping

For high frequency, to improve the coverage, beamforming and beam sweeping is used.

The antenna with multiple elements can be used to form a narrow beam with very high gain to cover one specific direction. Beams can sweep the whole coverage area of the serving cell. Since one beam can only cover a very narrow area, it is less possible for gNB with beam sweeping to support frequency division multiplexed (FDMed) multi-UE multiplexing because the probability of two or more UEs under scheduling located in the same beam is much smaller than that of a wide beam, therefore, it limits the possibility to multiplex those two users in frequency in a given beam. So it could be very often that just a single UE is scheduled in one beam and considering the huge bandwidth of high frequency, the resource block scheduled to this UE could be huge. To improve the scheduling flexibility, it is envisaged to adopt a short beam duration in time domain to reduce the scheduled resource block size. This very short duration is called “mini-slot” which could be as short as 1 or 2 OFDM symbols long.

As illustrated in Figure 4, several sequential beams may be used within the whole duration of the PRACH burst. Beam duration is selected as an integer number of PUSCH symbols which includes CP and different SCS (subcarrier spacing) could be used for PUSCH and PRACH which means the PUSCH and PRACH symbol lengths could be different.

The beam duration could be a mini-slot if a low SCS is used or several complete slots if a high SCS is used.

Coming back to PRACH receiving with beam sweeping, only a number of segments of the whole burst can be received with beam sweeping when the beam duration is less than the PRACH burst length. The gNB might be able to detect the PRACH preamble and TA value from the received segment(s).

Time Advance (TA) Ambiguity

TA is used by a UE to advance its timings of transmissions to the BS so as to compensate for a propagation delay. A propagation delay may also be referred to as a propagation latency, a round trip propagation delay or latency, a round trip time (RTT), a latency due to propagation, a latency etc.

One target of PRACH is for the terminal to achieve UL synchronization. When a terminal is switched on, it will synchronize with the DL first and read the system information for UL access (including relevant PRACH parameters). When the terminal initiates an UL transmission without valid TA, it sends a PRACH burst with 0 TA (Time Advance) from its DL timing and certainly, this burst will be received by the gNB after a round trip propagation delay. In the response of PRACH, the gNB can indicate the terminal a TA value so that UL transmission with this indicated TA value can be aligned in time with the gNB clock.

A TA ambiguity problem when gNB only receives with a specific beam during the FFT duration is shown in Figure 5 with respect to different PRACH preamble options, namely Option 1, Option 2 and Option 4. “Proposal” donates the solution proposed according to some embodiment of the invention. The gNB 1100 receiving (Rx) window is shown. T donates the length of one OFDM symbol. In this figure beam duration is equal to, e.g., 3 OFDM symbols. When the latency due to propagation is less than one OFDM symbol, the gNB can detect the difference from phase shift in frequency domain, i.e. ΔT. In this case $TA = \Delta T < T$. Option 1 and Option 4 can provide precis timing, but not Option 2. However when the latency is bigger than one OFDM symbol, i.e., $TA > T$, and gNB receives a fraction of the PRACH (like what may happen with beam-sweeping, beam duration is 3 OFDM symbols), the gNB can only detect Δt again with Option 1. The detected Δt part is the part less than one OFDM symbol from the segment received in one beam. In this case, TA = x OFDM symbol period + ΔT, here x is 2. Since gNB doesn't know UE position within the cell, it cannot be certain of the TA value. It is called TA ambiguity for latency bigger than one OFDM symbol. Such a TA ambiguity problem can only be solve by the receiving method according to some embodiments of the invention.

When gNB uses beam sweeping, employing Option 1 which consists of repetition of one sub-sequence multiple times will cause time ambiguity upon reception of a fraction of PRACH preamble. The problem may be more severe with Option 2 as gNB would not even be able to detect the preamble due to incomplete reception of orthogonal cover code. This time ambiguity problem can be solved by using the PRACH preambles formed for better identifiability as explained. These preambles have controlled repetition of sub-sequences designed for certain level of uniqueness and thus even the reception of a fraction of PRACH preamble allows gNB to correctly identify the PRACH preamble and the correct UE timing without TA ambiguity.

Active time per beam of 1 OFDM Symbol:

If gNB is using beam sweeping where each beam is active for 1 OFDM symbol time, each OFDM symbol of PRACH preamble may be unique. Thus the preamble set may be such where no sequence is repeated not only in one preamble but also in the set of available preambles.

Active time per beam of 2 OFDM Symbol:

If gNB is using beam sweeping where each beam is active for at least 2 OFDM symbols, gNB may indicate the users to use the PRACH preamble set where PRACH preambles are unique for each 2 OFDM symbols.

Please note that as UE timing is not known at gNB, for PRACH preambles which are unique within “n” OFDM symbols, gNB only needs to receive “n” complete OFDM symbols. Practically it would require gNB to have the beam duration of “n+1” OFDM symbols to completely capture “n” complete OFDM symbols.

Prime Use Cases for Application of Proposed PRACH Preambles

The proposed PRACH preamble can be quite useful in the following use cases where PRACH preambles of Option 1 are not very efficient:

gNB employing Beam-Sweeping:

When gNB is employing beam-sweeping, repetition of same sequence multiple times as PRACH preamble and the fact that gNB would receive a fraction of the transmitted preamble introduces time ambiguity. Then subsequent communication would resolve this ambiguity or it may result in interference or wasted communication in certain scenarios. All of this would require subsequent communications adding latency and increased energy consumption. The proposed PRACH can successfully resolve this time ambiguity arising for gNB beam-sweeping scenarios.

This quick UL synchronization with the proposed PRACH preambles translates into two big advantages: latency reduction and energy efficiency

Furthermore, some embodiments herein describe the criteria to adjust the uniqueness of PRACH preambles which are suitable for the beam sweeping durations.

***Large PRACH capacity for mMTC relevant use cases*:**

Independent of the use of beam-sweeping or not, the proposed solution is very beneficial for scenarios when there are a large number of MTC devices with severe energy constraints. When these devices transmit and they initiate a RACH procedure, the RACH collision probability should be minimal to avoid waste of energy. The proposed preamble provides very large PRACH capacity as it allows combinations of multiple sub-sequences used in the same sequence. This large PRACH capacity directly translates into very small collision probability providing a very positive energy benefit.

Uplink Delays (Delay Spread plus Round trip Time) Exceeding the Cyclic Prefix

Most designs of PRACH preamble format with cyclic prefix keep this constraint that the length of the cyclic prefix should be larger than the uplink delay which is sum of the delay spread (DS) plus the round trip time (RTT). At least some embodiments herein propose a receiving method with which it is not necessary to have the cyclic prefix larger than DS+RTT but only large than DS.

