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(54) COMMUNICATION SYSTEMS, APPARATUSES, METHODS, AND NON-TRANSITORY COMPUTER-READABLE STORAGE DEVICES FOR UPLINK PREAMBLE TRANSMISSION AND RECEPTION

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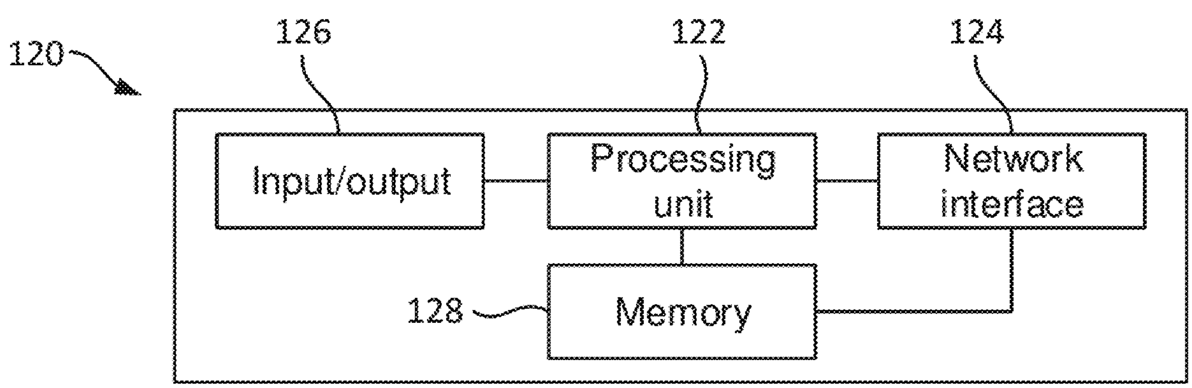
CPC *H04W 74/0833* (2013.01)

(57) **ABSTRACT**

Communication systems, apparatuses, methods, and one or more non-transitory computer-readable storage devices for physical random-access channel (PRACH) signaling and detection using a random-access preamble are provided. The random-access preamble has a modified sequence obtained from a first Zadoff-Chu (ZC) sequence rotated by an angle θ and scaled by a scaling factor R. In some embodiments, the random-access preamble may also have a second ZC sequence.



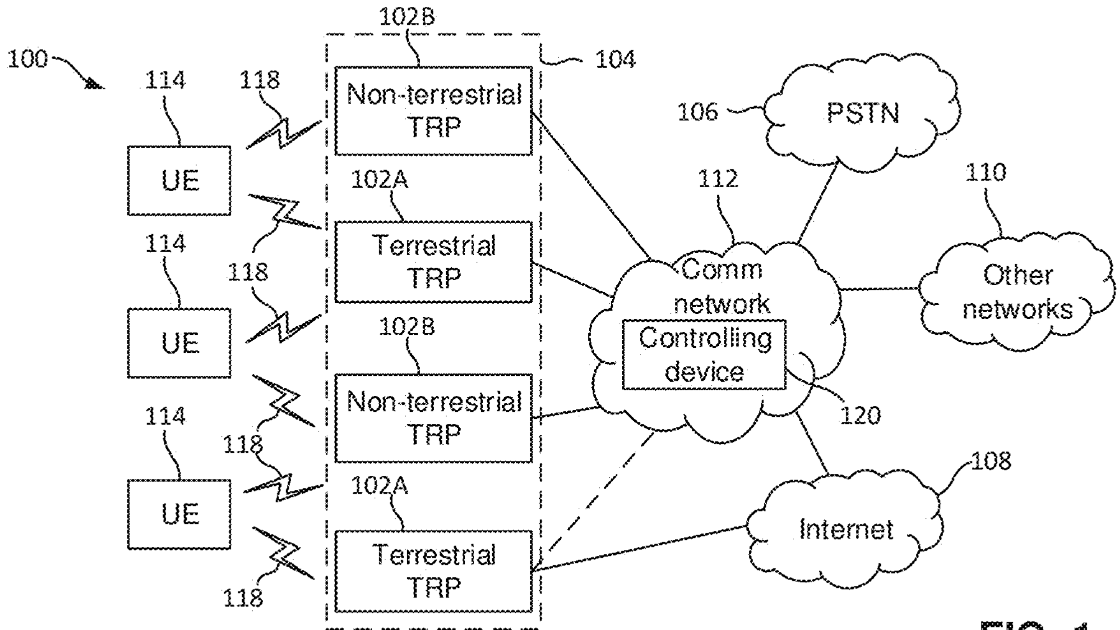


FIG. 1

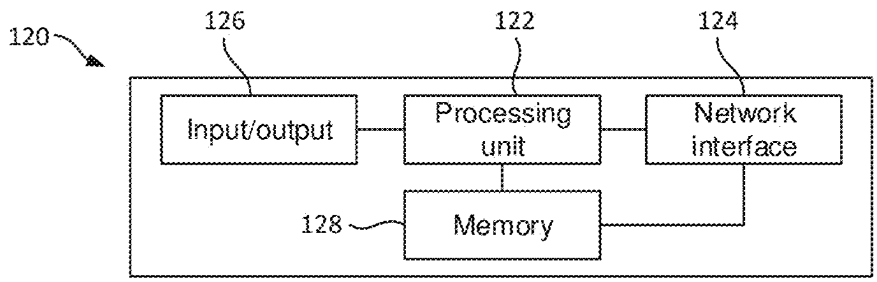


FIG. 2

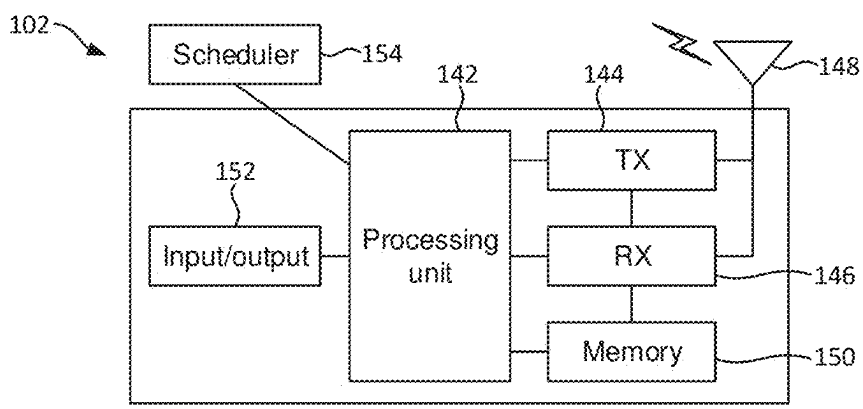


FIG. 3

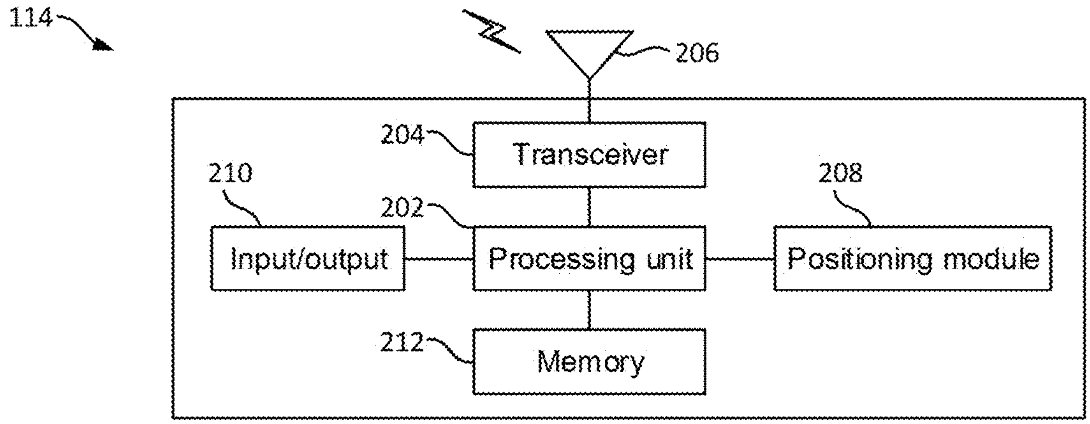


FIG. 4

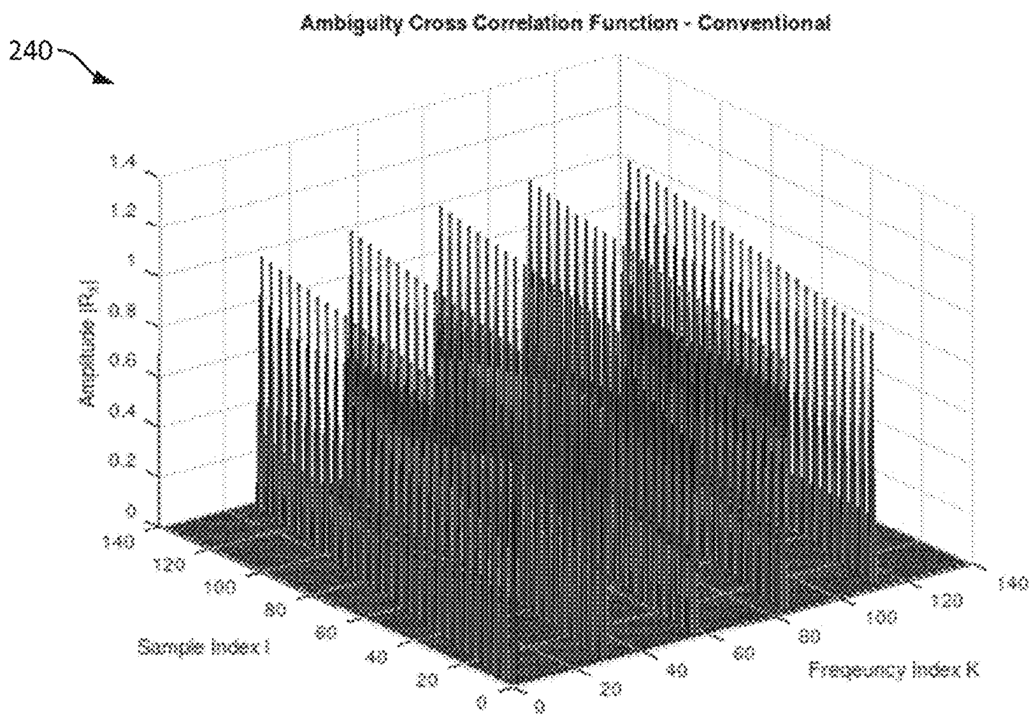


FIG. 5 (Prior Art)

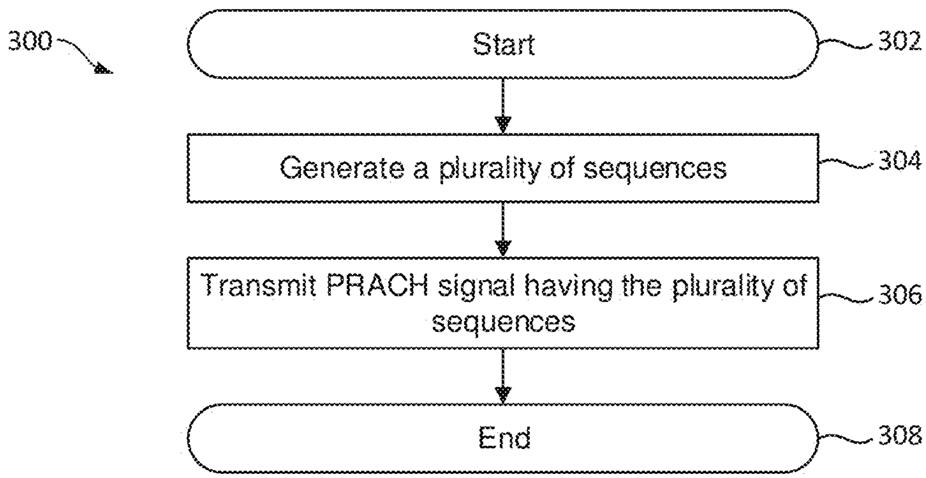

300
Start
302
Generate a plurality of sequences
304
Transmit PRACH signal having the plurality of sequences
306
End
308

FIG. 6

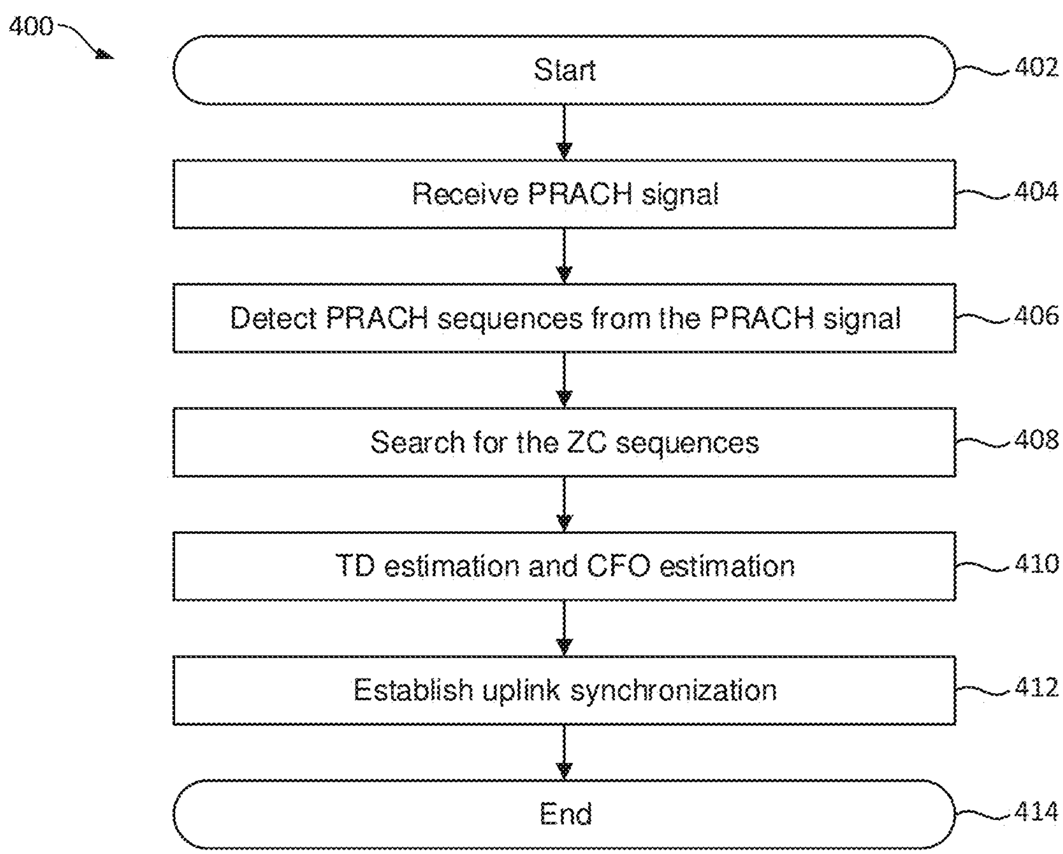

400
Start
402
Receive PRACH signal
404
Detect PRACH sequences from the PRACH signal
406
Search for the ZC sequences
408
TD estimation and CFO estimation
410
Establish uplink synchronization
412
End
414

FIG. 7

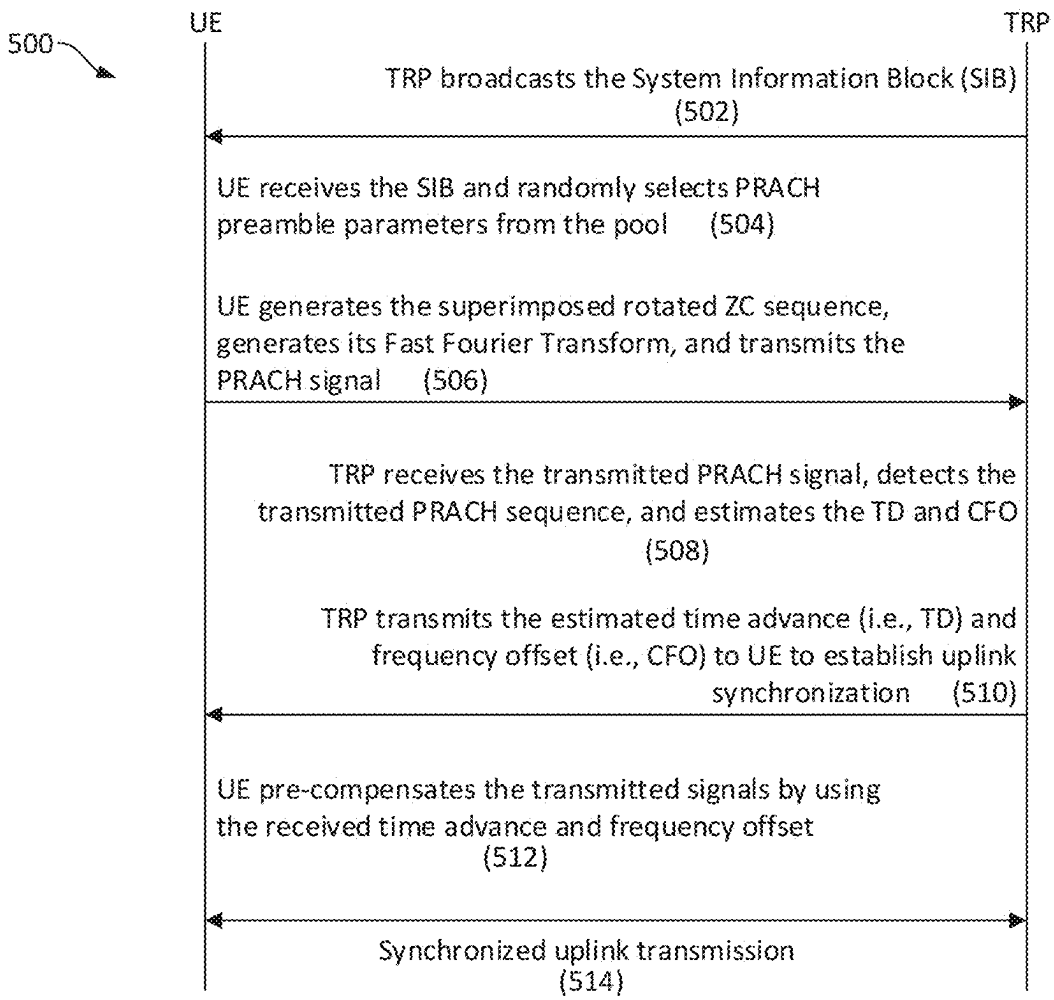

500
UE
TRP
TRP broadcasts the System Information Block (SIB) (502)
UE receives the SIB and randomly selects PRACH preamble parameters from the pool (504)
UE generates the superimposed rotated ZC sequence, generates its Fast Fourier Transform, and transmits the PRACH signal (506)
TRP receives the transmitted PRACH signal, detects the transmitted PRACH sequence, and estimates the TD and CFO (508)
TRP transmits the estimated time advance (i.e., TD) and frequency offset (i.e., CFO) to UE to establish uplink synchronization (510)
UE pre-compensates the transmitted signals by using the received time advance and frequency offset (512)
Synchronized uplink transmission (514)