The idea is to do multiple fast Fourier transform (FFT) windows per OFDM symbol delayed each by CP length as shown in Figure 9. The FFT window for which the CP part of the window contains the starting point of the received PRACH symbol will provide the best correlation results. When this idea is applied to PRACH detection, contiguous OFDM symbols can be coherently combined which are received with the same lag FFT window. The power comparison of results from multiple windows will indicate which FFT window contains the start of the PRACH preamble and indicate the correct UE timing.

Advantage of some embodiments comprises handling of uplink PRACH delays larger than CP length:

- Successful PRACH Detection: The gNB can use the proposed receiving method to successfully detect the PRACH preambles even when the Received PRACH has a delay (delay spread + Round Trip Time) larger than the CP length.

- Preamble Format Unification: With some embodiments herein, gNB is able to detect the PRACH from UEs located at larger distances than absorbable by the CP, the preamble formats can be the same between medium to large cells in terms of CP.

- Energy Efficient PRACH Preambles: As some embodiments herein allow successful detection of PRACH preambles with smaller cyclic prefixes than round trip times, less energy gets wasted in CP making the RACH preambles more energy efficient.

Figure 9 shows a gNB placing multiple receive (FFT) windows shifted by CP. The embodiment according to Figure 9 is not limited to any specific PRACH Option or any specific PRACH preamble format.

This aspect is to fight the delay spread. In case of PRACH preamble transmission as uplink synchronization is not there, CP would absorb the round trip time as well. For medium to large cells, RTT could be many times more than the delay spread thus very large CPs are required. This translates into large power consumption at the UEs in CP which are thrown away at the receiver so this energy gets completely wasted.

Figure 8 shows the PRACH sequence and CP lengths for PRACH preamble formats used in LTE. T-CP (in Ts) donates length of CP in Timeslots, T-CP (in ms) length of CP in millisecond, T-SEQ (in Ts) donotes length of Sequence in Timeslots, T-SEQ (in ms) donates length of Sequence in milisecond, Total Length (in Ts) donates a total length in Timeslots, Guard Time (in ms) is GT in milisecond, and Cell Radius is roughly the distance that this specific preamble format allows for correct detection.. For format 0 and 2, CP is 11% of the PRACH transmission. For formats 1 and 3, CP length is 46% and 30% of the PRACH transmission length respectively.

This clearly indicates the important fraction of UE energy which gets wasted in CP. Keeping in view these configurations, the embodiments herein may be particularly applicable for mMTC devices where energy efficiency is the prime metric of communication.

Innovative aspects of the embodiments may comprise at least one of:

- PRACH preamble comprising of multiple sub-sequences with cyclic prefix introduced for each sub-sequence.

- PRACH preamble where sub-sequences of same length and different roots are used in each preamble with cyclic prefix.

- PRACH preamble construction which allows unique identifiability of the preamble and timing resolution upon reception of a fraction of the preamble.

- PRACH preamble construction where PRACH preamble capacity and the detection complexity (in terms of how many different sub-sequences are allowed to make PRACH preamble set in a cell) trade-off can be solved.

- PRACH preamble construction for beam-sweeping where a fraction of PRACH preamble reception at gNB leads to successful PRACH detection and resolution of time ambiguity

- PRACH preamble construction for beam-sweeping which can be adapted to have PRACH detection and TA resolution for any number of OFDM symbols (1, 2, 3, etc) to match (or adjust with) the beam duration.

- PRACH preamble leading to increase of PRACH capacity and extremely low collision probability.

- Receiving method for correct PRACH detection by placing multiple receive FFT windows delayed each by CP allowing successful PRACH detection when the sum of the DS and RTT may be larger than CP. In the prior art detection of PRACH preamble consist of using only one receive window which is aligned to the downlink timing.

- Receiving method for correct PRACH detection by placing multiple FFT windows delayed by CP where multiple OFDM symbols of the same lag window can be combined coherently or non-coherently to obtain better detection performance of the correct timing.

- Receiving method for correct PRACH detection by placing multiple FFT windows delayed by CP which allows UL synchronization from PRACH even if CP of PRACH is smaller than DS+RTT allowing the unification of PRACH configurations.

The term 'computer' is used herein to refer to any device with processing capability such that it can execute instructions. Those skilled in the art will realize that such processing capabilities are incorporated into many different devices and therefore the term 'computer' or 'computing device' includes PCs, servers, base stations, eNBs, network nodes and other network elements, mobile telephones, UEs, personal digital assistants, other portable wireless communications devices and many other devices.

Those skilled in the art will realize that storage devices utilized to store program instructions can be distributed across a network. For example, a remote computer may store an example of the process described as software. A local or terminal computer may access the remote computer and download a part or all of the software to run the program.

Alternatively, the local computer may download pieces of the software as needed, or execute some software instructions at the local terminal and some at the remote computer (or computer network). Those skilled in the art will also realize that by utilizing conventional techniques known to those skilled in the art that all, or a portion of the software instructions may be carried out by a dedicated circuit, such as a DSP, programmable logic array, or the like.

Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person.

It will be understood that the benefits and advantages described above may relate to one example or embodiment or may relate to several examples or embodiments. The examples or embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages.

Any reference to 'an' item refers to one or more of those items. The term 'comprising' is used herein to mean including the method blocks, features or elements identified, but that such blocks, features or elements do not comprise an exclusive list and a method or apparatus may contain additional blocks, features or elements.

The steps of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. Additionally, individual blocks may be deleted from any of the methods without departing from the spirit and scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

It will be understood that the above description of a preferred embodiment is given by way of example only and that various modifications may be made by those skilled in the art. Although various embodiments have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this disclosure.

Claims

1. A method performed by a User Equipment, UE, for performing a random access to a base station, BS, in a telecommunication network, comprising:

- generating (620) a physical random access channel, PRACH, preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length;

- transmitting (640) the PRACH preamble.

2. The method as claimed in claim 1, wherein each base sequence in the PRACH preamble is unique.

3. The method as claimed in any one of claims 1 - 2, wherein every n number of consecutive base sequences in the PRACH preamble is unique, wherein n is an integer, and n≥2.

4. The method as claimed in any one of claims 1 - 3, wherein each base sequence in the base sequence set is unique in all cells of the telecommunication network.

5. The method as claimed in any one of claims 1 - 4, further comprising performing (630) a cyclic shift of the PRACH preamble in either a time domain or a frequency domain.

6. The method as claimed in any one of claims 1 - 5, further comprising receiving (610) an indication of the PRACH configuration.

7. The method as claimed in claim 6, wherein the PRACH configuration comprises an indication of the base sequence set.

8. The method as claimed in any one of claims 1 - 7, wherein a sum of a delay spread and a round trip delay of the UE is larger than the a length of one PRACH symbol.

9. A method performed by a base station, BS, in a telecommunication network for detecting a random access from a User Equipment, UE, comprising:

- receiving (1020) a physical random access channel, PRACH, preamble;

wherein the PRACH preamble comprising at least one orthogonal frequency-division multiplexing, OFDM, symbol, wherein each OFDM symbol comprises a base sequence, wherein the base sequence is from a base sequence set, which comprises one or more base sequences of a same length.