FIG. 8

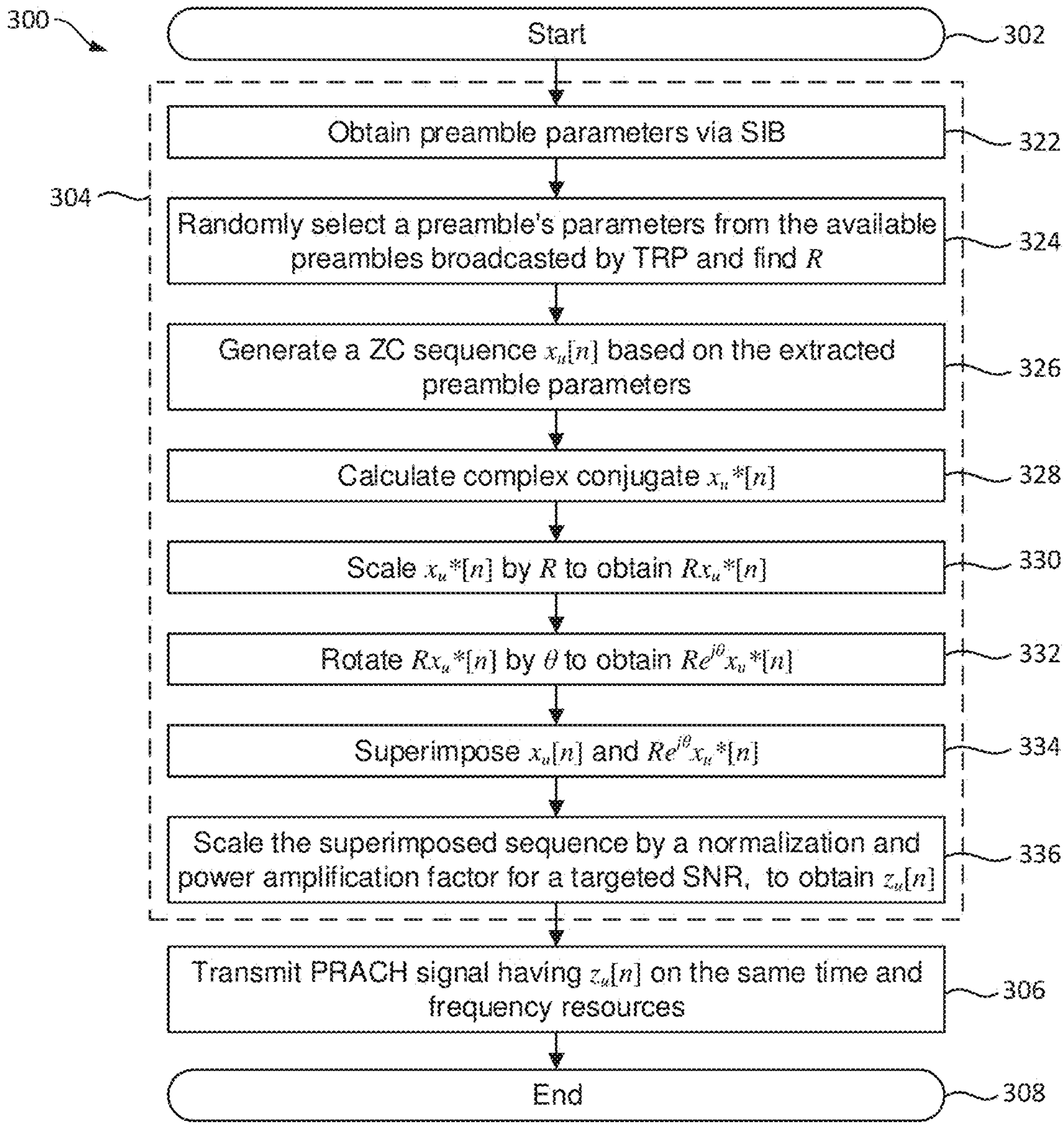

300
Start
302
304
Obtain preamble parameters via SIB
322
Randomly select a preamble's parameters from the available preambles broadcasted by TRP and find R
324
Generate a ZC sequence $x_u[n]$ based on the extracted preamble parameters
326
Calculate complex conjugate $x_u^*[n]$
328
Scale $x_u^*[n]$ by R to obtain $Rx_u^*[n]$
330
Rotate $Rx_u^*[n]$ by θ to obtain $Re^{j\theta}x_u^*[n]$
332
Superimpose $x_u[n]$ and $Re^{j\theta}x_u^*[n]$
334
Scale the superimposed sequence by a normalization and power amplification factor for a targeted SNR, to obtain $z_u[n]$
336
Transmit PRACH signal having $z_u[n]$ on the same time and frequency resources
306
End
308

FIG. 9A

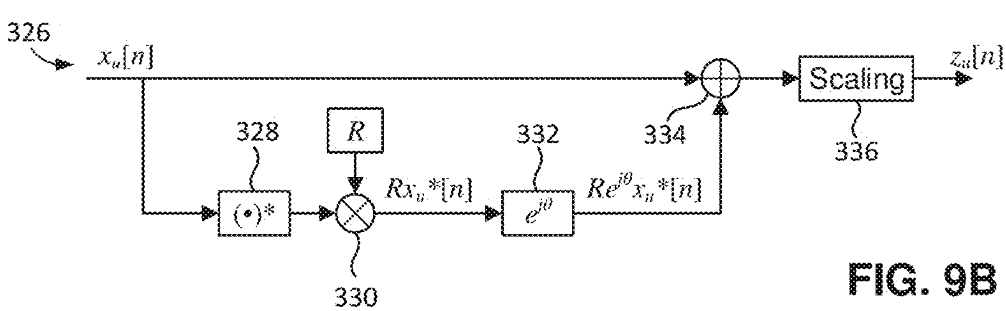

326
$x_u[n]$
328
$(\bullet)^*$
R
$Rx_u^*[n]$
332
$e^{j\theta}$
$Re^{j\theta}x_u^*[n]$
334
Scaling
$z_u[n]$
336
330

FIG. 9B

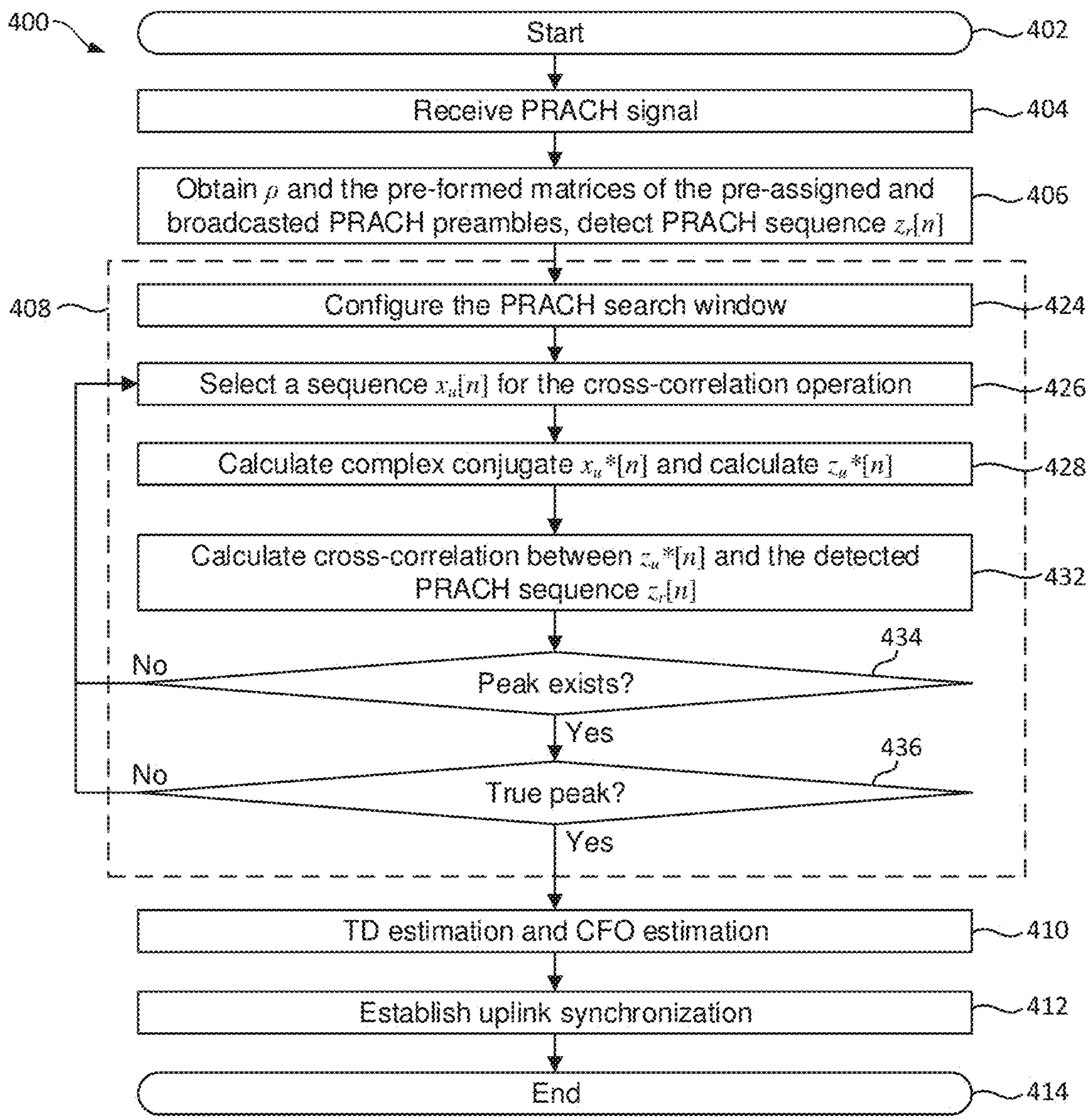

400
Start
402
Receive PRACH signal
404
Obtain ρ and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles, detect PRACH sequence $z_r[n]$
406
408
Configure the PRACH search window
424
Select a sequence $x_u[n]$ for the cross-correlation operation
426
Calculate complex conjugate $x_u*[n]$ and calculate $z_u*[n]$
428
Calculate cross-correlation between $z_u*[n]$ and the detected PRACH sequence $z_r[n]$
432
No
Peak exists?
434
Yes
No
True peak?
436
Yes
TD estimation and CFO estimation
410
Establish uplink synchronization
412
End
414

FIG. 10A

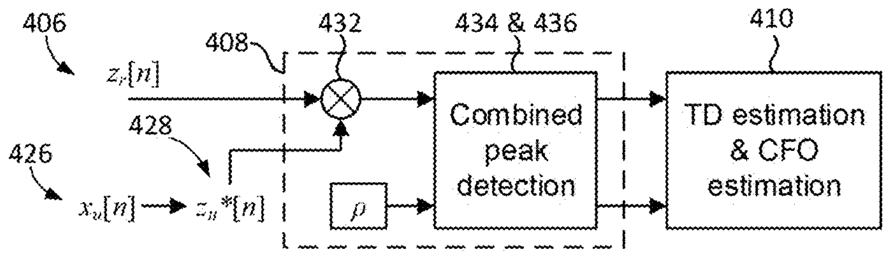


FIG. 10B

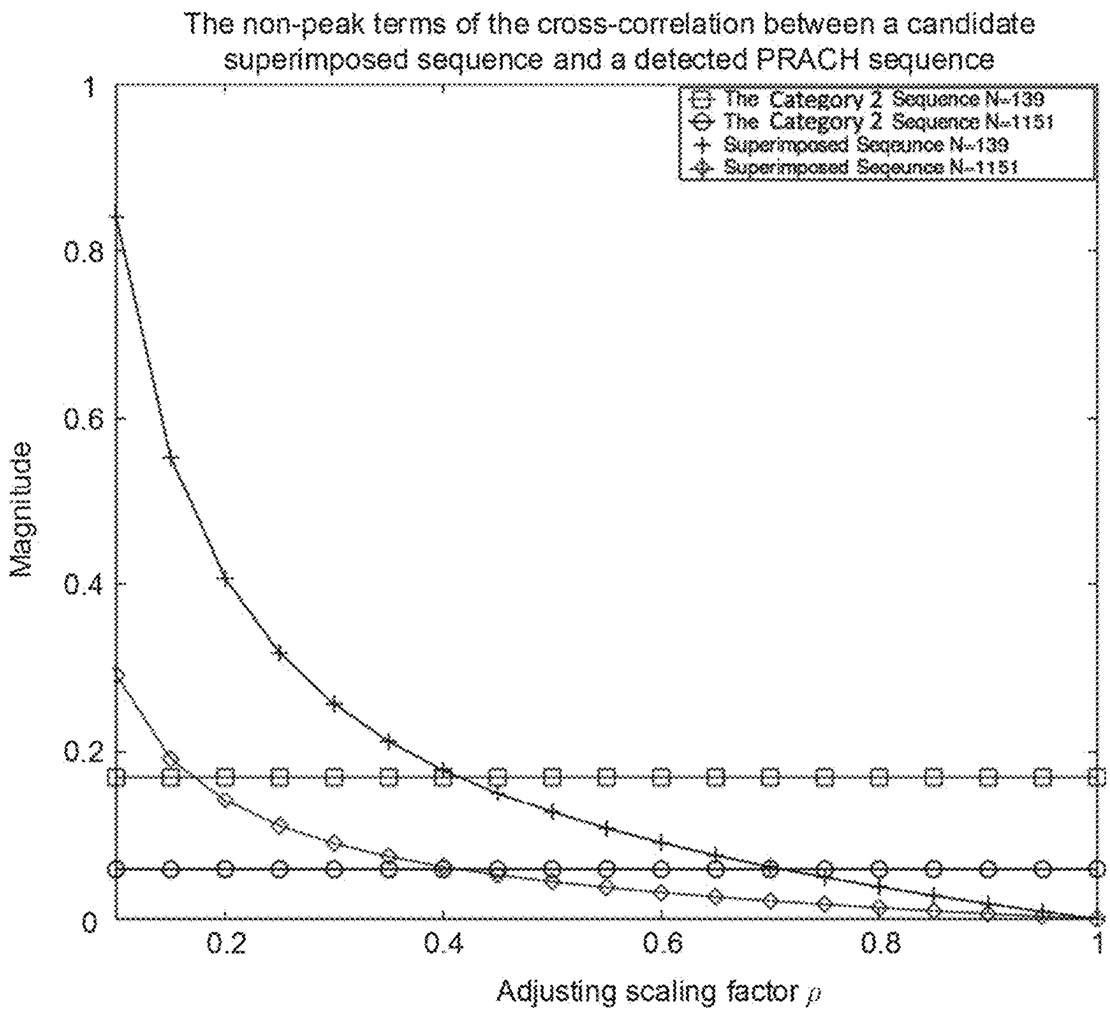


FIG. 11

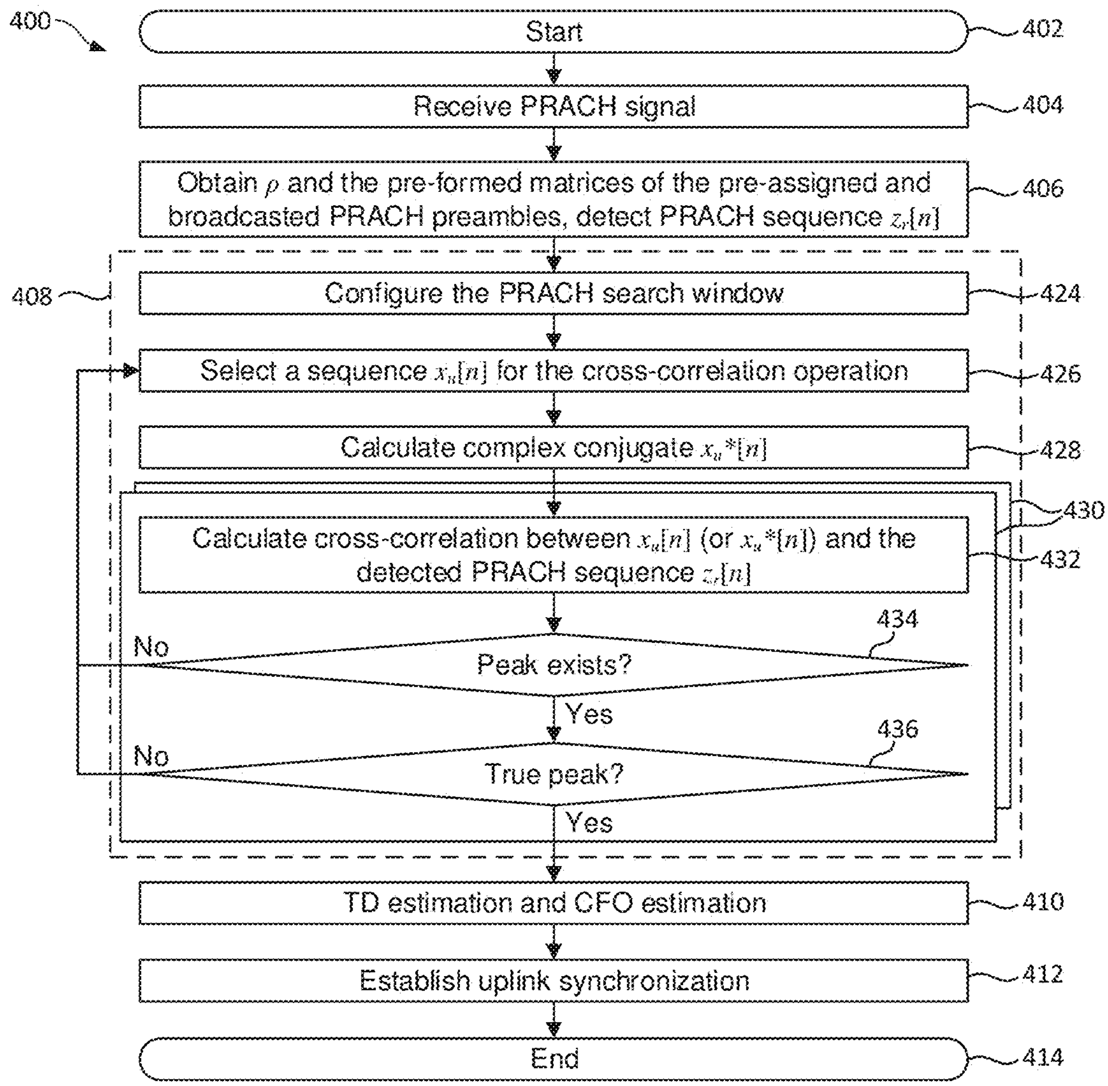

400
Start
402
Receive PRACH signal
404
Obtain ρ and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles, detect PRACH sequence $z_r[n]$
406
408
Configure the PRACH search window
424
Select a sequence $x_u[n]$ for the cross-correlation operation
426
Calculate complex conjugate $x_u*[n]$
428
430
Calculate cross-correlation between $x_u[n]$ (or $x_u*[n]$) and the detected PRACH sequence $z_r[n]$
432
434
No
Peak exists?
Yes
436
No
True peak?
Yes
TD estimation and CFO estimation
410
Establish uplink synchronization
412
End
414