10. The method as claimed in claim 9, further comprising detecting (1030) the PRACH preamble in m number of fast Fourier transform, FFT, windows, wherein m is an integer, and m times a length of a cyclic prefix, CP, is no less than a length of one OFDM symbol when the CP is comprised in the OFDM symbol.

11. The method as claimed in claim 10, wherein a starting point of a ith FFT window is the starting point in time of a (i-1)th FFT window plus a time period, which is less than or equal to the length of the CP, wherein i is an integer, and $1 \leq i \leq m$.

12. The method as claimed in any one of claims 9 - 11, further comprising transmitting (1010) an indication of the PRACH configuration to the UE.

13. The method as claimed in claim 12, wherein the PRACH configuration comprises an indication of the base sequence set to the UE.

14. The method as claimed in any one of claims 9 - 13, wherein the BS is performing beam sweeping.

15. A computer readable medium comprising program code stored thereon, which when executed on a processor, causes the processor to perform a method according to any one of claims 1-8 or any one of claims 9-14.

16. A non-transitory computer readable medium having computer readable instructions stored thereon for execution by a processor to perform the method according to any one of claims 1-8 or any one of claims 9-14.

17. The non-transitory computer readable medium of claim 16 comprising at least one of: a hard disk, a Compact Disc, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, an Electrically Erasable Programmable Read Only Memory and a Flash memory and a Solid State Drive.

18. A user equipment, UE, apparatus (700) comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 1-8.

19. A base station, BS, apparatus (1100) comprising a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method as claimed in any one of claims 9-14.

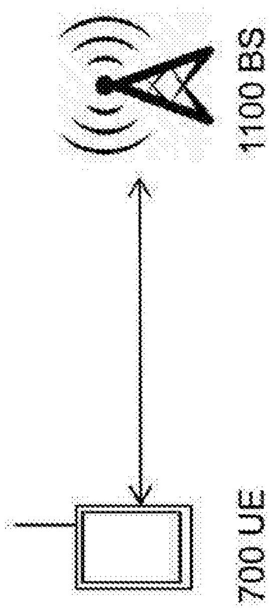

Fig. 1

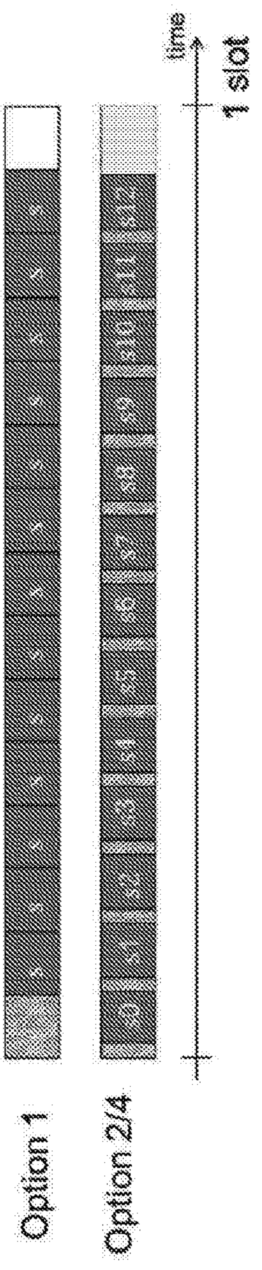
Option 1
Option 2/4
time
1 slot

Fig. 2a

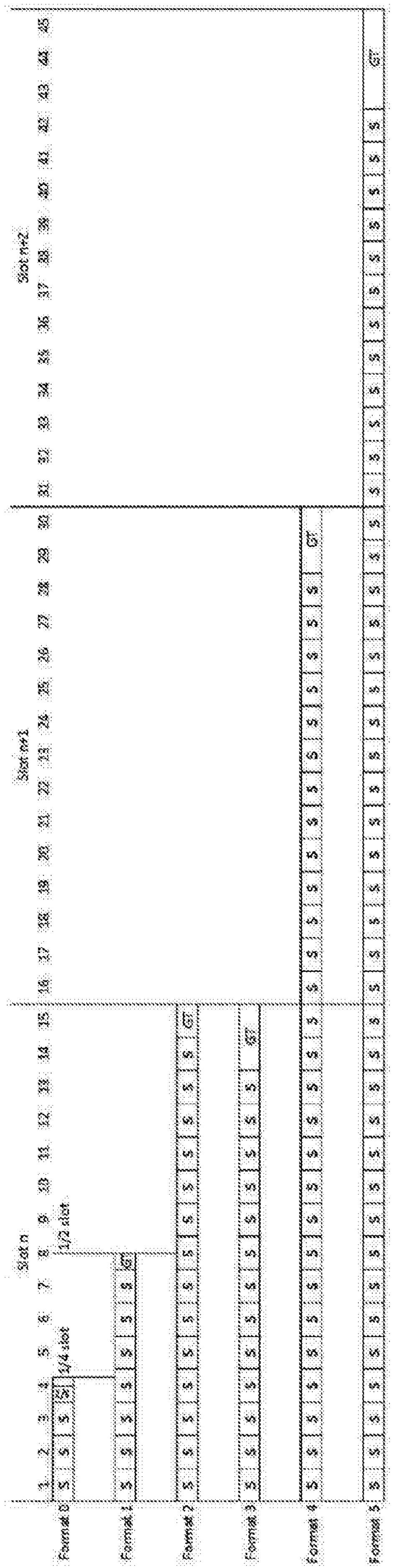
Slot n
Slot n+1
Slot n+2
1/4 slot
1/2 slot
Format 0
Format 1
Format 2
Format 3
Format 4
Format 5
GT

Fig. 2b

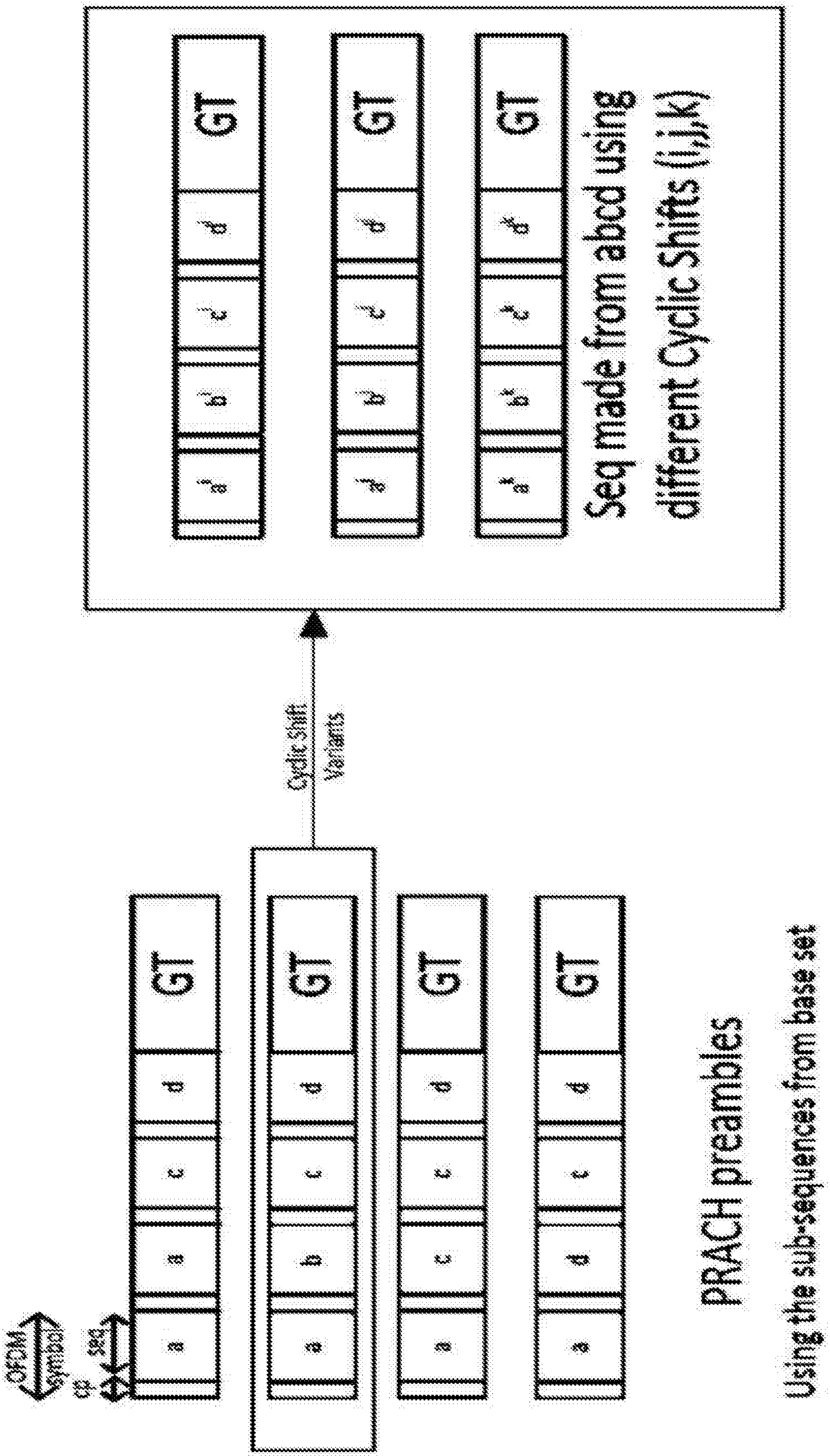
OFDM symbol
CP
Seq
PRACH preambles
Using the sub-sequences from base set
Cyclic Shift Variants
GT
Seq made from abcd using different Cyclic Shifts (i,j,k)

Fig. 3

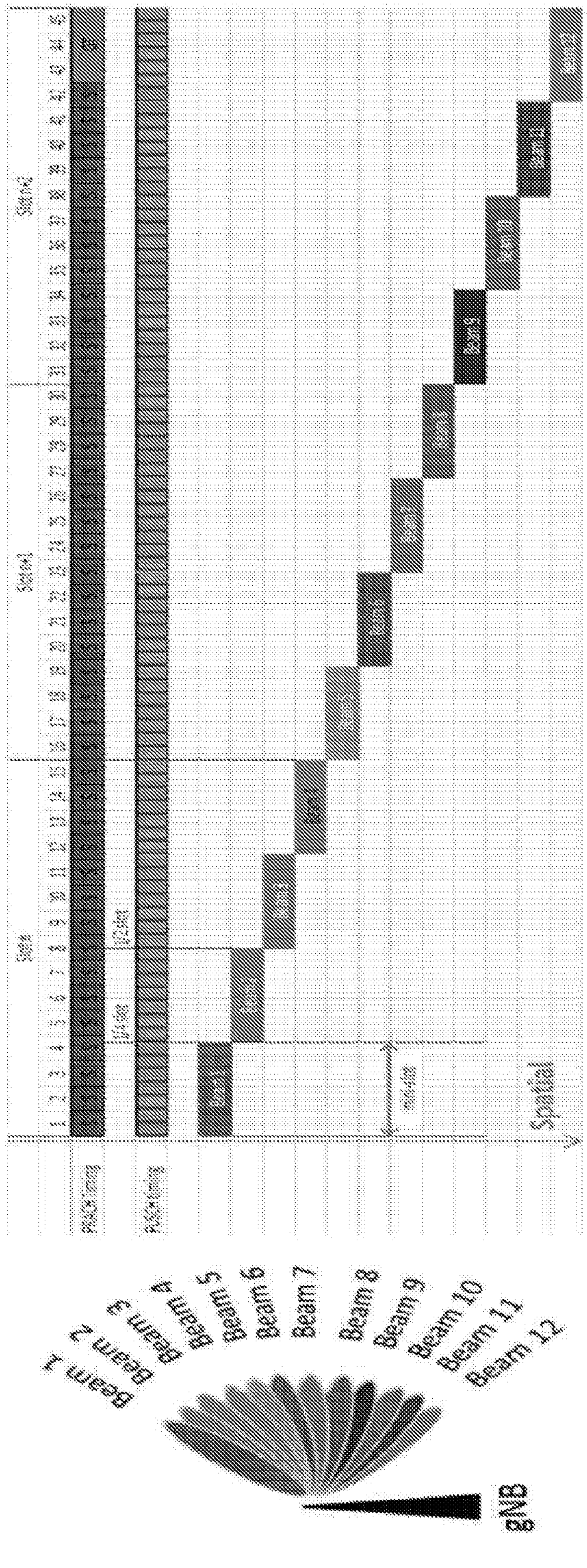
Beam 1
Beam 2
Beam 3
Beam 4
Beam 5
Beam 6
Beam 7
Beam 8
Beam 9
Beam 10
Beam 11
Beam 12
gNB
Spatial