FIG. 12A

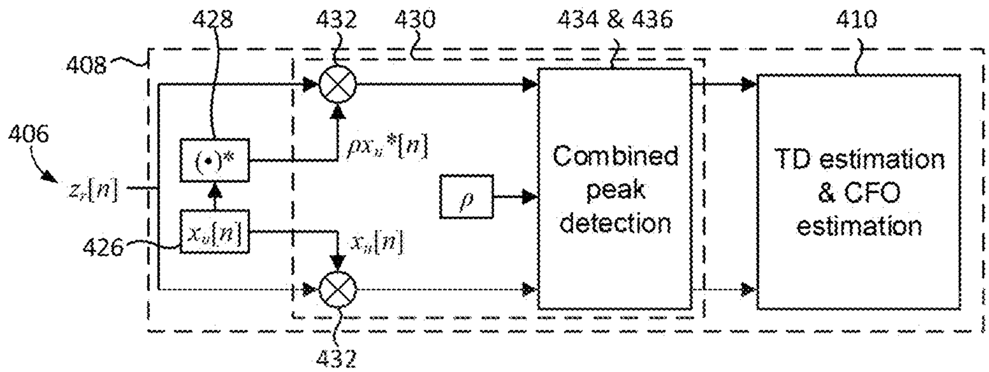


FIG. 12B

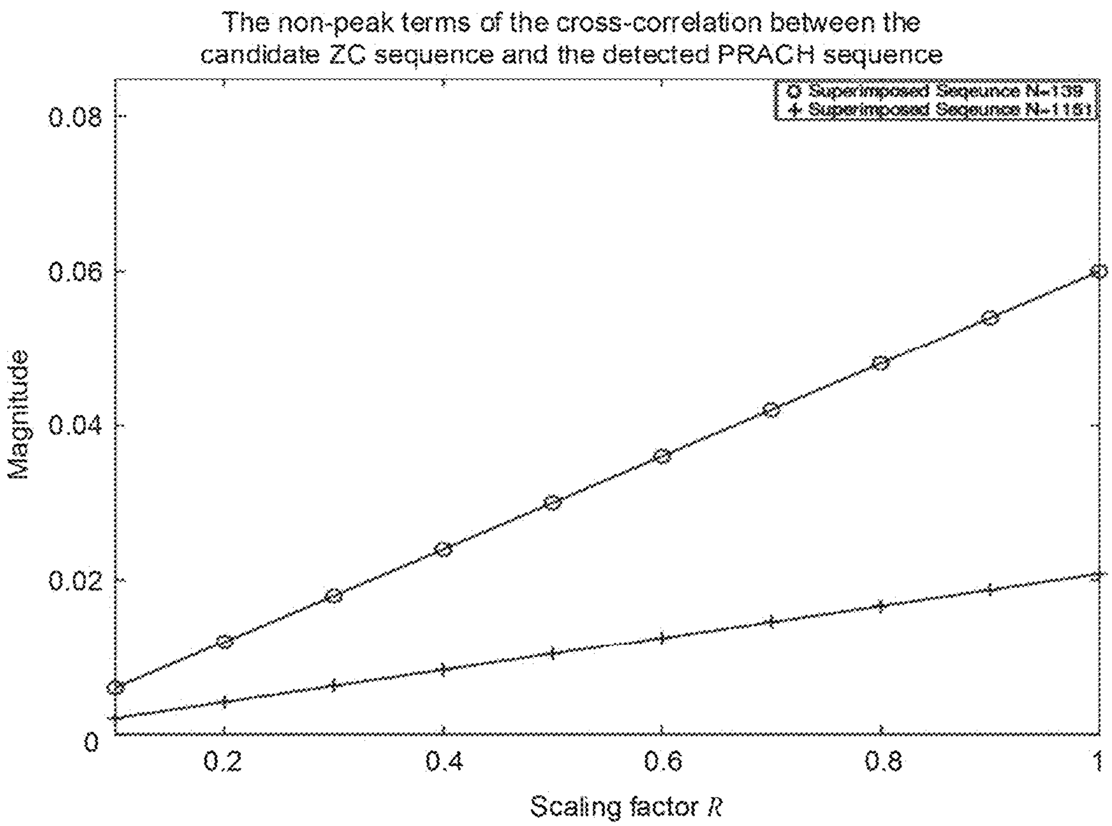


FIG. 13

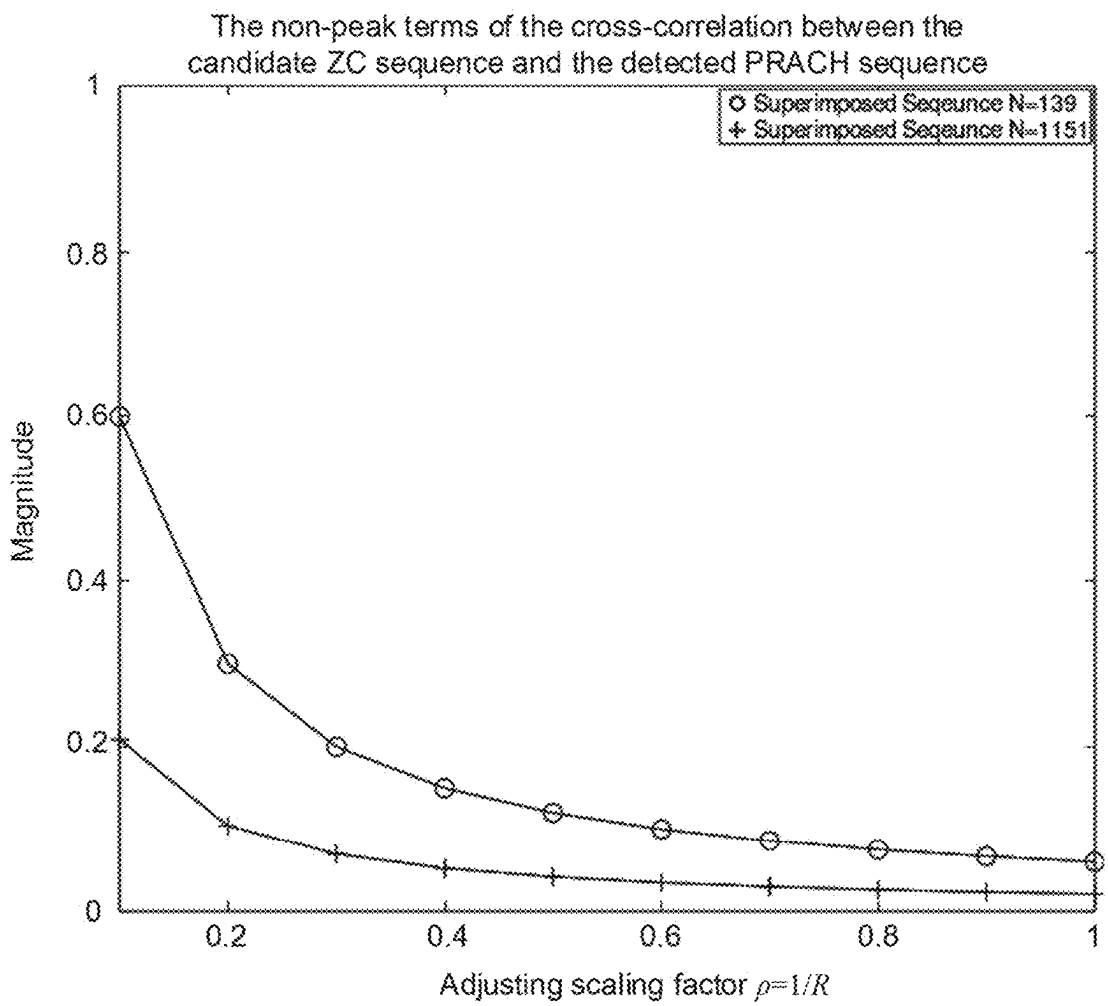

The non-peak terms of the cross-correlation between the candidate ZC sequence and the detected PRACH sequence
Superimposed Seqeunce N=139
Superimposed Seqeunce N=1151
Magnitude
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
Adjusting scaling factor ρ=1/R