Fig. 4

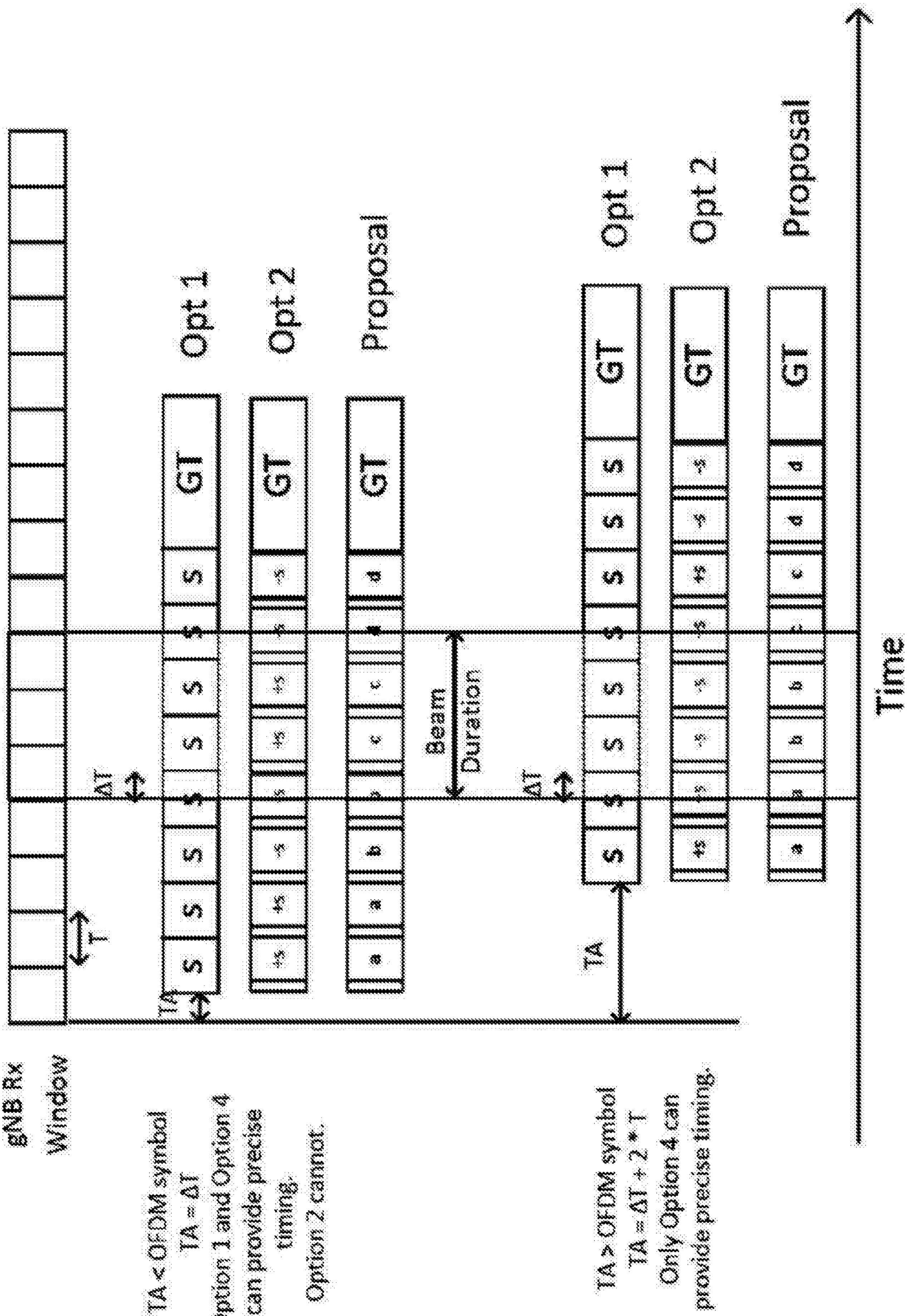
gNB Rx Window
TA < OFDM symbol
TA = ΔT
Option 1 and Option 4 can provide precise timing.
Option 2 cannot.
TA > OFDM symbol
TA = ΔT + 2 * T
Only Option 4 can provide precise timing.
T
TA
ΔT
Beam Duration
GT
Opt 1
Opt 2
Proposal
Time

Fig. 5

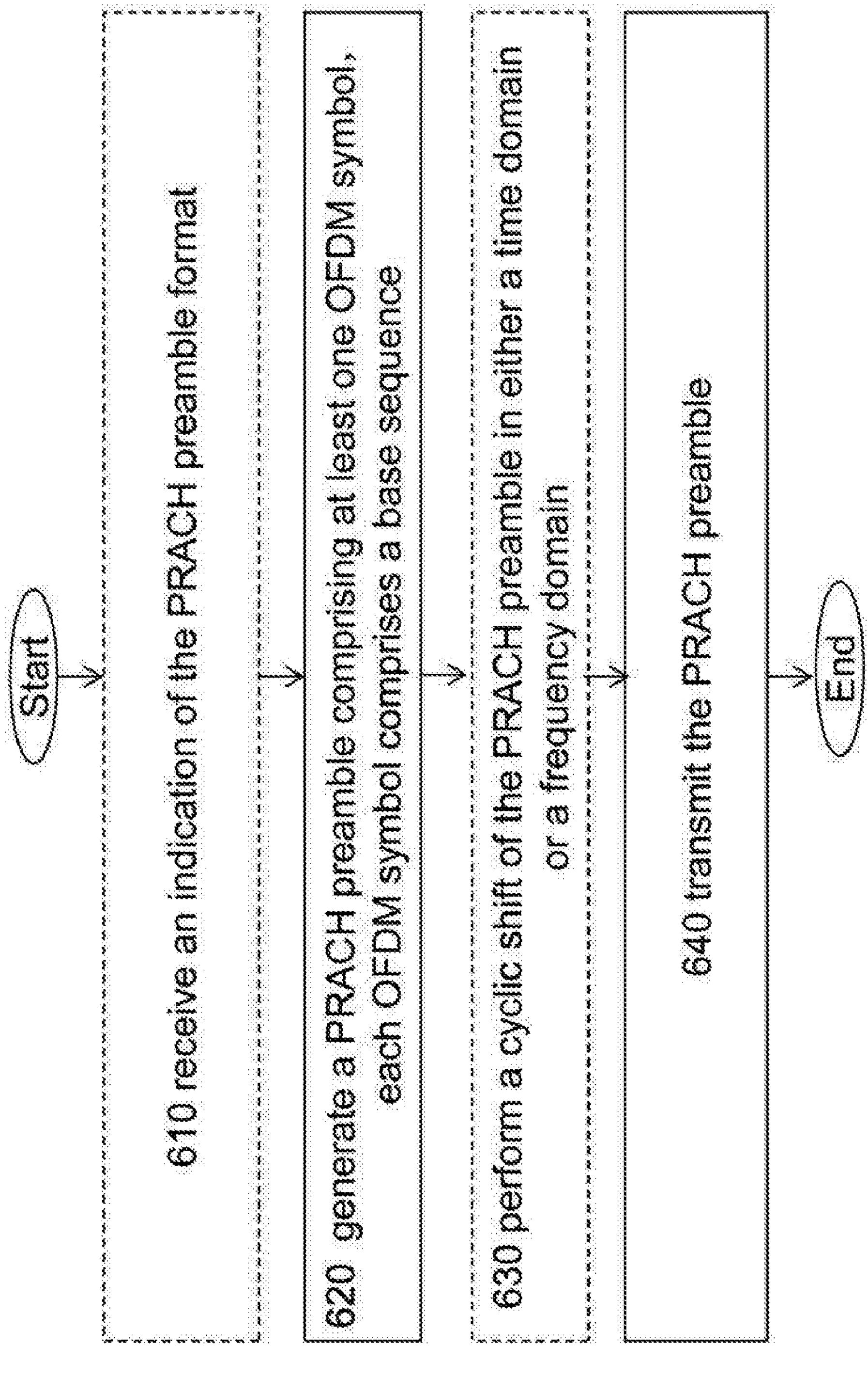
Start
610 receive an indication of the PRACH preamble format
620 generate a PRACH preamble comprising at least one OFDM symbol, each OFDM symbol comprises a base sequence
630 perform a cyclic shift of the PRACH preamble in either a time domain or a frequency domain
640 transmit the PRACH preamble
End

Fig. 6

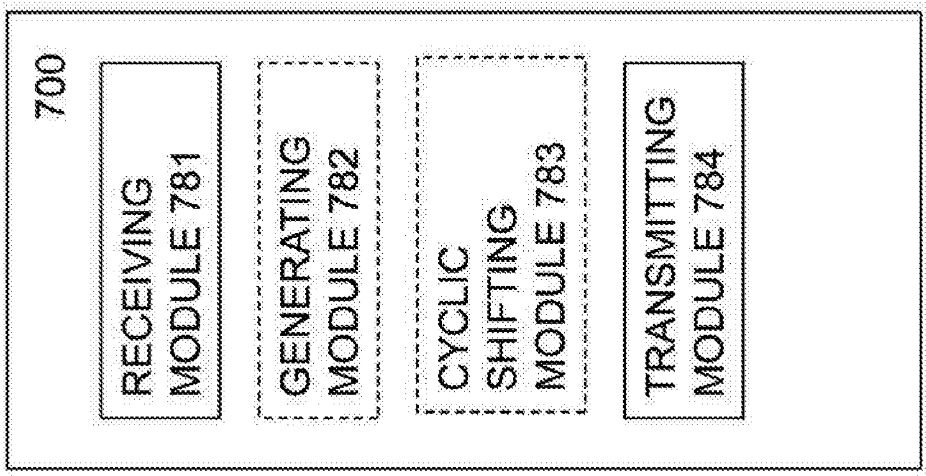
700
RECEIVING MODULE 781
GENERATING MODULE 782
CYCLIC SHIFTING MODULE 783
TRANSMITTING MODULE 784

Fig. 7b

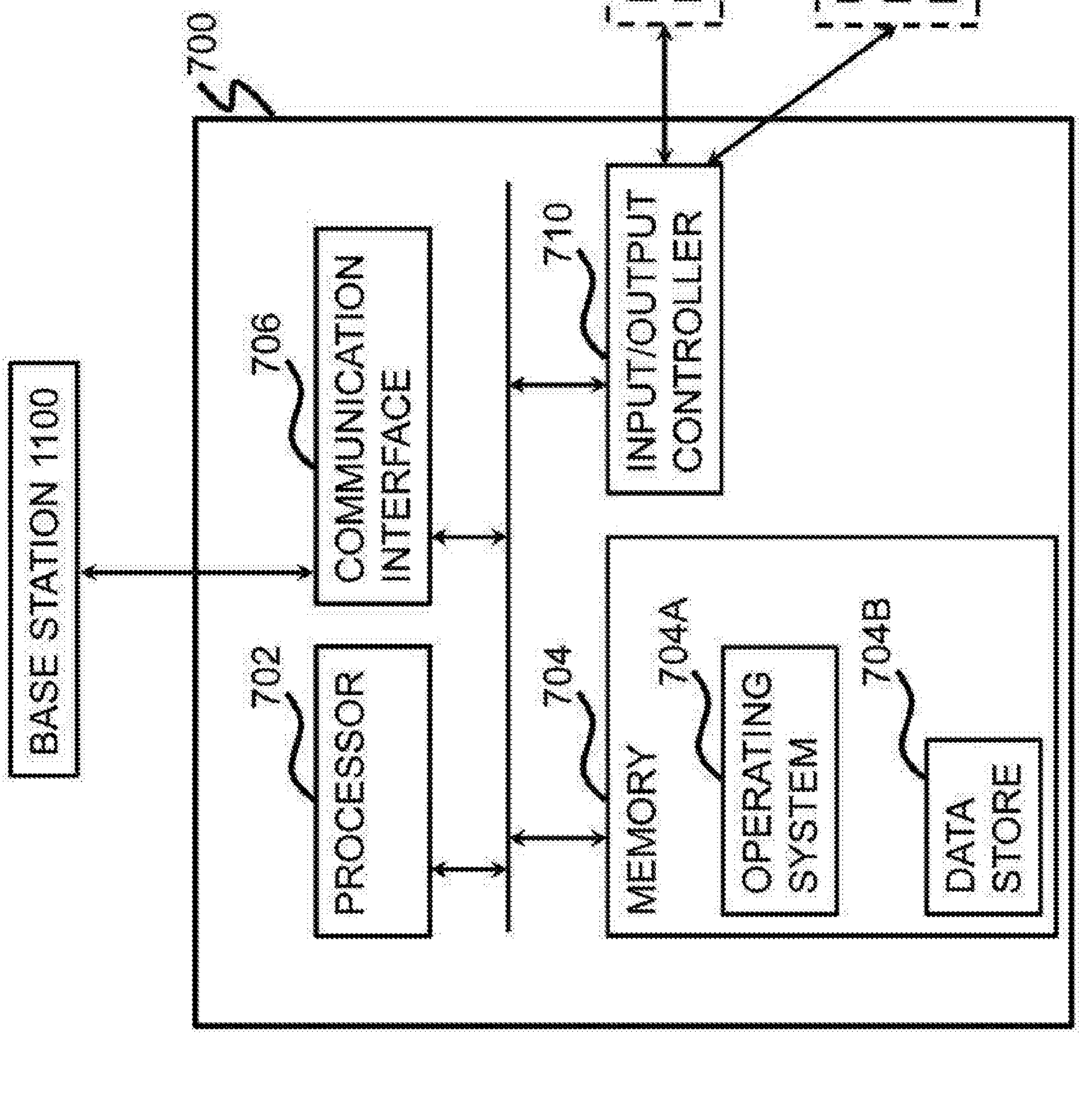
BASE STATION 1100
700
702
PROCESSOR
706
COMMUNICATION INTERFACE
704
MEMORY
704A
OPERATING SYSTEM
704B
DATA STORE
710
INPUT/OUTPUT CONTROLLER
712
DISPLAY DEVICE
714
USER INPUT DEVICE

Fig. 7a

Preamble Format	T_CP (in Ts)	T_CP (in ms)	T_SEQ (in Ts)	T_SEQ (in ms)	Total Length (in ms)	Number of Subframes	Guard Time (in ms)	Cell Radius
0	3168	0.103	24576	0.800	0.903	1	0.097	~ 14 km
1	21024	0.684	24576	0.800	1.484	2	0.516	~ 75 km
2	6240	0.203	2 x 24576	1.600	1.803	2	0.197	~ 28 km
3	21024	0.684	2 x 24576	1.600	2.284	3	0.716	~ 108 km
4	448	0.015	4096	0.133	0.148			