FIG. 14

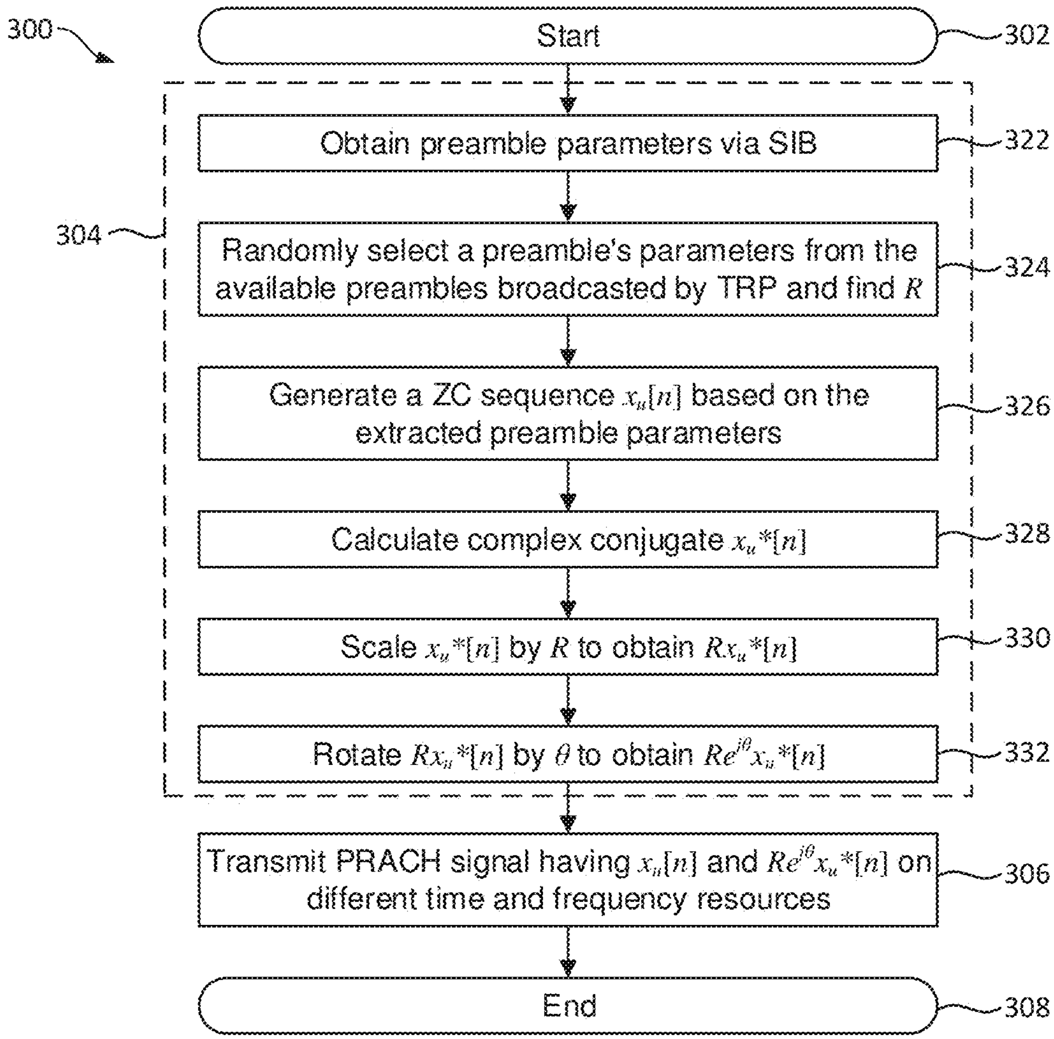


FIG. 15A

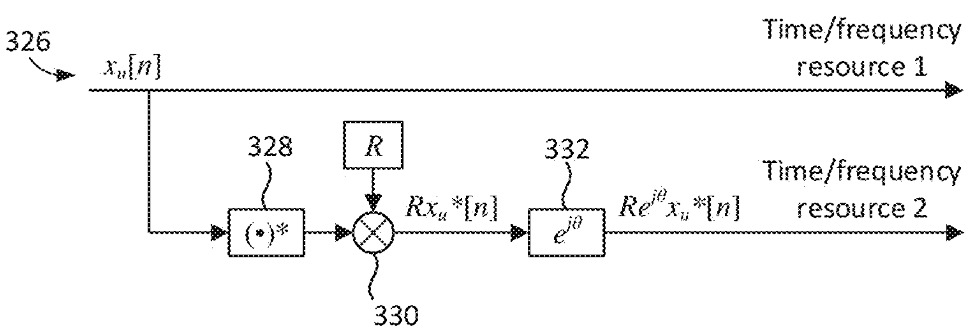


FIG. 15B

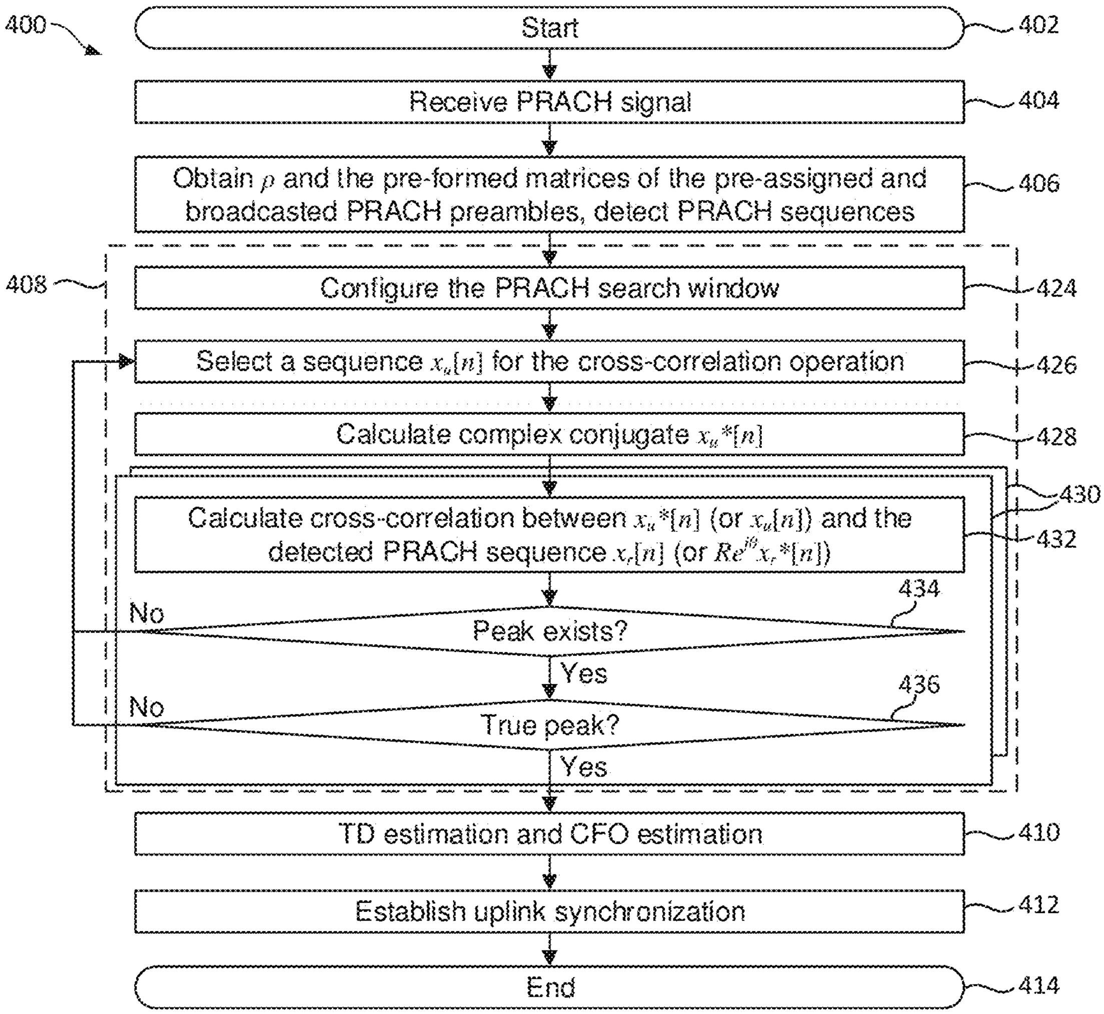


FIG. 16A

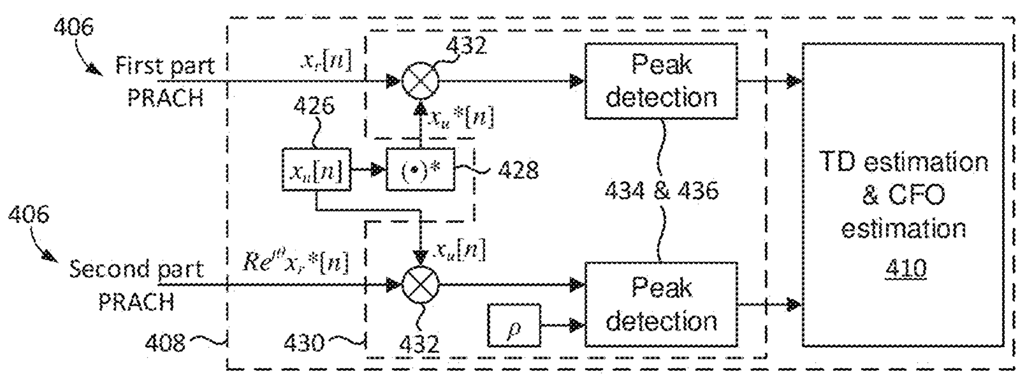


FIG. 16B

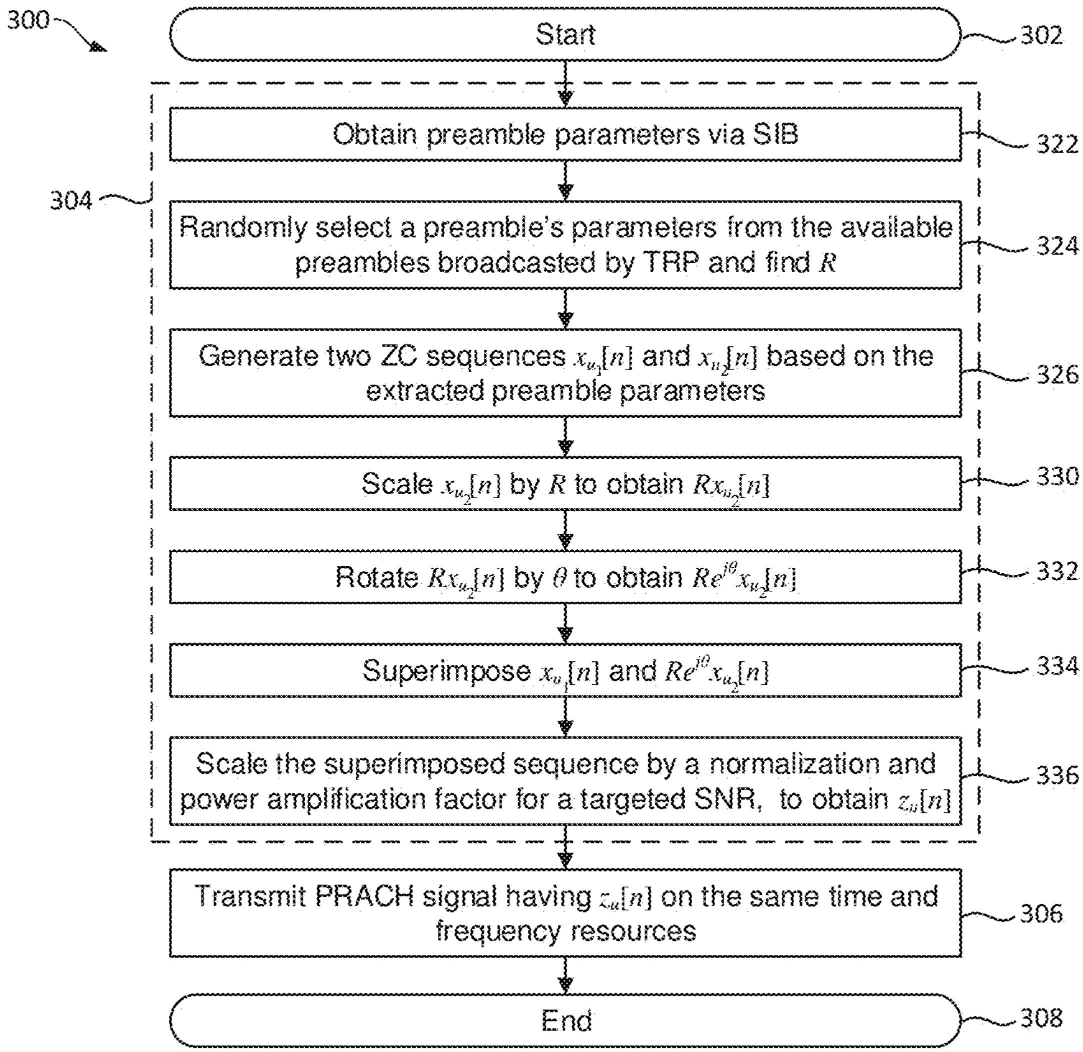


FIG. 17A

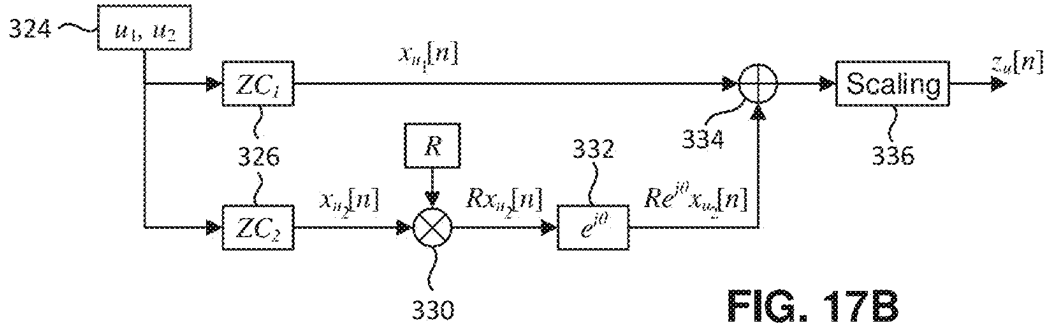


FIG. 17B

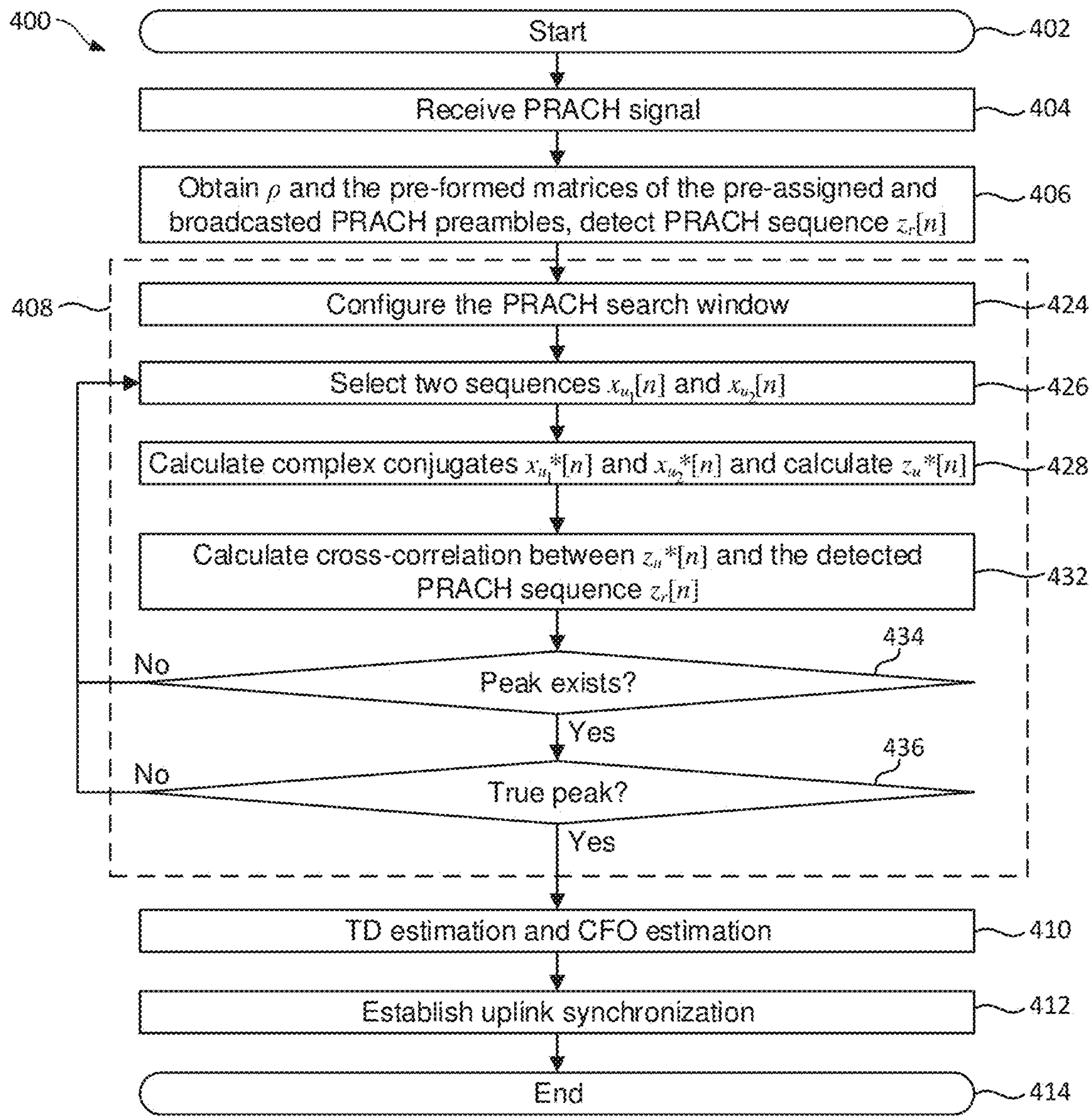


FIG. 18A

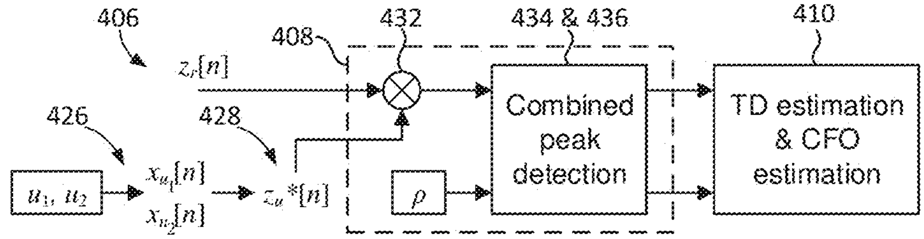


FIG. 18B

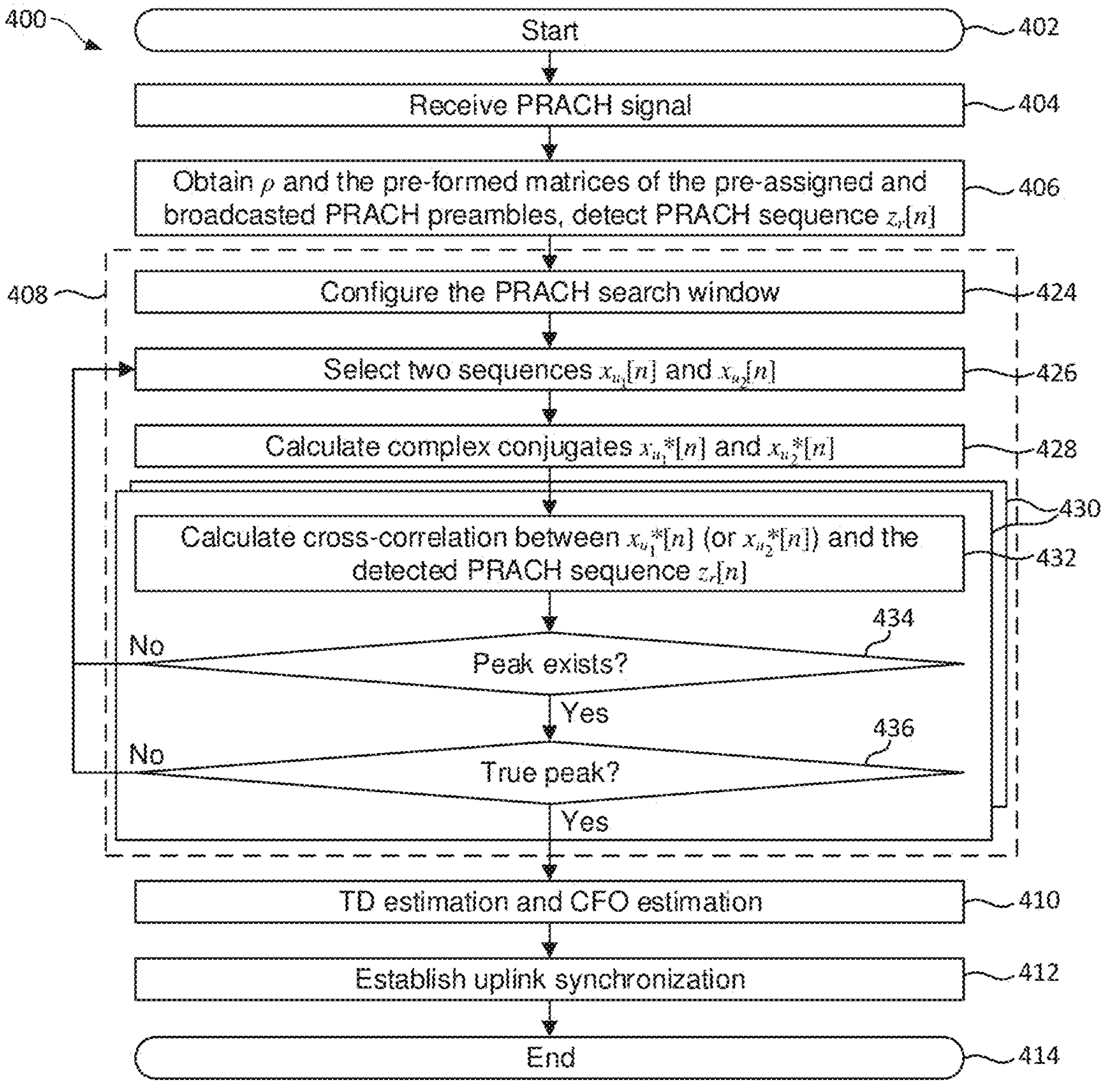


FIG. 19A

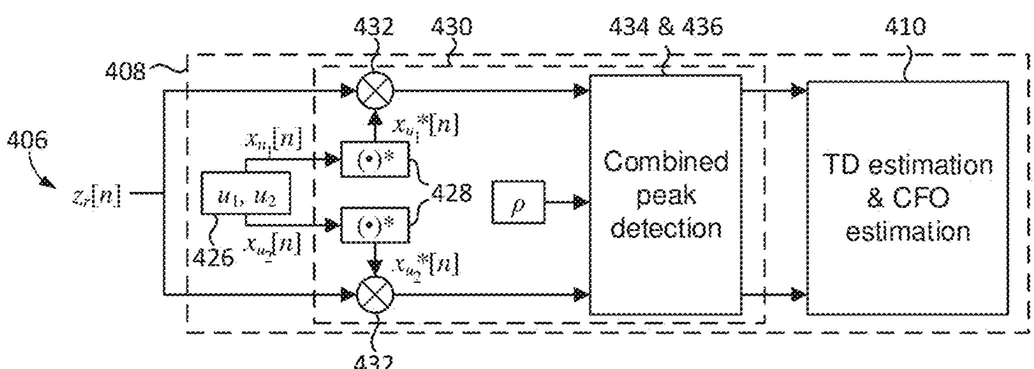


FIG. 19B

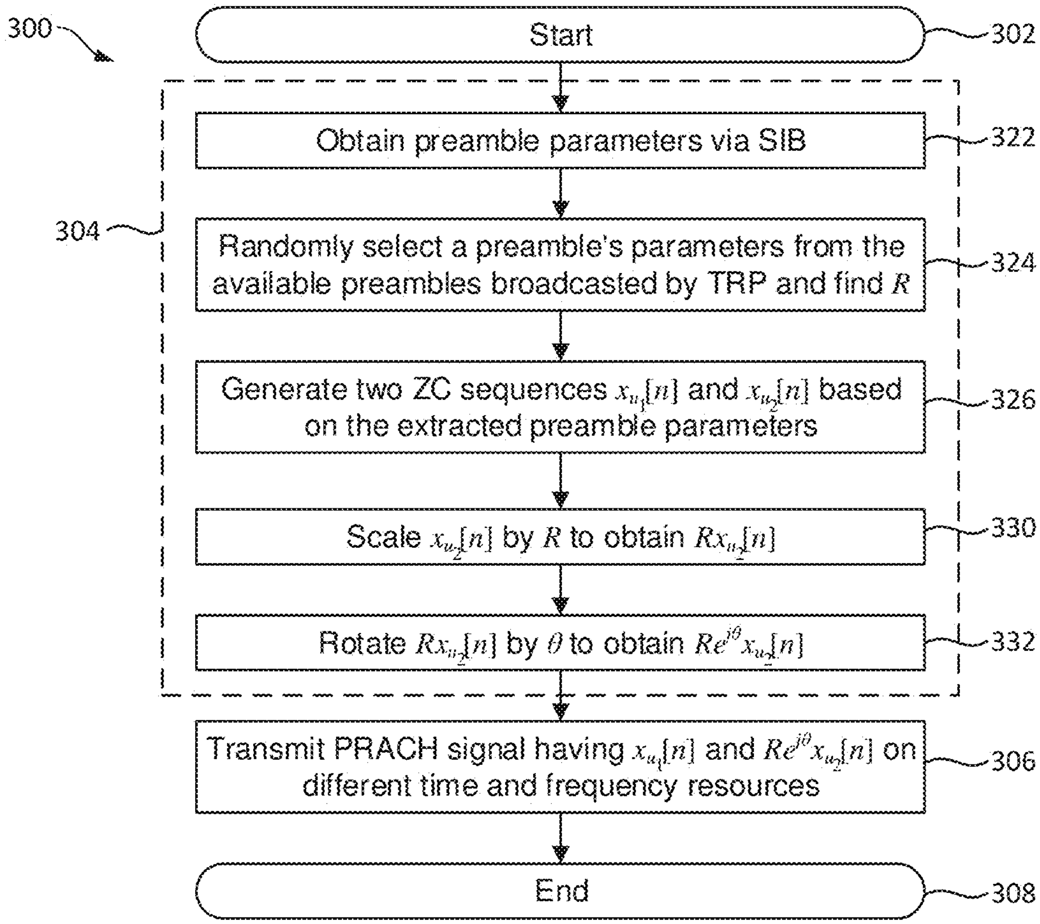


FIG. 20A

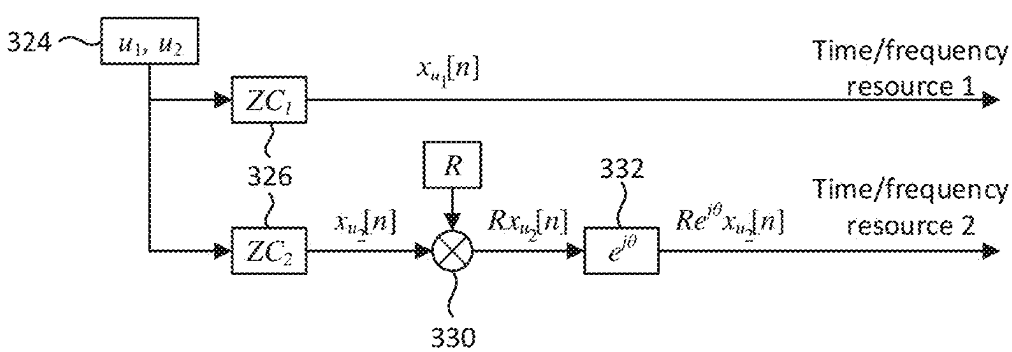


FIG. 20B

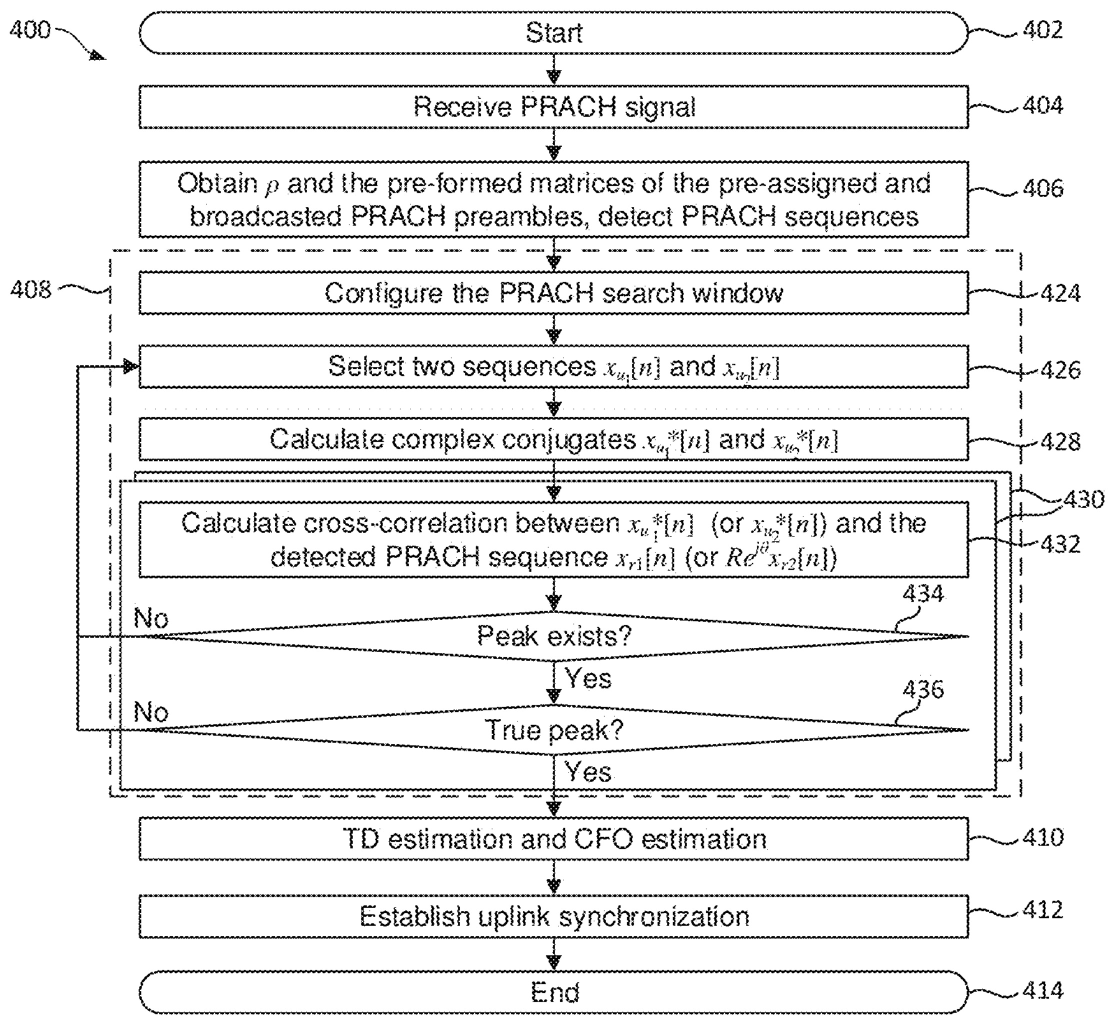


FIG. 21A

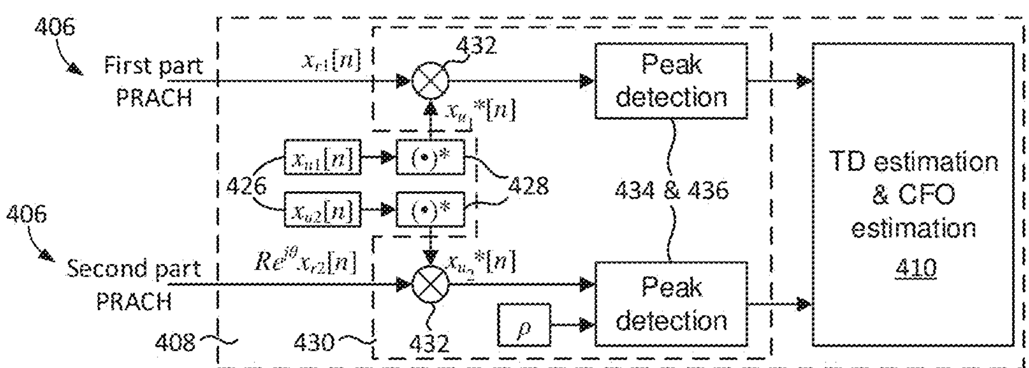


FIG. 21B

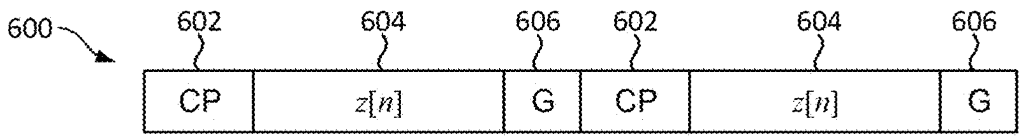


FIG. 22A

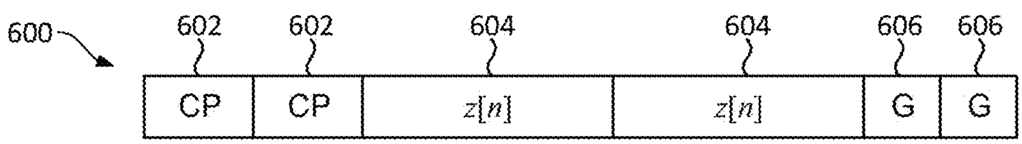


FIG. 22B

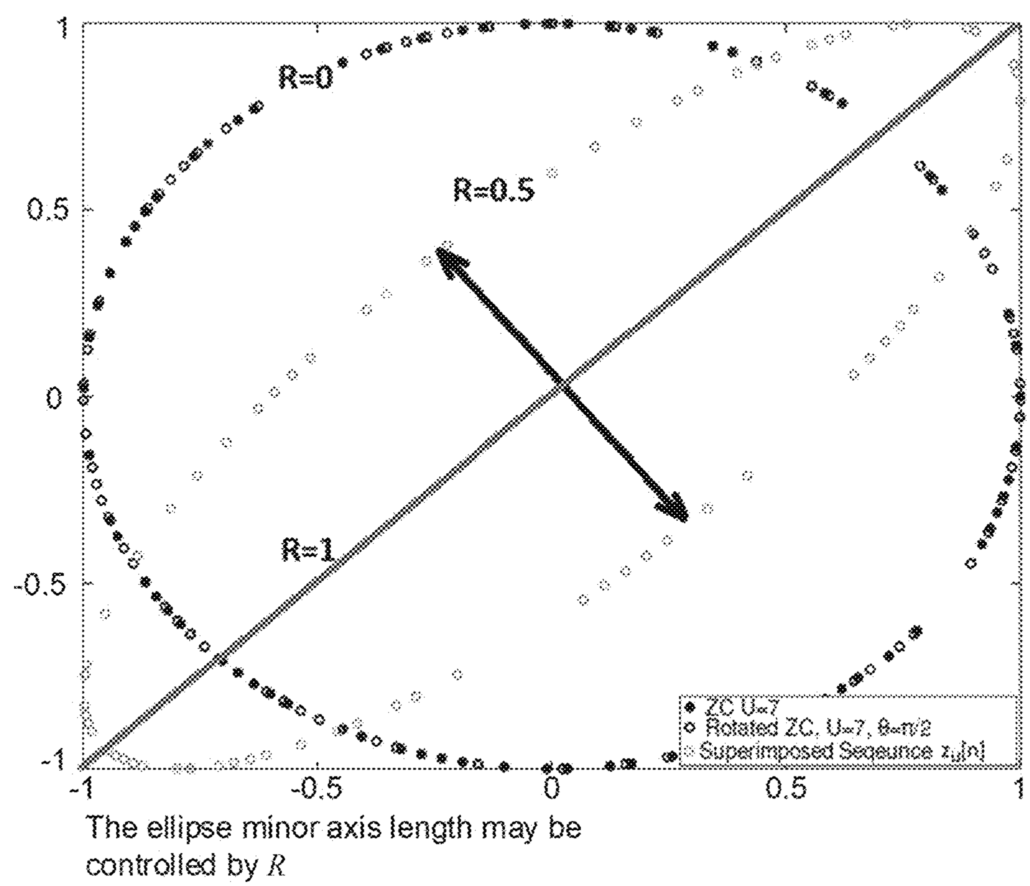


FIG. 23

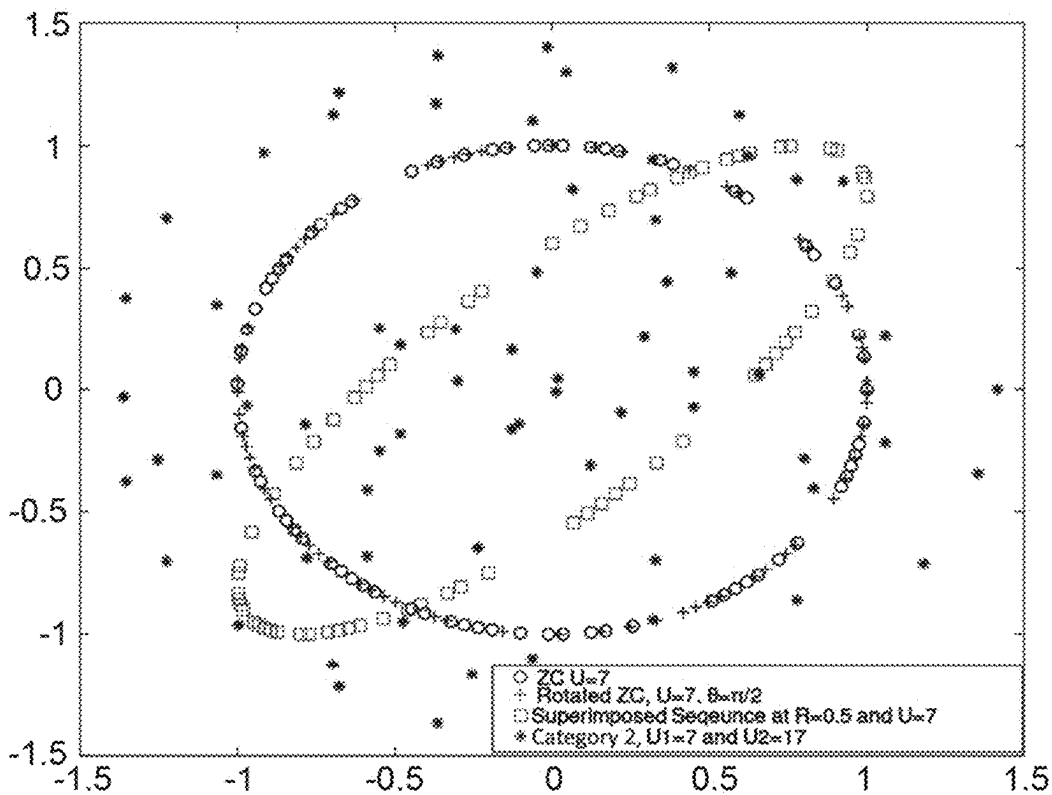

1.5
1
0.5
0
-0.5
-1
-1.5
-1.5
-1
-0.5
0
0.5
1
1.5
ZC U=7
Rotated ZC, U=7, θ=π/2
Superimposed Seqeunce at R=0.5 and U=7
Category 2, U1=7 and U2=17

FIG. 24

COMMUNICATION SYSTEMS, APPARATUSES, METHODS, AND NON-TRANSITORY COMPUTER-READABLE STORAGE DEVICES FOR UPLINK PREAMBLE TRANSMISSION AND RECEPTION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation of International Application No. PCT/CN2022/125172, filed on Oct. 13, 2022, titled "COMMUNICATION SYSTEMS, APPARATUSES, METHODS, AND NON-TRANSITORY COMPUTER-READABLE STORAGE DEVICES FOR UPLINK PREAMBLE TRANSMISSION AND RECEPTION," which is hereby incorporated by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates generally to communication systems, apparatuses, methods, and non-transitory computer-readable storage devices, and in particular to communication systems, apparatuses, methods, and non-transitory computer-readable storage devices for uplink preamble transmission and reception.

Acronym Key and Definitions of Some Technical Terms

[0003] For ease of reading, subsections C and D of the Detailed Description list the acronyms and definitions of some technical terms used in this disclosure.

BACKGROUND

[0004] Mobile communication systems are known. While most mobile communication systems are so-called terrestrial network (TN) systems (which generally comprise a plurality of transmit-receive points (TRPs) deployed on the ground), non-terrestrial network (NTN) systems (which generally comprise a plurality of non-terrestrial TRPs such as satellites and high altitude platform stations (HAPS) deployed above ground or in the space) are also deployed or have started their deployment in recent years.

[0005] In mobile wireless communication systems such as fourth generation (4G) and fifth generation (5G) mobile wireless communication systems, user equipments (UEs) use a process known as random access to communicate with a TRP via a shared wireless-communication channel. In a random access process, physical random-access channel (PRACH) sequences are often used to establish uplink synchronization between a UE and a TRP by determining the carrier frequency offset (CFO) and the time delay (TD) therebetween. In 5G new radio (NR), the TRP and UE use Zadoff-Chu (ZC) sequences as the PRACH sequences to establish the uplink synchronizations therebetween.

[0006] Unlike TRPs of the TN systems where TRPs are at fixed locations, the TRPs of NTN systems are often movable. The TRPs' speeds of movements in NTN depends on the type of implementation, and in many applications such as those using low-earth satellites as the TRPs, the satellites or TRPs move at high speeds which may result in large Doppler shifts represented by large CFOs in the signals received at the TRPs. Moreover, compared to the TN systems, the cell size in NTN systems is relatively large which may result in large differential TDs between edge UEs (that is, UEs around the edge of a TRP cell or the edge of a TRP beam) and central UEs (that is, UEs around the center of the a TRP cell or the edge of the TRP beam) that belong to the same TRP cell or served by the same TRP beam. Moreover, the large distance between UEs and the TRPs may cause high propagation round-trip delay (RTD) which may require long cyclic prefix. In addition, the TRPs in NTN systems usually have a power capacity limitation, which generally requires low-power computational algorithms and fast computational algorithms at the same time.

SUMMARY

[0007] Embodiments of this disclosure relate to communication systems, apparatuses, methods, and one or more non-transitory computer-readable storage devices for physical random-access channel (PRACH) signaling and detection using a PRACH preamble. Embodiments of this disclosure may solve or mitigate the aforementioned problems associated with NTN random access.

[0008] More particularly, embodiments of the present disclosure employ modified ZC sequences including a rotation parameter, which may provide improved detection performance, estimation accuracy, and/or lower complexity implementation as compared to conventional solutions for NTN random access.

[0009] According to one aspect of this disclosure, there is provided a first method comprising: transmitting a physical random-access channel (PRACH) preamble comprising at least a modified sequence generated from a first Zadoff-Chu (ZC) sequence rotated by an angle θ, the first ZC sequence belonging to a set of ZC sequences.

[0010] In some embodiments, the first method further comprises: receiving the angle θ via radio resource control (RRC) signaling.

[0011] In some embodiments, the modified sequence is the first ZC sequence rotated by the angle θ and scaled by a scaling factor R.

[0012] In some embodiments, the first method further comprises: receiving the scaling factor R via the RRC signaling.

[0013] In some embodiments, $0<R\leq 1$.

[0014] In some embodiments, $\theta=\pi/2$.

[0015] In some embodiments, the first ZC sequence is randomly selected from the set of ZC sequences.

[0016] In some embodiments, the PRACH preamble further comprises a second ZC sequence.

[0017] In some embodiments, the second ZC sequence is randomly selected from the set of ZC sequences.

[0018] In some embodiments, the first and second ZC sequences are ZC sequences of different roots.

[0019] In some embodiments, the first ZC sequence is a complex conjugate of the second ZC sequence.

[0020] In some embodiments, the PRACH preamble comprises a superimposed PRACH sequence being a superimposition of the modified sequence and the second ZC sequence.

[0021] In some embodiments, said transmitting the PRACH preamble comprises:

> **[0022]** transmitting the modified sequence and the second ZC sequence using a same communication resource or using different communication resources.

[0023] In some embodiments, the PRACH preamble comprises a first and a second copies of the superimposed

PRACH sequence; and the first and the second copies sandwich a cyclic prefix (CP) therebetween.

[0024] In some embodiments, the first and the second copies further sandwich a guard interval therebetween.

[0025] In some embodiments, the PRACH preamble comprises a first and a second copies of the superimposed PRACH sequence; and the second copy is directly concatenated to the first copy.

[0026] According to one aspect of this disclosure, there is provided a user equipment comprising: a memory; a transmitter; and a processing unit functionally coupled to the memory and the transmitter for performing the above-described first method.

[0027] According to one aspect of this disclosure, there is provided one or more non-transitory computer-readable storage devices comprising computer-executable instructions, wherein the instructions, when executed, cause a processing unit of the user equipment to perform the above-described first method.

[0028] According to one aspect of this disclosure, there is provided a second method comprising: receiving a PRACH preamble; determining from the PRACH preamble at least a modified sequence, the modified sequence being a first ZC sequence rotated by an angle θ, the first ZC sequence belonging to a set of ZC sequences; and estimating at least one of a time delay (TD) and a carrier frequency offset (CFO) based on the PRACH preamble and the modified sequence for establishing uplink synchronization with the UE.

[0029] In some embodiments, the second method further comprises: transmitting the angle θ via RRC signaling.

[0030] In some embodiments, the modified sequence is the first ZC sequence rotated by the angle θ and scaled by a scaling factor ρ.

[0031] In some embodiments, the second method further comprises: transmitting a scaling factor R via the RRC signaling, the scaling factor ρ corresponding to the scaling factor R.

[0032] In some embodiments, $0<\rho\leq 1$.

[0033] In some embodiments, $\theta=\pi/2$.

[0034] In some embodiments, said determining from the PRACH preamble at least the modified sequence comprises: determining from the PRACH preamble the modified sequence and a second ZC sequence.

[0035] In some embodiments, the first and second ZC sequences are ZC sequences of different roots.

[0036] In some embodiments, the first ZC sequence is a complex conjugate of the second ZC sequence.