Fig. 8

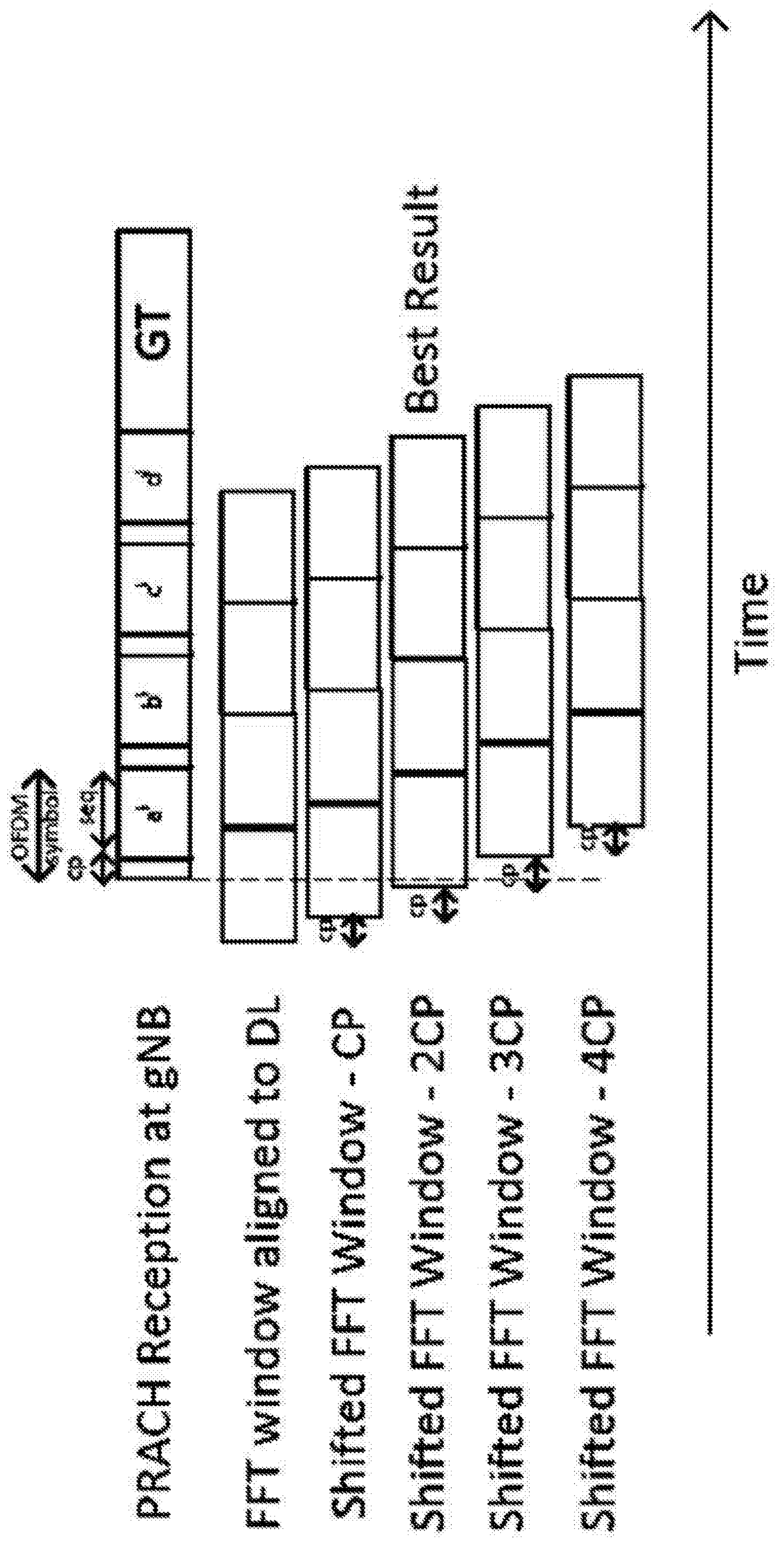
PRACH Reception at gNB
FFT window aligned to DL
Shifted FFT Window - CP
Shifted FFT Window - 2CP
Shifted FFT Window - 3CP
Shifted FFT Window - 4CP
OFDM symbol
seq
cp
GT
Best Result
Time

Fig. 9

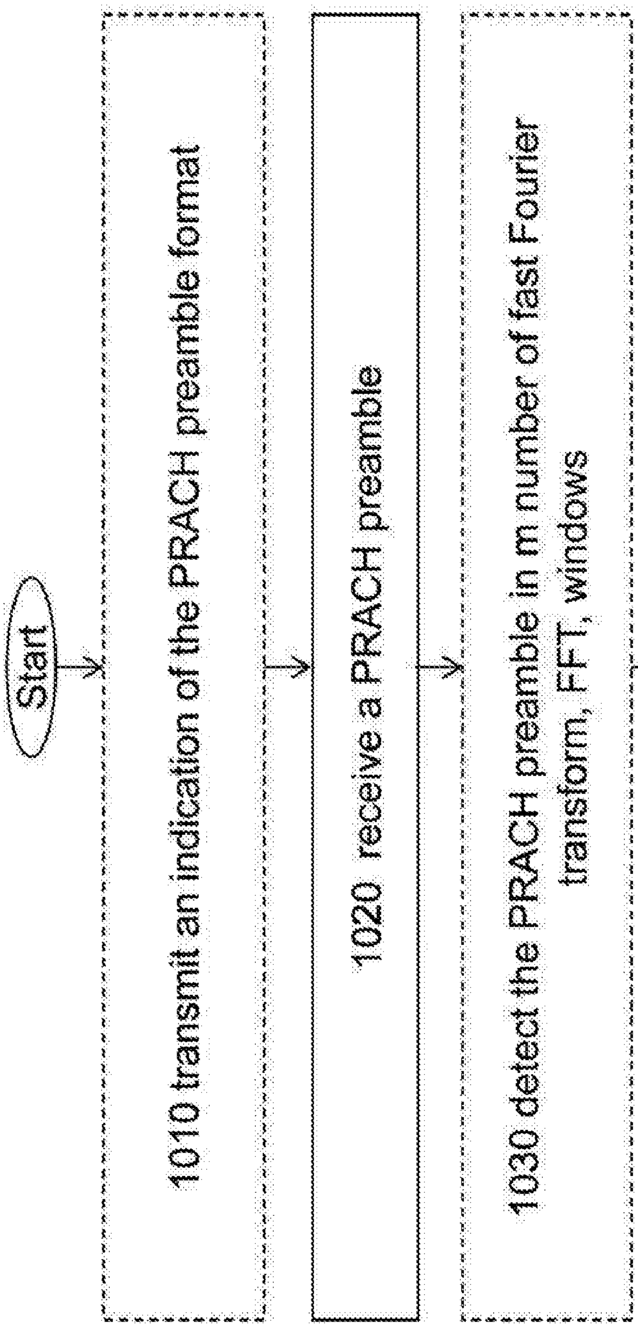
Start
1010 transmit an indication of the PRACH preamble format
1020 receive a PRACH preamble
1030 detect the PRACH preamble in m number of fast Fourier transform, FFT, windows
End

Fig. 10

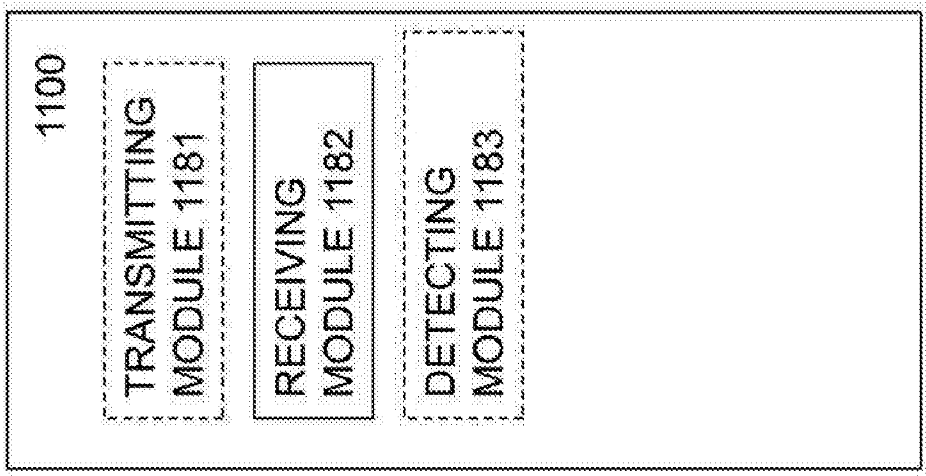

Fig. 11b

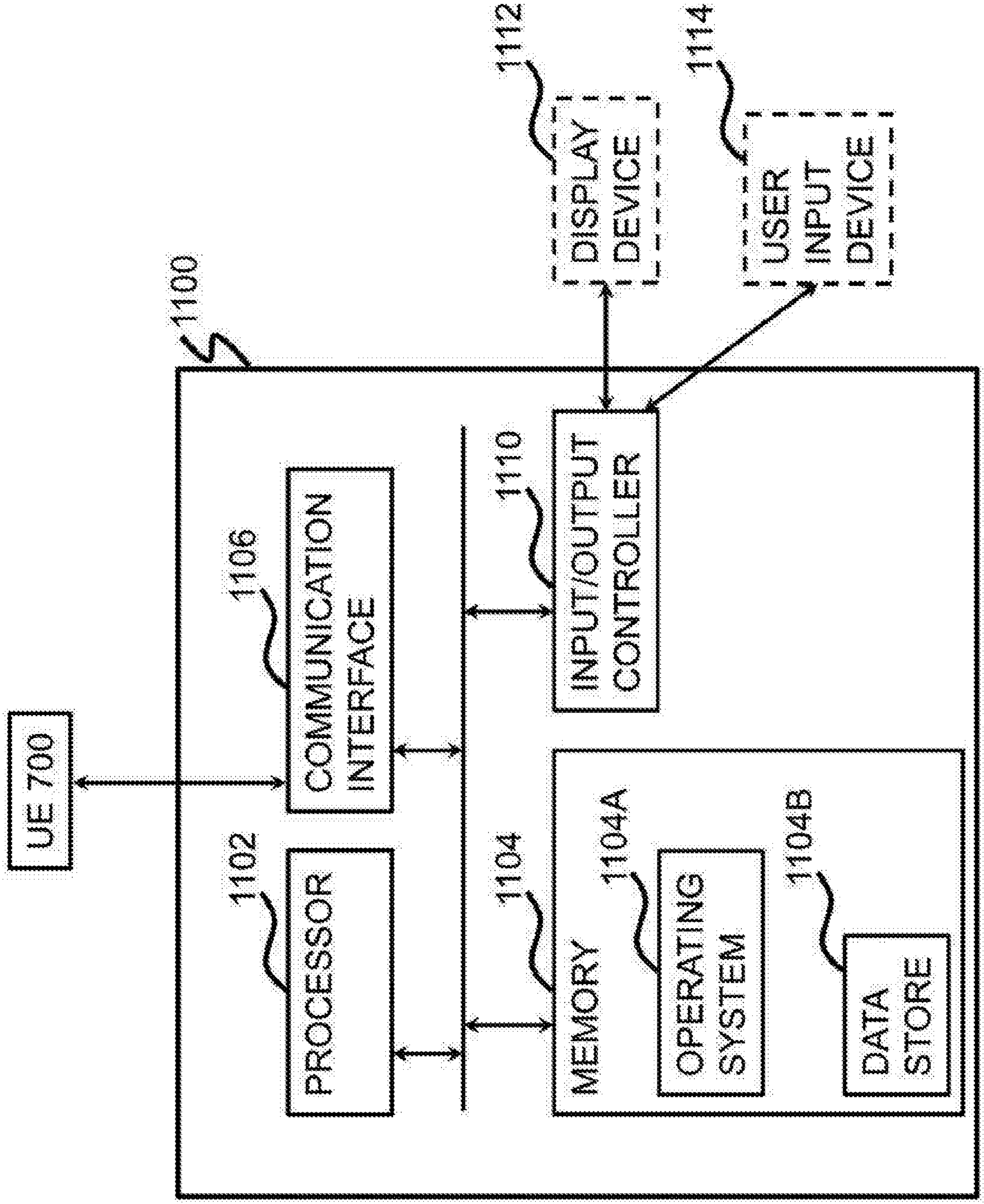

Fig. 11a

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/084644

A. CLASSIFICATION OF SUBJECT MATTER

H04W 74/08(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W H04Q H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI,EPODOC,CNPAT,CNKI,IEEE:random, access, PRACH, preamble, OFDM, symbol, sequence, base, set, length, same

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 106105361 A (TELEFONAKTIEBOLAGET LM ERICSSONPUBL) 09 November 2016 (2016-11-09) claims 1-5, description, paragraphs[0113]-[0322], figures 26-27	1-19
A	CN 101247658 A (ZTE COMMUNICATION CO., LTD.) 20 August 2008 (2008-08-20) the whole document	1-19
A	CN 101335713 A (ZTE COMMUNICATION CO., LTD.) 31 December 2008 (2008-12-31) the whole document	1-19

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 July 2018	**30 July 2018**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**JU,Bo**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961534**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2018/084644

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	106105361	A	09 November 2016	EP	3123803	A1	01 February 2017
				WO	2015144256	A1	01 October 2015
				US	2017006638	A1	05 January 2017
				BR	112016020990	A2	15 August 2017
CN	101247658	A	20 August 2008	None			
CN	101335713	A	31 December 2008	None			