[0037] In some embodiments, the PRACH preamble comprises a superimposed PRACH sequence being a summation of the modified sequence and the second ZC sequence.

[0038] In some embodiments, said determining from the PRACH preamble at least the modified sequence comprises: obtaining at least a candidate modified sequence based on the set of ZC sequences; calculating a candidate PRACH sequence at least based on the candidate modified sequence; calculating a cross-correlation between the candidate PRACH sequence and the superimposed PRACH sequence; using a correlation peak detection method to detect one or more peaks of the cross-correlation greater than other values thereof by at least a threshold value; and determining at least the modified sequence as the candidate modified sequence.

[0039] In some embodiments, said using the correlation peak detection method to detect the one or more peaks of the cross-correlation greater than the other values thereof by the at least threshold value comprises: using the correlation peak detection method to detect one peak of the cross-correlation greater than other values thereof by the at least threshold value; and said estimating the TD and/or the CFO based on the PRACH preamble and the modified sequence comprises: estimating the TD based on the detected peak.

[0040] In some embodiments, said using the correlation peak detection method to detect the one or more peaks of the cross-correlation greater than the other values thereof by the at least threshold value comprises: using the correlation peak detection method to detect a plurality of peaks of the cross-correlation greater than other values thereof by the at least threshold value; and said estimating the TD and/or the CFO based on the PRACH preamble and the modified sequence comprises: estimating the TD and the CFO based on the detected peaks.

[0041] In some embodiments, said obtaining at least the candidate modified sequence based on the set of ZC sequences comprises: obtaining at least the candidate modified sequence and a second candidate ZC sequence based on the set of ZC sequences; said calculating the candidate PRACH sequence at least based on the candidate modified sequence comprises: calculating the candidate PRACH sequence based on the candidate modified sequence and the second candidate ZC sequence; and said determining at least the modified sequence as the candidate modified sequence comprises: determining the modified sequence and the second ZC sequence as the candidate modified sequence and the second candidate ZC sequence, respectively.

[0042] In some embodiments, said determining from the PRACH preamble at least the modified sequence comprises: obtaining a candidate modified sequence and a second candidate ZC sequence based on a set of ZC sequences; calculating a first cross-correlation between the superimposed PRACH sequence and the modified ZC sequence; calculating a second cross-correlation between the superimposed PRACH sequence and the second candidate ZC sequence; and using a correlation peak detection method to detect one or more peaks of the first and second cross-correlations respectively greater than other values thereof by at least a threshold value; and determining the modified sequence and the second ZC sequence as the candidate modified sequence and the second candidate ZC sequence, respectively.

[0043] In some embodiments, said determining from the PRACH preamble at least the modified sequence comprises: determining the modified sequence and the second ZC sequence from a first PRACH sequence and a second PRACH sequence, respectively, the first and second PRACH sequences being detected from different communication resources of the PRACH preamble.

[0044] In some embodiments, said determining from the PRACH preamble at least the modified sequence comprises: obtaining a candidate modified sequence and a second candidate ZC sequence based on a set of ZC sequences; calculating a first cross-correlation between the first PRACH sequence and the candidate modified sequence; calculating a second cross-correlation between the second PRACH sequence and the second candidate sequence; and using a correlation peak detection method to detect one or more peaks of the first and second cross-correlations respectively greater than other values thereof by at least a threshold value; and determining the modified sequence and the second ZC sequence as the candidate modified sequence and the second candidate ZC sequence, respectively.

[0045] In some embodiments, said obtaining at least the candidate modified sequence based on the set of ZC sequences comprises: selecting the second candidate ZC sequence from the set of ZC sequences; and calculating the candidate modified sequence as a complex conjugate of the second candidate ZC sequence, rotated by the angle θ and scaled by the scaling factor ρ.

[0046] In some embodiments, said obtaining at least the candidate modified sequence based on the set of ZC sequences comprises: selecting a first candidate ZC sequence from the set of ZC sequences; selecting the second candidate ZC sequence from the set of ZC sequences; and calculating the candidate modified sequence as the first candidate ZC sequence rotated by the angle θ and scaled by the scaling factor ρ.

[0047] According to one aspect of this disclosure, there is provided an apparatus comprising: a memory; a transmitter; and a processing unit functionally coupled to the memory and the transmitter for performing the above-described second method.

[0048] According to one aspect of this disclosure, there is provided one or more non-transitory computer-readable storage devices comprising computer-executable instructions, wherein the instructions, when executed, cause a processing unit of the user equipment to perform the above-described second method.

[0049] According to one aspect of this disclosure, there is provided a system comprising a first apparatus and a second apparatus. The first apparatus is configured to receive a random-access preamble. The first apparatus is further configured to transmit, based on the received random-access preamble, an indication of at least one of a time delay (TD) value or a carrier frequency offset (CFO) value. The second apparatus is configured to transmit the random-access preamble to the first apparatus. The second apparatus is further configured to receive the indication of at least one of the TD value or the CFO value from the first apparatus. The second apparatus is further configured to communicate with the first apparatus in accordance with at least one of the TD value or the CFO value.

[0050] Thus the technical features and benefits of the communication systems, apparatuses, methods, and one or more non-transitory computer-readable storage devices disclosed herein in various embodiments may include, but are not limited to:

- **[0051]** Providing two linearly independent measurements as the inputs of the estimator, which improves the estimation accuracy of TD and/or CFO;
- **[0052]** Using a single root to generate the ZC sequence and its complex conjugate, which simplifies the receiver circuitry and PRACH detection at the TRP **102**;
- **[0053]** Enabling detection of large CFOs in various environments (such as up to half of the used PRACH bandwidth), which facilitates the establishment of uplink synchronization between the UE and the TRP;
- **[0054]** The design parameter R, wherein, when R=0, the above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and PRACH-detection procedures may operate for TN systems or the terrestrial TRPs, which provides backward compatible with NR;
- **[0055]** The tunable design parameters R and θ, which facilitate adapting of various communications environments;
- **[0056]** Having a rotational angle that eliminates the ambiguity and adds an independency to the components of PRACH preamble, which may be used instead of using two non-complex conjugate PRACH preambles with different roots for the same UE, thereby giving the TRP the capability to efficiently use the allocated PRACH preambles to simultaneously serve a large number of UEs, as the number of PRACH sequences per UE is minimized.
- **[0057]** Providing an ability to control the PAPR at UEs using R and θ to select the minimum optimal PAPR. At the TRP, the receiver thereof may only use one root to generate the ZC sequence with its complex conjugate and subsequently their cyclically shifted versions, which minimizes the number of correlation operations and consequently reduces the computational complexity, thereby improving the energy efficiency in both UEs (through lowering the PAPRs) and at TRPs (through lowered receiver complexity with a fast searching algorithm);
- **[0058]** Option of transmitting the PRACH preamble using the PRACH sequence and its complex conjugate on same time and frequency resources with the capability to estimate TD and/or CFO, thereby preserving time/frequency resources and improving the PRACH occasions utilizations;
- **[0059]** Having a concatenated sequential version either on the same or different PRACH occasions, thereby expanding the ability to accommodate multiple communications configurations and also ensuring orthogonality.

BRIEF DESCRIPTION OF THE DRAWINGS

[0060] FIG. **1** is a simplified schematic diagram showing the structure of a communication system, according to some embodiments of this disclosure;

[0061] FIG. **2** is a simplified schematic diagram of a controlling device of a communication network of the communication system shown in FIG. **1**;

[0062] FIG. **3** is a simplified schematic diagram of a transmit-receive point (TRP) of the communication system shown in FIG. **1**;

[0063] FIG. **4** is a simplified schematic diagram of a user equipment (UE) of the communication system shown in FIG. **1**;

[0064] FIG. **5** is a plot showing the ambiguity cross-correlation function of the PRACH preamble when both time delay (TD) and integer carrier frequency offset (CFO) exist between the TRP and UE of a conventional wireless communication system;

[0065] FIG. **6** is a flowchart showing a physical random-access channel (PRACH) signaling procedure executed by a UE of the communication system shown in FIG. **1** for uplink PRACH preamble transmission, wherein the PRACH preamble comprises modified Zadoff-Chu (ZC) sequences;

[0066] FIG. **7** is a flowchart showing a PRACH-detection procedure executed by a TRP of the communication system shown in FIG. **1** corresponding to the PRACH-signaling procedure shown in FIG. **6**;

[0067] FIG. **8** is a diagram showing the sequence of operations performed by the UE and the TRP of the communication system shown in FIG. **1** for establishing the uplink synchronization therebetween according to the PRACH-signaling procedure shown in FIG. **6** and the PRACH-detection procedure shown in FIG. **7**;

[0068] FIG. **9**A is a flowchart showing the PRACH-signaling procedure shown in FIG. **6** with the detail of the sequence-generation step, according to some embodiments of this disclosure;

[0069] FIG. **9**B is a flow diagram showing some steps of the PRACH-signaling procedure shown in FIG. **9**A;

[0070] FIG. **10**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **9**A, according to some embodiments of this disclosure;

[0071] FIG. **10**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **10**A;

[0072] FIG. **11** is a plot showing the magnitudes of the non-peak terms of the output of the correlator used in a prior-art PRACH-detection method and in the PRACH-detection procedure shown in FIG. **10**A;

[0073] FIG. **12**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **9**A, according to some embodiments of this disclosure;

[0074] FIG. **12**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **12**A;

[0075] FIGS. **13** and **14** are plots showing the magnitudes of the non-peak terms of the output of the correlators used in the PRACH-detection procedure shown in FIG. **12**A;

[0076] FIG. **15**A is a flowchart showing the PRACH-signaling procedure shown in FIG. **6** with the detail of the sequence-generation step, according to some embodiments of this disclosure;

[0077] FIG. **15**B is a flow diagram showing some steps of the PRACH-signaling procedure shown in FIG. **15**A;

[0078] FIG. **16**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **15**A, according to some embodiments of this disclosure;

[0079] FIG. **16**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **16**A;

[0080] FIG. **17**A is a flowchart showing the PRACH-signaling procedure shown in FIG. **6** with the detail of the sequence-generation step, according to some embodiments of this disclosure;

[0081] FIG. **17**B is a flow diagram showing some steps of the PRACH-signaling procedure shown in FIG. **17**A;

[0082] FIG. **18**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **17**A, according to some embodiments of this disclosure;

[0083] FIG. **18**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **18**A;

[0084] FIG. **19**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **17**A, according to some embodiments of this disclosure;

[0085] FIG. **19**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **19**A;

[0086] FIG. **20**A is a flowchart showing the PRACH-signaling procedure shown in FIG. **6** with the detail of the sequence-generation step, according to some embodiments of this disclosure;

[0087] FIG. **20**B is a flow diagram showing some steps of the PRACH-signaling procedure shown in FIG. **20**A;

[0088] FIG. **21**A is a flowchart showing the PRACH-detection procedure shown in FIG. **7** corresponding to the PRACH-signaling procedure shown in FIG. **20**A, according to some embodiments of this disclosure;

[0089] FIG. **21**B is a flow diagram showing some steps of the PRACH-detection procedure shown in FIG. **21**A;

[0090] FIG. **22**A is a schematic diagram showing a PRACH preamble with two copies of a PRACH sequence having modified ZC sequences, wherein the two copies of a PRACH sequence are concatenated in a sequential manner;

[0091] FIG. **22**B is a schematic diagram showing a PRACH preamble with two copies of a PRACH sequence having modified ZC sequences, wherein the two copies of a PRACH sequence are concatenated in an aggregated manner;

[0092] FIG. **23** is a plot showing a comparison of the constellations of the entries of a conventional ZC sequence, the rotated complex-conjugate of the conventional ZC sequence, and a superimposed PRACH sequence having modified ZC sequences; and

[0093] FIG. **24** is a plot showing a comparison of the constellations of a conventional ZC sequence, the rotated complex-conjugate of the conventional ZC sequence, a prior-art PRACH signaling and detection method using two ZC sequences, and a superimposed PRACH sequence having modified ZC sequences.

DETAILED DESCRIPTION

A. System Structure

[0094] Turning now to FIG. **1**, a communication system is shown and is generally identified using reference numeral **100**. As shown, the communication system **100** comprises a plurality of transmit-receive points (TRPs) **102** forming a radio access network (RAN) **104** in communication with a plurality of user equipments (UEs) **114** for providing wireless communication services to the UEs **114** such that the UEs **114** may access one or more public switched telephone networks (PSTNs) **106**, the Internet **108**, and other networks **110** via a communication network **112** to make phone calls (to, for example, other UEs **114**, landline phones (not shown), and/or the like), exchanging data (for example, sending/receiving emails, sending/receiving instant messages, and/or the like), accessing contents (such as text content, audio content, and/or video content), and/or the like. Herein, a TRP **102** may also be referred to as a communication node, a gNodeB (next generation node of base station (NodeB), also called a “gigabit” NodeB or a “gNB”), a base station, an access point, and/or the like, and may comprise a plurality of terrestrial TRPs **102**A and a plurality of non-terrestrial TRPs **102**B (for example, satellite, high altitude platforms stations, unmanned aerial vehicles, and/or the like).

[0095] The PSTN **106**, in addition to packet switched, may include circuit switched telephone networks for providing plain old telephone service (POTS). The Internet **108** may include a network of computers and subnets (intranets) or both, and incorporate protocols, such as IP, TCP, UDP, and/or the like.

[0096] The communication network **112** comprises one or more controlling devices **120** in communication with the TRPs **102** to provide various services such as voice, data, and other services to the UEs **114**. The one or more controlling devices **120** of the communication network **112** may also serve as a gateway access between (i) the TRPs **102** or UEs **114** or both, and (ii) other networks (such as the PSTN **106**, the Internet **108**, and the other networks **110**).

[0097] FIG. **2** is a simplified schematic diagram of the controlling device **120**. As shown, the controlling device **120** comprises at least one processing unit **122** (also denoted "processor"), at least one network interface **124**, one or more input/output components or interfaces **126**, and at least one memory **128** (also denoted "storage device" hereinafter).

[0098] The processing unit **122** is configured for performing various processing operations and may comprise a microprocessor, a microcontroller, a digital signal processor, a field programmable gate array (FPGA), an application specific integrated circuit (ASIC), and/or the like.

[0099] The network interface **124** comprises a circuitry for directly or indirectly (that, via one or more intermediate devices) communicating with other devices such as the TRPs **102**, the PSTN **106**, the Internet **108**, and other networks **110** using suitable wired or wireless communication technologies and suitable protocols.

[0100] Each input/output component **126** enables interaction with a user or other devices in the communication system **100**. Each input/output device **126** may comprise any suitable structure for providing information to or receiving information from a user and may be, for example, a speaker, a microphone, a keypad, a keyboard, a display, a touch screen, and/or the like.

[0101] Each memory **128** may comprise any suitable volatile and/or non-volatile storage and retrieval components such as random access memory (RAM), read only memory (ROM), hard disk, optical disc, subscriber identity module (SIM) card, solid-state memory modules, memory stick, secure digital (SD) memory card, and/or the like. The memory **128** may be used for storing instructions executable by the processing unit **122** and data used, generated, or collected by the processing unit **122** and/or the network interface **124**. For example, the memory **126** may store software instructions or modules executable by the processing unit **122** for implementing some or all of the functionalities and/or embodiments of the controlling device **120** described herein. The memory **126** may also store coverage information of the TRPs **102** (described in more detail later) in, for example, a database thereof.

[0102] Referring back to FIG. **1**, the TRPs **102** comprise a plurality of terrestrial TRPs **102**A and a plurality of non-terrestrial TRPs **102**B. Herein, a terrestrial TRP **102**A is generally deployed on the ground (including on ground-based infrastructures such as buildings, towers, and/or the like). The terrestrial TRP **102**A may typically comprise a plurality of components such as one or more transmitters and receivers, one or more base station controllers (BSCs), radio network controllers (RNCs), relay nodes, elements, and/or the like. Each terrestrial TRP **102**A (or more specifically the base station thereof) transmits and/or receives wireless signals within a particular geographic region or area (that is, a "cell" or a "coverage area"). A cell may be further partitioned into cell sectors, and a terrestrial TRP **102**A may, for example, employ multiple transceivers to provide service to multiple cell sectors. In some embodiments, there may be established pico or femto cells where the radio access technology supports such. In some embodiments, multiple transceivers may be used for each cell, for example using multiple-input multiple-output (MIMO) technology.

[0103] As those skilled in the art understand, cellular coverage (that is, the coverage of the terrestrial TRPs **102**A) typically varies depending on the regions. For example, cellular coverage is typically strong and widely available in regions with dense cellular infrastructure deployment; examples of such regions may be urban regions with high population density where carriers are more willing to deploy more cellular infrastructure. On the other hand, cellular coverage may be sparse and poorly available in regions with sparse cellular infrastructure deployment; examples of such regions may be rural or remote regions with low population density where carriers are less motivated to deploy cellular infrastructure.

[0104] On the other hand, a non-terrestrial TRP **102**B is a TRP generally deployed above ground or in the space such as a communication satellite or a high altitude platform stations (HAPS) (for example, a drone, a balloon, an airship, an aircraft, or the like). In various embodiments, a non-terrestrial TRP **102**B may be permanently or semi-permanently deployed (such as a non-terrestrial TRP **102**B in the form of a communication satellite, a communication balloon or airship anchored at a fixed location, or the like), or may be temporarily deployed (for example, a non-terrestrial TRP **102**B in the form of a drone, a balloon, or an airship temporarily deployed about a location) for supporting an anticipated intensive-communication event such as a concert, a game, or the like, wherein the deployment of the non-terrestrial TRP **102**B may be cancelled after the event.

[0105] The terrestrial TRP **102**A and non-terrestrial TRP **102**B may have a similar structure although they may be different in some aspects such as their communication bandwidths, power units, communication technologies, protocols, and/or the like. FIG. **3** is a simplified schematic diagram of a TRP **102**. As shown, the TRP **102** comprises at least one processing unit **142**, at least one transmitter **144**, at least one receiver **146**, one or more antennas **148**, at least one memory **150**, and one or more input/output components or interfaces **152**. A scheduler **154** may be coupled to the processing unit **142**. The scheduler **154** may be included within or operated separately from the TRP **102**.

[0106] The processing unit **142** is configured for performing various processing operations such as signal coding, data processing, power control, input/output processing, or any other suitable functionalities. The processing unit **142** may comprise a microprocessor, a microcontroller, a digital signal processor, a FPGA, an ASIC, and/or the like.

[0107] Each transmitter **144** may comprise any suitable structure for generating signals for wireless transmission to one or more UEs **114** or other devices. Each receiver **146** may comprise any suitable structure for processing signals received wirelessly from one or more UEs **114** or other devices. Although shown as separate components, at least one transmitter **144** and at least one receiver **146** may be integrated and implemented as a transceiver. Each antenna **148** may comprise any suitable structure for transmitting and/or receiving wireless signals. Although a common antenna **148** is shown in FIG. **4** as being coupled to both the transmitter **144** and the receiver **146**, one or more antennas **148** may be coupled to the transmitter **144**, and one or more separate antennas **148** may be coupled to the receiver **146**.

[0108] Each memory **150** may comprise any suitable volatile and/or non-volatile storage and retrieval components such as RAM, ROM, hard disk, optical disc, SIM card, solid-state memory modules, memory stick, SD memory card, and/or the like. The memory **150** may be used for storing instructions executable by the processing unit **142** and data used, generated, or collected by the processing unit **142**. For example, the memory **150** may store software instructions or modules executable by the processing unit **142** for implementing some or all of the functionalities and/or embodiments of the TRP **102** described herein.

[0109] Each input/output component **152** enables interaction with a user or other devices in the system **100**. Each input/output device **152** may comprise any suitable structure for providing information to or receiving information from a user and may be, for example, a speaker, a microphone, a keypad, a keyboard, a display, a touch screen, a network communication interface, and/or the like.

[0110] Referring back to FIG. **1**, the TRPs **102** may communicate with the UEs **114** over one or more air interfaces **118** using any suitable wireless communication links such as radio frequency (RF), microwave, infrared (IR), and/or the like. The air interfaces **118** may utilize any suitable channel access methods such as time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), code division multiple access (CDMA), wideband CDMA (WCDMA), and/or the like.

[0111] The air interfaces **118** may use any suitable radio access technologies such as universal mobile telecommunication system (UMTS), high speed packet access (HSPA), HSPA+ (optionally including high speed downlink packet access (HSDPA), high-speed uplink packet access (HSUPA), or both), Long-Term Evolution (LTE), LTE-A, LTE-B, IEEE 802.11, 802.15, 802.16, CDMA2000, CDMA2000 1×, CDMA2000 EV-DO, IS-2000, IS-95, IS-856, global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), 5G New Radio (NR), standard or non-standard satellite internet access technologies, and/or the like. Moreover, the communication system **100** may use multiple channel access functionality. Of course, other multiple access schemes and wireless protocols may be used.

[0112] Herein, a UE **114** generally refers to a wireless device that may join the communication system **100** via a joint initial access procedure (described in more detail later). In various embodiments, a UE **114** may be a wireless device used by a human or user (such as a smartphone, a cellphone, a personal digital assistant (PDA), a laptop, a computer, a tablet, a smart watch, a consumer electronics device, and/or the like. A UE **114** may alternatively be a wireless sensor, an Internet-of-things (IoT) device, a robot, a shopping cart, a vehicle, a smart TV, a smart appliance, or the like. Depending on the implementation, the UE **114** may be movable autonomously or under the direct or remote control of a human, or may be positioned at a fixed position. In some embodiments, a UE **114** may be a network device (such as a TRP **102**, a wireless transmit/receive unit (WTRU), a mobile station, a fixed or mobile subscriber unit, a machine type communication (MTC) device, a device of the communication network **112**, or the like) which is considered as a UE when it is powered on and joins the communication system **100** via the joint initial access procedure; and then acts as a network device after the joint initial access procedure is completed). In some embodiments, the UEs **114** may be multimode devices capable of operation according to multiple radio access technologies and incorporate multiple transceivers necessary to support such.

[0113] FIG. **4** is a simplified schematic diagram of a UE **114**. As shown, the UE **114** comprises at least one processing unit **202**, at least one transceiver **204**, at least one antenna or network interface controller (NIC) **206**, at least one positioning module **208**, one or more input/output components **210**, and at least one memory **212**.

[0114] The processing unit **202** is configured for performing various processing operations such as signal coding, data processing, power control, input/output processing, or any other functionalities to enable the UE **114** to join the communication system **100** and operate therein. The processing unit **202** may also be configured to implement some or all of the functionalities and/or embodiments of the UE **114** described in this disclosure. The processing unit **202** may comprise a microprocessor, a microcontroller, a digital signal processor, a FPGA, or an ASIC. Examples of the processing unit **202** may be an ARM® microprocessor (ARM is a registered trademark of Arm Ltd., Cambridge, UK) manufactured by a variety of manufactures such as Qualcomm of San Diego, California, USA, under the ARM® architecture, an INTEL® microprocessor (INTEL is a registered trademark of Intel Corp., Santa Clara, CA, USA), an AMD® microprocessor (AMD is a registered trademark of Advanced Micro Devices Inc., Sunnyvale, CA, USA), and the like.

[0115] The at least one transceiver **204** may be configured for modulating data or other content for transmission by the at least one antenna **206**. The transceiver **204** is also configured for demodulating data or other content received by the at least one antenna **206**. Each transceiver **204** may comprise any suitable structure for generating signals for wireless transmission and/or processing signals received wirelessly. Each antenna **206** may comprise any suitable structure for transmitting and/or receiving wireless signals. Although shown as a single functional unit, a transceiver **204** may be implemented separately as at least one transmitter and at least one receiver.

[0116] The positioning module **208** is configured for communicating with a plurality of global or regional positioning anchors. The positioning module **208** may use the transceiver **204** and antenna **206** for communicating with the positioning anchors, or may comprise separate transceiver and antenna for communicating with the positioning anchors. In some embodiments, the positioning anchors may be positioning devices such as navigation satellites and/or HAPS separated from the non-terrestrial TRPs **102**B. For example, the navigation satellites may be satellites of a global navigation satellite system (GNSS) such as the Global Positioning System (GPS) of USA, Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) of Russia, the Galileo positioning system of the European Union, and/or the Beidou system of China. The navigation satellites may also be satellites of a regional navigation satellite system (RNSS) such as the Indian Regional Navigation Satellite System (IRNSS) of India, the Quasi-Zenith Satellite System (QZSS) of Japan, or the like. In some other embodiments, the positioning anchors may be devices (for example, navigation satellites and/or HAPS) acting as both positioning anchors for providing positioning reference signals and as non-terrestrial TRPs **102**B.

[0117] The one or more input/output components **210** is configured for interaction with a user or other devices in the system **100**. Each input/output component **210** may comprise any suitable structure for providing information to or receiving information from a user and may be, for example, a speaker, a microphone, a keypad, a keyboard, a display, a touch screen, a network communication interface, and/or the like.

[0118] The at least one memory **212** is configured for storing instructions executable by the processing unit **202** and data used, generated, or collected by the processing unit **202**. For example, the memory **212** may store software instructions or modules executable by the processing unit **202** for implementing some or all of the functionalities and/or embodiments of the UE **114** described herein. Each memory **212** may comprise any suitable volatile and/or non-volatile storage and retrieval components such as AM, ROM, hard disk, optical disc, SIM card, solid-state memory modules, memory stick, SD memory card, and/or the like.

[0119] For ease of description, in the following, a communication system **100** having one or more terrestrial TRPs **102**A without any non-terrestrial TRPs **102**B is denoted a terrestrial network (TN) system, and a communication system **100** having one or more non-terrestrial TRPs **102**B is denoted a non-terrestrial network (NTN) system. Those skilled in the art will appreciate that an NTN system **100** may also comprise one or more terrestrial TRPs **102**A. Moreover, while an NTN system **100** is described as an example in the following description, those skilled in the art will appreciate that the methods describe below may also be used for TN systems, and/or the terrestrial TRPs **102**A of NTN systems. Thus, in the following description, the terms "TN" and "terrestrial TRP" may be used interchangeably in that a feature, characteristic, or method described for a TN system may be applicable for a terrestrial TRP **102**A (regardless whether the terrestrial TRP**102**A is in a terrestrial network system or in a non-terrestrial network system). Similarly, the terms "NTN" and "non-terrestrial TRP" may be used interchangeably in that a feature, characteristic, or method described for an NTN system may be applicable for a non-terrestrial TRP **102**B.

B. Physical Random-Access Channel (PRACH)

[0120] As those skilled in the art will appreciate, the communication system **100** may operate by sharing resources such as bandwidth, and allow data transmission (for example, transmission of voice, data, video, text, and/or the like) via broadcast (one device to all devices in the system **100**; that is, one-to-all), multicast (one device to a plurality of device; that is, one-to-many), unicast (one device to another device such as one UE **114** to another UE; that is, one-to-one), and/or the like.

[0121] In the communication system **100**, a UE **114** generally needs to execute an initial access procedure to establish a "connection" (that is, to establish communication) with a TRP **102** for joining the network system for communicating with other components thereof such as other UEs **114**, the communication network **104**, the PSTNs **104**, the Internet **106**, and other networks **108**. The purpose of the initial access procedure is for the UE **114** to acquire downlink and uplink synchronization with the TRP **102**.

[0122] For example, the initial access procedure defined since LTE comprises four physical-layer steps: (i) cell search, (ii) cell selection, (iii) system information acquisition, and (iv) random access. Initial access is typically initiated when the UE **114** is in the IDLE state or the INACTIVE state. After performing the initial access procedure, the UE **114** then transitions from the IDLE or INACTIVE states to the CONNECTED state. Upon completing the initial access procedure, the UE **114** is considered to have acquired both downlink and uplink synchronization with the TRP **102**.

[0123] UEs **114** usually use random access to communicate with a TRP **102** via a shared wireless-communication channel. In the initial access procedure, physical random-access channel (PRACH) signals are used for transmitting random-access preambles (also denoted "PRACH preambles") from the UEs **114** to the TRP **102** for initiation of random access. A PRACH preamble is a type of an orthogonal frequency-division multiplexing (OFDM) signal (which has a plurality of subcarriers with predefined subcarrier spacing) and generally comprises a cyclic prefix, a PRACH sequence generated based on Zadoff-Chu (ZC) sequences, and a guard time. The PRACH sequence is used by the TRP **102** for determining the carrier frequency offset (CFO) and the time delay (TD) between the TRP **102** and UE **114** for establishing the uplink synchronization therebetween.

[0124] If only a TD exists between the TRP **102** and UE **114**, the TD may cause a cyclic shift of the ZC sequence of the PRACH preamble and consequently causes a cyclic shift for the peak of its cross/auto-correlation function by the same amount of shifting, which may be exploited to determine the TD. The determined TD may then be fed back to the UE **114** to use as time advance to establish an uplink time synchronization.

[0125] On the other hand, the existence of CFO may cause more complicated issues.

[0126] In 5G NR, the assigned cyclic prefix of a PRACH preamble is inversely proportional to the PRACH subcarrier spacing, which may only support a small cyclic prefix for a relatively large sub-carrier frequency spacing. For example, the frequency range 2 (FR2; referring to the millimeter-wave (mmWave) frequency bands from 24.25 GHz to 52.6 GHZ) PRACH formats in NR focus on the mmWave configuration which only requires a short propagation range. In contrast, the non-terrestrial TRP **102**B requires a relatively massive propagation range and consequently a long cyclic prefix while at the same time using relatively large sub-carrier frequency spacing. Therefore, NR PRACH preamble formats may not support all non-terrestrial TRPs **102**B as increasing PRACH subcarrier spacing proportionally decreases the length of the cyclic prefix. On the other hand, the product of CFO and differential TD may be significantly greater than 0.5, where the existing PRACHs in NR only support the value of 0.5 or less to ensure orthogonality and maintain the zero-correlation zone (ZCZ).

[0127] In 5G NR, several existing PRACH preamble formats may be used, which are all generated based on ZC sequences. As those skilled in the art understand, such PRACH preamble formats can capture CFOs less than the half of the PRACH sub-carrier spacing (known as the fractional CFO) and may be suitable for communication between terrestrial TRP **102**A and UE **114** where the terrestrial TRP **102**A is deployed at a fixed location.

[0128] The non-terrestrial TRPs **102**B are often movable and some non-terrestrial TRPs **102**B (such as low-earth satellites) may move at high speeds, which may result in large Doppler shifts represented by large CFOs in the received signals at the TRPs **102**B. Such large CFOs are often several integer times of the PRACH sub-carrier spacing for non-terrestrial TRPs **102**B. However, the existing PRACH preamble formats cannot capture a CFO greater than the half of the PRACH sub-carrier spacing.

[0129] The non-terrestrial TRPs **102**B may experience both TD and integer CFO of the PRACH preamble. Herein, an integer CFO is a CFO that is an integer multiple of the PRACH sub-carrier spacing. In the current NR, it may be difficult to find both TD and integer CFO of the PRACH preamble because their existence may cause a mixed cyclic shift for the peak of the cross/auto-correlation function of the ZC sequences of the PRACH preamble.

[0130] While the existence of the fractional CFO of ZC sequence of the PRACH preamble may cause additional smaller peaks of its cross/auto-correlation function and at the same time cause a reduction in the magnitude of the cross/auto-correlation function true peak, the amount of such a reduction may be proportionally related to the level of the fractional CFO, which may be used to estimate the fractional CFO. However, the existence of both TD and integer CFO with/without a fractional frequency offset may cause multiple peaks in the ambiguity cross-correlation function (or simply the "ambiguity function"). FIG. **5** shows the ambiguity cross-correlation function when both TD and integer CFO exist. As can be seen, the multiple peaks in the ambiguity function may cause an uncertainty in identifying the true peak, thereby making it very complicated to extract both time advance and CFO. Consequently, the non-terrestrial TRP **102**B may not be able to find the TD and integer CFO from a single measurement. This is a main impairment of PRACH preambles in NR.

[0131] In prior art, there are some methods to tackle this limitation of NR to solve the above-described issues in the PRACH of the non-terrestrial TRPs **102**B. These methods may be grouped into two modes:

- **[0132]** Concatenation mode: concatenating two or several ZC sequences using same or different roots; and
- **[0133]** Superposition mode: using the superposition of two complex conjugate ZC sequences.

[0134] For example, one method is to use two ZC sequences in a concatenated mode using different time/frequency resources. The two sequences are complex conjugate to each other and are generated using the same root. Another method is to use two ZC sequences in a concatenated mode or in a superposition mode using the same time/frequency resources, where these two ZC sequences are generated using different roots and cannot be complex conjugate of each other. As an extension of this method, another method is to use several ZC sequences in a concatenated mode using different roots.

[0135] These prior-art methods may be categorized as:

- **[0136]** Category 1: using a ZC sequence and its complex conjugate in a concatenated mode in different PRACH occasions; and
- **[0137]** Category 2: using two or more ZC sequences that have different roots in the same or different PRACH occasions.

[0138] The main drawback of the prior-art methods of Category 1 is that a UE **114** cannot superpose the ZC sequence and its complex conjugate on the same PRACH resources, which may reduce the PRACH resource utilization and increase the transmission overheads. Moreover, the prior-art methods in Category 1 may lead to a detection ambiguity at the TRP **102** when two complex conjugate ZC sequences from different UEs **114** use the same PRACH resources. Thus, transmitting ZC sequence and its complex conjugate by a UE **114** on the same PRACH occasion leads to detection ambiguity at the TRP **102**, which consequently prevents the TRP **102** from detecting the TD and CFO for the UE **114**. Transmitting a ZC sequence and its complex conjugate by two UEs **114** of the same or different cell or beam, using the same time frequency resources, also leads to PRACH detection failure for those UEs.

[0139] In the prior-art methods of Category 2, using two or more ZC sequences with different roots for the same UE **114** reduces the available sequences for serving more UEs while ensuring orthogonality, or increases the level of inter-cell/inter-beam interference in the communication system **100**, thereby increasing the number of used sequences to generate the PRACH, which also leads to increasing the complexity of the TRP receiver (especially when using more than two ZC sequences). Moreover, using the superposition of two complex conjugate ZC sequences may effectively result in a pure real non-ZC sequence.

[0140] According to one aspect of this disclosure, the communication system **100** uses a PRACH preamble having modified ZC sequences and related methods or procedures for uplink synchronization.

[0141] FIG. **6** is a flowchart showing a PRACH-signaling procedure **300** executed by a UE **114** for uplink PRACH preamble transmission, wherein the PRACH preamble comprises modified ZC sequences. When the procedure **300** starts (step **302**), the UE **114** generates a plurality of sequences which comprise one or more ZC sequences and their scaled and rotated complex-conjugates (step **304**).

[0142] As those skilled in the art understand, a ZC sequence is a sequence of complex values of a constant amplitude. Cyclically shifted versions of a ZC sequence are uncorrelated with each another.

[0143] A ZC sequence may be generated according to a mathematical formula. Such a generated ZC sequence is usually denoted by a root sequence for differentiating it from its cyclically shifted versions.

[0144] In some embodiments, the ZC sequence $x_u[n]$ may be generated as

$$x_u[n] = e^{-j\frac{\pi un(n+1)}{L_{RA}}} \tag{1}$$

where L_{RA} is a prime number and u=1, 2, 3, . . . , $L_{RA}-1$. The complex conjugate of the ZC sequence $x_u[n]$ is:

$$x_u^*[n] = e^{j\frac{\pi un(n+1)}{L_{RA}}} \tag{2}$$

where the superscript * represents complex conjugate. Those skilled in the art will appreciate that $x_u^*[n]$ can also be seen as $x_{L_{RA}-u}[n]$. In other words, the complex conjugate of a ZC sequence is also a ZC sequence of a different root.

[0145] Thus, at step **304** of the procedure **300**, the UE **114** receives a rotation angle θ and a scaling factor R (1≥R>0) from the TRP **102** via radio resource control (RRC) signaling, and generates one or more ZC sequences $x_u[n]$ and their scaled and rotated complex-conjugates $Re^{j\theta} x_u^*[n]$.

[0146] The generated one or more ZC sequences $x_u[n]$ and their scaled and rotated complex-conjugates $Re^{j\theta} x_u^*[n]$ are then transmitted from the UE **114** to a TRP **102** (being the terrestrial TRP **102**A or non-terrestrial TRP **102**B) in the same or different PRACH occasions such as same or different time-frequency resources (step **306**). The procedure **300** then ends (step **308**).

[0147] The rotation angle θ introduces a new degree of freedom which helps in resolving multiple ambiguities and increases ZC roots available for PRACH for simultaneous transmissions from a plurality of UEs **114**. Such a PRACH preamble, having modified ZC sequences, and the related PRACH-signaling procedure **300** enlarge the sequence design into multiple dimensions, which helps in resolving multiple ambiguities and enhances estimation accuracy. Accordingly, the TRP **102** may estimate the TD and/or CFO to ensure a proper uplink synchronization wherein the estimation accuracy may be improved by using two linearly independent measurements. Consequently, the TRP **102** may more accurately detect the integer and differential CFO.

[0148] Thus, the use of PRACH preambles having modified ZC sequences solves the problem of simultaneously estimating the TD and/or CFO in both terrestrial and non-terrestrial TRPs **102**A and **102**B to ensure a proper uplink synchronization. By properly selecting the scaling factor R, the PRACH preamble having modified ZC sequences and the PRACH-signaling procedure **300** provide backward compatibility with existing mobile wireless communication systems (such as NR systems), and provide a smooth transition from PRACH of TN systems (such as NR systems) to PRACH of NTN systems (such as 6G and/or other mobile wireless communication systems). Moreover, as compared to the prior-art methods of Category 1, the PRACH-signaling procedure **300** may additionally or alternatively use superposition on the same time and frequency resources for the ZC sequence and its rotated complex conjugate, and therefore provides various benefits such as:

- **[0149]** The superposition mode is beneficial in terms of optimizing the number of PRACH occasions and reducing PRACH overhead.
- **[0150]** In the concatenation mode, the PRACH-signaling procedure **300** allows two UEs **114** in the same or different cell/beam can use roots u and L_{RA}−u without creating detection ambiguity at gNB which is not the case for Category 2.

[0151] With the added degree of freedom, the PRACH-signaling procedure **300** efficiently utilizes either the same time/frequency or different time/frequency resources in PRACH signaling. Furthermore, the PRACH-signaling procedure **300** lowers implementation complexity.

[0152] As those skilled in the art understand, the prior-art Category-2 methods described above uses two ZC sequences with different roots u_1 and u_2. Consequently, the roots L_{RA}−u_1 and L_{RA}−u_2 may not be used by other UEs without creating detection ambiguity or PRACH failure. Moreover, using two different roots per preamble may create a complexity for the TRP **102** as the root pair selection needs to be optimized to avoid a negative impact to the detection performance.

[0153] On the other hand, the PRACH-signaling procedure **300** only uses a single root, thereby resulting in various benefits such as:

- **[0154]** Simplicity in sequence generation and sequence detection at UE **114** and TRP **102** respectively;
- **[0155]** Increasing the available number of preambles that can be allocated per UE, per cell.

[0156] In addition, the PRACH-signaling procedure **300** further provides a reduction of the peak-to-average power ratio (PAPR) of the used PRACH sequences as compared to prior-art methods.

[0157] FIG. **7** is a flowchart showing a PRACH-detection procedure **400** executed by a TRP **102** corresponding to the PRACH-signaling procedure **300**.

[0158] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**) and detects a plurality of PRACH sequences therefrom (step **406**). At step **408**, the TRP **102** searches for and determines ZC sequences corresponding to the PRACH sequences. Then, the TRP **102** estimates the TD and/or CFO based on the received PRACH signal and the determined ZC sequences using any suitable methods (step **410**), and establishes uplink synchronization with the UE **114** based on the estimated TD and/or CFO (step **412**), for example, by sending the estimated TD and/or CFO to the UE **114** such that the UE **114** may pre-compensate its transmitted signals by using the received TD and/or CFO. The procedure **400** then ends (step **414**).

[0159] FIG. **8** is a diagram **500** showing the sequence of operations to establish the uplink synchronization between the UE **114** and the TRP **102** according to the PRACH-signaling procedure **300** and the PRACH-detection procedure **400**.

[0160] In these embodiments, a plurality of ZC sequences have been generated according to formula (1) by applying a predetermined cyclic shift value N_{CS} and set type. The sequences are then stored as a pool or a set of PRACH preambles in, for example, the memory of the UE **114**.

[0161] As shown in FIG. **8**, the TRP first broadcasts the SIB (step **502**). The UE **114** receives the SIB and selects PRACH preamble parameters from the pool (step **504**). The UE **114** may, for example, randomly select the PRACH preamble parameters from the pool. At step **506**, the UE **114** generates the superimposed rotated ZC sequence as described above, performs a time-domain to frequency-domain conversion operation, such as a Fast Fourier Transform (FFT), to generate the OFDM PRACH signal, and transmits the PRACH signal. At step **508**, the TRP **102** receives the transmitted PRACH signal, detects the transmitted PRACH sequence, and estimates the TD and/or CFO. Then, the TRP **102** transmits the estimated TD and/or CFO to the UE **114** to establish uplink synchronization (step **510**). At step **512**, the UE **114** pre-compensates the transmitted signals by using the received TD and/or CFO. The synchronized uplink transmission is then established (step **514**).

[0162] In the following, various embodiments of the procedures **300** and **400** are described.

[0163] FIG. **9**A is a flowchart showing the PRACH-signaling procedure **300** with the detail of the sequence-generation step **304** according to some embodiments of this disclosure. FIG. **9**B is a flow diagram showing steps **326** to **336** of the PRACH-signaling procedure **300** shown in FIG. **9**A.

[0164] At step **304** of the PRACH-signaling procedure **300**, the UE **114** selects a ZC sequence (denoted $x_u[n]$) from the pool of PRACH preambles. The UE **114** may, for example, randomly select the ZC sequence from the pool. More specifically, at step **322**, the UE **114** obtains preamble parameters from the system information block (SIB), and then selects (e.g., randomly selects) the parameters of a preamble from the available preambles broadcasted by the TRP **102** and determines the scaling factor R (step **324**). Based on the selected preamble parameters, the UE **114** selects a ZC sequence $x_u[n]$ from the pool of PRACH preambles (step **326**).

[0165] Next, the complex conjugate $x_u^*[n]$ of the ZC sequence $x_u[n]$ is calculated (step **328**), which is then weighted by the scaling factor R and rotated by a rotation angle θ (steps **330** and **332**; the order of which may be reversed) to obtain the scaled and rotated complex-conjugate $Re^{j\theta}x_u^*[n]$ of the selected ZC sequence $x_u[n]$. The two sequences $x_u[n]$ and $Re^{j\theta}x_u^*[n]$ are then superimposed or otherwise summed together (step **334**) and may be further scaled or weighted by a normalization and power amplification factor

$$\gamma = \frac{1}{\sqrt{1+R^2}}$$

for a targeted signal-to-ratio (SNR) (step **336**) to obtain a normalized superimposed sequence $z_u[n]$. Thus, $z_u[n]$ may be written as:

$$z_u[n] = \gamma\left(x_u[n] + Re^{j\theta}x_u^*[n]\right) = \frac{1}{\sqrt{1+R^2}}\left(x_u[n] + Re^{j\theta}x_u^*[n]\right) \tag{3}$$

[0166] At step **306**, the UE **114** transmits the normalized superimposed sequence $z_u[n]$ to the TRP **102** on the same time and frequency resources.

[0167] FIG. **10**A is a flowchart showing the PRACH-detection procedure **400** corresponding to the PRACH-signaling procedure **300** shown in FIG. **9**A. FIG. **10**B is a flow diagram showing steps **406** to **410** of the PRACH-detection procedure **400** shown in FIG. **10**A.

[0168] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**). At step **406**, the TRP **102** obtains an adjustment scaling factor ρ and pre-formed matrices of the pre-assigned and broadcasted PRACH preambles. The adjustment scaling factor ρ is used by the TRP **102** to adjust the peaks level, such that the adjustment scaling factor ρ may be initialized as equal to the parameter R used by the UE **114**, and then adjusted or tuned during searching of peaks. Next, the TRP **102** detects a PRACH sequence, which is the received superimposed sequence $z_r[n]$ (corresponding to the normalized superimposed sequence $z_u[n]$ transmitted from the UE **114**).

[0169] At step **408**, the TRP **102** searches for and determines a ZC sequence $x_u[n]$ corresponding to the PRACH sequence $z_r[n]$.

[0170] More specifically, the TRP **102** configures the PRACH search window at step **424**. Then, at step **426**, the TRP **102** selects a candidate ZC sequence $x_u[n]$ from a pool or a set of ZC sequences. At step **428**, the TRP **102** calculates $x_u^*[n]$ and then calculates $z_u^*[n]$ (denoted a candidate superimposed sequence) which is the superimposed sequences $x_u^*[n]$ and $\rho e^{-j\theta}x_u[n]$, that is:

$$z_u^*[n] = x_u^*[n] + \rho e^{-j\theta}x_u[n] \tag{4}$$

[0171] The TRP **102** uses a single correlator to calculate the cross-correlation between $z_u^*[n]$ and the detected PRACH sequence $z_r[n]$ (step **432**). The correlator output $C_{z_{ur}^*}(n)$ may be expressed as:

$$\begin{aligned}
C_{z_{ur}^*}(n) &= \frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1} z_u[l]z_r^*[(l-n)] \\
&= \frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1} \gamma\left(x_u[l] + Re^{j\theta}x_u^*[l]\right)\left(x_u^*[(l-n)] + \rho e^{-j\theta}x_u[(l-n)]\right) \\
&= \frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1} \gamma\left(x_u[l]x_u^*[(l-n)] + \rho e^{-j\theta}x_u[l]x_u[(l-n)]\right. \\
&\quad \left. + Re^{j\theta}x_u^*[l]x_u^*[(l-n)] + R\rho x_u^*[l]x_u[(l-n)]\right) \\
&= \frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1} x_u[l]x_u^*[(l-n)] + \frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1} R\rho x_u^*[l]x_u[(l-n)] + \frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}} + \frac{\gamma Re^{j\theta}}{\sqrt{L_{RA}}}
\end{aligned} \tag{5}$$

[0172] The two terms

$$\frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}} + \frac{\gamma Re^{j\theta}}{\sqrt{L_{RA}}}$$

may cancel each other by tuning ρ, R, and θ such that

$$\frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}} = \frac{-\gamma Re^{j\theta}}{\sqrt{L_{RA}}},$$

which may happen when ρ=R and θ=π/2, which leads to:

$$C_{z_{ur}^*}(n) = \frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1} x_u[l]x_u^*[(l-n)] + \frac{\gamma R^2}{L_{RA}}\sum_{l=0}^{L_{RA}-1} x_u^*[l]x_u[(l-n)] \tag{6}$$

[0173] At step **434**, the TRP **102** uses a correlation peak detection method to detect one or more true peaks in the calculated cross-correlation $C_{z_{ur}^*}(n)$. In these embodiments, a true peak refers to a peak falling within the search window and greater than other cross-correlation values by at least a threshold value (for example, by at least a specific noise level).

[0174] More specifically, at step **434**, the TRP **102** checks if any peak exists in the calculated cross-correlation $C_{z_{ur}^*}(n)$. If no peak exists in the calculated cross-correlation, the procedure **400** goes back to step **426** to select another candidate ZC sequence $x_u[n]$.

[0175] If at step **434**, one or more peaks are detected, the TRP **102** then checks if any of the detected peaks is a true peak (step **436**). If the detected peaks are not true peaks, the procedure **400** goes back to step **426** to select another candidate ZC sequence $x_u[n]$. Herein, the one or more true peaks are also denoted as one or more measurements. In the embodiments wherein a plurality of true peaks are detected, these true peaks or measurements are linearly independent from each other.

[0176] If at step **426**, one or more true peaks are detected, the selected candidate ZC sequence is the ZC sequence used by the UE **114**.

[0177] The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequence $x_u[n]$ and the detected PRACH sequence $z_r[n]$ (step **410**). More specifically, in some embodiments, the TRP **102** uses the detected one or more true peaks for estimating the TD and/or CFO.

[0178] For example, in some embodiments wherein the TRP **102** is a terrestrial TRP **102**A, the CFO may be a differential CFO (which is a CFO less than half of the PRACH frequency spacing). Thus, the terrestrial TRP **102**A in these embodiments may detect one true peak and use the detected true peak for estimating the TD. The differential CFO may be estimated based on the reduction level of the true peak's amplitude (that is, the amount of reduction determines the differential CFO).

[0179] In some other embodiments wherein the TRP **102** is a terrestrial TRP **102**A, the terrestrial TRP **102**A may detect two true peaks and use the detected true peaks for estimating the TD and CFO with improved accuracy.

[0180] In yet some other embodiments wherein the TRP **102** is a non-terrestrial TRP **102**B, the CFO may be either an integer CFO (which is an integer multiple of the PRACH frequency spacing) or a combination of integer and differential CFO. In these embodiments, the non-terrestrial TRP **102**B may detect two or more true peaks using one correlator (for example, see FIG. **18**B; to be described in more detail later) or a plurality of correlators in parallel (for example, see FIG. **16**B; to be described in more detail later), and use the detected two or more true peaks for estimating the integer CFO and TD. As described above, the differential CFO may be estimated with an improved accuracy based on the reduction level of the true peaks' amplitudes.

[0181] After estimating the TD and/or CFO, the TRP **102** sends the estimated TD and/or CFO to the UE **114** and establishes uplink synchronization therewith (step **412**). The procedure **400** then ends (step **414**).

[0182] Those skilled in the art will appreciate that the cross-correlation $C_{z_{ur}^*}(n)$ in these embodiments (see Equation (6)) may not have the terms

$$\frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}}+\frac{\gamma R e^{j\theta}}{\sqrt{L_{RA}}}$$

when $\rho=R$ and $\theta=\pi/2$. As a comparison, the prior-art Category-2 methods do not have a rotation angle θ and a scaling factor R (and correspondingly, no scaling factor ρ). Thus, in the sequence used in the Category-2 methods, the cross-correlation has two terms

$$\frac{1}{\sqrt{L_{RA}}}+\frac{1}{\sqrt{L_{RA}}},$$

which lead to a constant term

$$\frac{2}{\sqrt{L_{RA}}}$$

that exists in any configuration. FIG. **11** shows the resultant magnitude of the two terms and how the variation of the scaling factor ρ of $z_u[n]$ at the TRP **102** may change the resultant magnitude for two different lengths of superimposed sequences. FIG. **11** also compares the performance of using $z_u[n]$ with the performance of using the sequence of the prior-art Category-2 method and illustrates the resultant magnitude of these arising terms at the correlator of the TRP **102**. However, it is important to note that the prior-art Category-2 method needs to use two correlators with a more complicated structure of different ZC roots to perform the correlation operation.

[0183] In the embodiments shown in FIGS. **10**A and **10**B, the TRP uses a single correlator to calculate the cross-correlation between $z_u^*[n]$ and the detected PRACH sequence $z_r[n]$. In some alternative embodiments as shown in FIGS. **12**A and **12**B, the TRP uses two correlators.

[0184] More specifically, steps **432** to **436** in these embodiments are performed for each of the $x_u[n]$ and $x_u^*[n]$ (the operations therefor being represented by the box **430** in FIGS. **12**A and **12**B) to use two correlators to calculate the cross-correlations at step **432**.

[0185] The first cross-correlation is between the candidate ZC sequence $x_u[n]$ and the detected PRACH sequence $z_r[n]$, which may be expressed as:

$$\begin{aligned}C_{x_u^*}(n) &= \frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1} z_r[l]x_u^*[(l-n)] \\ &\frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1}\left(x_u[l]+Re^{j\theta}x_u^*[l]\right)x_u^*[(l-n)] \\ &\frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1}x_u[l]x_u^*[(l-n)]+\frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1}Re^{j\theta}x_u^*[l]x_u^*[(l-n)] \\ &\frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1}x_u[l]x_u^*[(l-n)]+\frac{\gamma Re^{j\theta}}{\sqrt{L_{RA}}}\end{aligned} \tag{7}$$

[0186] As the scaling factor R increases, the magnitude of the second term

$$\frac{\gamma Re^{j\theta}}{\sqrt{L_{RA}}}$$

of $C_{x_u^*}(n)$ increases, where it has an upper limit equal to

$$\frac{1}{\sqrt{2L_{RA}}}.$$

FIG. **13** shows the magnitude of the second term

$$\frac{\gamma Re^{j\theta}}{\sqrt{L_{RA}}}$$

with respect to different values of R for two different lengths of $z_r[n]$ (which corresponds to $z_u[n]$ on the UE side).

[0187] The second cross-correlation is between $\rho x_u^*[n]$ and the detected PRACH sequence $z_r[n]$, which may be expressed as:

$$C_{x_u}(n)=\frac{1}{L_{RA}}\sum_{l=0}^{L_{RA}-1}z_r[l]\rho x_u[(l-n)] \tag{8}$$

-continued

$$\frac{\gamma}{L_{RA}}\sum_{l=0}^{L_{RA}-1}\left(x_u[l]+Re^{j\theta}x_u^*[l]\right)\rho x_u[(l-n)]$$

$$\frac{\gamma R\rho e^{j\theta}}{L_{RA}}\sum_{l=0}^{L_{RA}-1}x_u^*[l]x_u[(l-n)]+\frac{\gamma\rho}{L_{RA}}\sum_{l=0}^{L_{RA}-1}x_u[l]x_u[(l-n)]$$

$$\frac{\gamma R\rho e^{j\theta}}{L_{RA}}\sum_{l=0}^{L_{RA}-1}x_u^*[l]x_u[(l-n)]+\frac{\gamma\rho}{\sqrt{L_{RA}}}$$

[0188] As the adjustment scaling factor ρ decreases, the magnitude of the second term

$$\frac{\gamma\rho}{\sqrt{L_{RA}}}$$

of $C_{x_u}(n)$ decreases, where it has a lower limit equal to

$$\frac{1}{\sqrt{2L_{RA}}}.$$

FIG. **14** shows the second term

$$\frac{\gamma\rho}{\sqrt{L_{RA}}}$$

with respect to various values of the adjustment scaling factor ρ for two different lengths of $z_r[n]$ (which corresponds to $z_u[n]$ on the UE side).

[0189] Referring back to FIGS. **12**A and **12**B, the TRP **102** checks if any peaks exist in the calculated cross-correlations (step **434**), and if the peaks are true peaks (step **436**). If either of the calculated cross-correlations does not have any true peak, then the procedure **400** goes back to step **426** to select another candidate ZC sequence $x_u[n]$.

[0190] If both the cross-correlation of $x_u[n]$ and the detected PRACH sequence $z_r[n]$ and the cross-correlation of $x_u^*[n]$ and the detected PRACH sequence $z_r[n]$ have one or more true peaks, the selected candidate ZC sequence is the ZC sequence used by the UE **114**. The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequence $x_u[n]$ and the detected PRACH sequence $z_r[n]$ as described above (step **410**), and establishes uplink synchronization with the UE **114** (step **412**). The procedure **400** then ends (step **414**).

[0191] FIG. **15**A is a flowchart showing the PRACH-signaling procedure **300** with the detail of the sequence-generation step **304** according to some embodiments of this disclosure. FIG. **15**B is a flow diagram showing steps **326** to **336** of the flowchart shown in FIG. **15**A.

[0192] The PRACH-signaling procedure **300** in these embodiments is similar to that shown in FIGS. **9**A and **9**B except that, in these embodiments, the two sequences $x_u[n]$ and $Re^{j\theta}$ $x_u^*[n]$ are not superimposed to obtain the sequence $z_u[n]$. Rather, the UE **114** at step **306** transmits to the TRP **102** a PRACH signal having the two sequences $x_u[n]$ and $Re^{j\theta}$ $x_u^*[n]$ on different time and frequency resources.

[0193] FIG. **16**A is a flowchart showing the PRACH-detection procedure **400** corresponding to the PRACH-signaling procedure **300** shown in FIG. **15**A. FIG. **16**B is a flow diagram showing steps **406** to **410** of the flowchart shown in FIG. **16**A.

[0194] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**). At step **406**, the TRP **102** obtains the scaling factor parameter p and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles. Next, the TRP **102** detects two PRACH sequences $x_r[n]$ and $y_r[n]=Re^{j\theta}$ $x_r^*[n]$ (corresponding to the sequences $x_u[n]$ and $Re^{j\theta}$ $x_u^*[n]$ transmitted from the UE **114**).

[0195] At step **408**, the TRP **102** searches for and determines a ZC sequence $x_u[n]$ corresponding to the PRACH sequences $x_r[n]$ and $y_r[n]$.

[0196] More specifically, the TRP **102** configures the PRACH search window at step **424**. Then, the TRP **102** selects a candidate ZC sequence $x_u[n]$ from a pool or a set of ZC sequences (step **426**) and calculates its complex conjugate $x_u^*[n]$ (step **428**).

[0197] The TRP **102** calculates the cross-correlation between $x_u^*[n]$ and the detected PRACH sequence $x_r[n]$ (step **432**) and the cross-correlation between $x_u[n]$ and the detected PRACH sequence $y_r[n]$ (step **432**), and checks if each of the calculated cross-correlations has any true peak (steps **434** and **436**). If either of the calculated cross-correlations does not have any true peak, then the procedure **400** goes back to step **426** to select another candidate ZC sequence $x_u[n]$.

[0198] If both calculated cross-correlations have one or more true peaks, the selected candidate ZC sequence is the ZC sequence used by the UE **114**. The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequence $x_u[n]$ and the detected PRACH sequences $x_r[n]$ and $y_r[n]$ as described above (step **410**), and establishes uplink synchronization with the UE **114** (step **412**). The procedure **400** then ends (step **414**).

[0199] FIG. **17**A is a flowchart showing the PRACH-signaling procedure **300** with the detail of the sequence-generation step **304** according to some embodiments of this disclosure. FIG. **17**B is a flow diagram showing steps **326** to **336** of the flowchart shown in FIG. **17**A.

[0200] In these embodiments, a plurality of ZC sequences have been generated according to formula (1) by applying a predetermined cyclic shift value N_{CS} and set type. The sequences are then stored as a pool of PRACH preambles in, for example, the memory of the UE **114**.

[0201] At step **304** of the PRACH-signaling procedure **300**, the UE **114** selects two ZC sequences (denoted $x_{u_1}[n]$ and $x_{u_2}[n]$) from the pool of PRACH preambles. The UE **114** may, for example, randomly select the ZC sequences from the pool. More specifically, at step **322**, the UE **114** obtains preamble parameters from the SIB, and then selects the parameters of a preamble from the available preambles broadcasted by the TRP **102** and determines the scaling factor R (step **324**). The UE **114** may, for example, randomly select the parameters from the available preambles. The randomly selected parameters include two randomly selected ZC-sequence roots u_1 and u_2. Based on the selected preamble parameters, the UE **114** selects two ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ from the pool of PRACH preambles (step **326**).

[0202] Then, the ZC sequence $x_{u_2}[n]$ is weighted by the scaling factor R and rotated by a rotation angle θ (steps **330** and **332**; the order of which may be reversed) to obtain the scaled and rotated version $Re^{j\theta}\, x_{u_2}[n]$ of the ZC sequence $x_{u_2}[n]$. The two sequences $x_{u_1}[n]$ and $Re^{j\theta}\, x_{u_2}[n]$ are then superimposed (step **334**) and may be further scaled or weighted by a normalization and power amplification factor

$$\gamma = \frac{1}{\sqrt{1+R^2}}$$

for a targeted SNR (step **336**) to obtain a normalized superimposed sequence $z_u[n]$. Thus, $z_u[n]$ may be written as:

$$z_u[n] = \gamma\left(x_{u_1}[n] + Re^{j\theta} x_{u_2}[n]\right) \tag{9}$$

[0203] At step **306**, the UE **114** transmits the normalized superimposed sequence $z_u[n]$ to the TRP **102** on the same time and frequency resources.

[0204] FIG. **18**A is a flowchart showing the PRACH-detection procedure **400** corresponding to the PRACH-signaling procedure **300** shown in FIG. **17**A. FIG. **18**B is a flow diagram showing steps **406** to **410** of the flowchart shown in FIG. **18**A.

[0205] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**). At step **406**, the TRP **102** obtains the scaling factor parameter p and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles. Next, the TRP **102** detects a PRACH sequence which is the received superimposed sequence $z_r[n]$ (corresponding to the normalized superimposed sequence $z_u[n]$ transmitted from the UE **114**).

[0206] At step **408**, the TRP **102** searches for and determines a pair of ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ corresponding to the PRACH sequence $z_r[n]$.

[0207] More specifically, the TRP **102** configures the PRACH search window at step **424**. Then, the TRP **102** selects two candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ from a pool or a set of ZC sequences at step **426**.

[0208] At step **428**, the TRP **102** calculates the complex conjugates xx, [n] and xx, [n] and calculates $z_u{}^*[n]$ as:

$$z_u^*[n] = (z_u[n])^* = x_{u_1}^*[n] + \rho e^{-j\theta} x_{u_2}^*[n] \tag{10}$$

[0209] The TRP **102** uses a single correlator to calculate the cross-correlation between $z_u{}^*[n]$ and the detected PRACH sequence $z_r[n]$ (step **432**). The correlator output $C_{z_{ur}{}^*}(n)$ may be expressed as:

$$C_{z_{ur}^*}(n) = \frac{\gamma}{L_{RA}} \sum_{l=0}^{L_{RA}-1} x_{u_1}[l] x_{u_1}^*[(l-n)] + \frac{\gamma}{L_{RA}} \sum_{l=0}^{L_{RA}-1} R\rho x_{u_2}[l] x_{u_2}^*[(l-n)] + \frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}} + \frac{\gamma R e^{j\theta}}{\sqrt{L_{RA}}} \tag{11}$$

[0210] Similarly, the two terms

$$\frac{\gamma\rho e^{-j\theta}}{\sqrt{L_{RA}}} + \frac{\gamma R e^{j\theta}}{\sqrt{L_{RA}}}$$

may cancel each other when $\rho=R$ and $\theta=\pi/2$, and then:

$$C_{z_{ur}^*}(n) = \frac{\gamma}{L_{RA}} \sum_{l=0}^{L_{RA}-1} x_{u_1}[l] x_{u_1}^*[(l-n)] + \frac{\gamma R^2}{L_{RA}} \sum_{l=0}^{L_{RA}-1} x_{u_2}[l] x_{u_2}^*[(l-n)] \tag{12}$$

[0211] At step **434**, the TRP **102** checks if any peak exists in the calculated cross-correlation (step **434**). If no peak exists in the calculated cross-correlation, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0212] If at step **434**, one or more peaks are detected, the TRP **102** then checks if any of the detected peaks is a true peak (step **436**). If the detected peaks are not true peaks, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0213] If at step **426**, one or more true peaks are detected, the selected candidate ZC sequences are the ZC sequences used by the UE **114**. The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ and the detected PRACH sequence $z_r[n]$ as described above (step **410**), and establishes uplink synchronization with the UE **114** (step **412**). The procedure **400** then ends (step **414**).

[0214] FIG. **19**A is a flowchart showing the PRACH-detection procedure **400** corresponding to the PRACH-signaling procedure **300** shown in FIG. **17**A. FIG. **19**B is a flow diagram showing steps **406** to **410** of the flowchart shown in FIG. **19**A.

[0215] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**). At step **406**, the TRP **102** obtains the scaling factor parameter p and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles. Next, the TRP **102** detects a PRACH sequence which is the received superimposed sequence $z_r[n]$ (corresponding to the normalized superimposed sequence $z_u[n]$ transmitted from the UE **114**).

[0216] At step **408**, the TRP **102** searches for and determines a pair of ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ corresponding to the PRACH sequence $z_r[n]$.

[0217] More specifically, the TRP **102** configures the PRACH search window at step **424**. Then, the TRP **102** selects two candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ from a pool or a set of ZC sequences (step **426**) and calculates their complex conjugates $x_{u_1}{}^*[n]$ and $x_{u_2}{}^*[n]$ (step **428**).

[0218] For each of $x_{u_1}{}^*[n]$ and $x_{u_2}{}^*[n]$ (the operations thereof being represented by box **430**), the TRP **102** calculates two cross-correlations.

[0219] The first cross-correlation is between $x_{u_1}[n]$ and the detected PRACH sequence $z_r[n]$, which may be expressed as:

$$C_{x_u^*}(n) = \frac{1}{L_{RA}} \sum_{l=0}^{L_{RA}-1} x_{u_1}[l] x_{u_1}^*[(l-n)] + \frac{\gamma R e^{j\theta}}{\sqrt{L_{RA}}} \tag{13}$$

[0220] The second cross-correlation is between $x_{u_2}[n]$ and the detected PRACH sequence $z_r[n]$, which may be expressed as:

$$C_{x_u}(n) = \frac{\gamma R \rho e^{j\theta}}{L_{RA}} \sum_{l=0}^{L_{RA}-1} x_{u_2}[l] x^*_{u_2}[(l-n)] + \frac{\gamma\rho}{\sqrt{L_{RA}}} \tag{14}$$

[0221] The TRP **102** then checks if any peak exists in the calculated cross-correlation (step **434**). If no peak exists in the calculated cross-correlation, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0222] If at step **434**, one or more peaks are detected, the TRP **102** then checks if any of the detected peaks is a true peak (step **436**). If the detected peaks are not true peaks, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0223] If both cross-correlations have true peaks, the selected candidate ZC sequences are the ZC sequences used by the UE **114**. The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ and the detected PRACH sequence $z_r[n]$ as described above (step **410**), and establishes uplink synchronization with the UE **114** (step **412**). The procedure **400** then ends (step **414**).

[0224] FIG. **20**A is a flowchart showing the PRACH-signaling procedure **300** with the detail of the sequence-generation step **304** according to some embodiments of this disclosure. FIG. **20**B is a flow diagram showing steps **326** to **336** of the flowchart shown in FIG. **20**A.

[0225] In these embodiments, a plurality of ZC sequences have been generated according to formula (1) by applying a predetermined cyclic shift value N_{CS} and set type. The sequences are then stored as a pool of PRACH preambles in, for example, the memory of the UE **114**.

[0226] At step **304** of the PRACH-signaling procedure **300**, the UE **114** selects two ZC sequences (denoted $x_{u_1}[n]$ and $x_{u_2}[n]$) from the pool of PRACH preambles. The UE **114** may, for example, randomly select the ZC sequences from the pool. More specifically, at step **322**, the UE **114** obtains preamble parameters from the SIB, and then selects the parameters of a preamble from the available preambles broadcasted by the TRP **102** and determines the scaling factor R (step **324**). The UE **114** may, for example, randomly select the parameters from the available preambles. The randomly selected parameters include two randomly selected ZC-sequence roots u_1 and u_2. Based on the selected preamble parameters, the UE **114** selects two ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ from the pool of PRACH preambles (step **326**).

[0227] Then, the ZC sequence $x_{u_2}[n]$ is weighted by the scaling factor R and rotated by a rotation angle θ (steps **330** and **332**; the order of which may be reversed) to obtain the scaled and rotated version $Re^{j\theta}$ $x_{u_2}[n]$ of the ZC sequence $x_{u_2}[n]$. At step **306**, the UE **114** transmits to the TRP **102** a PRACH signal having the two sequences $x_{u_1}[n]$ and $Re^{j\theta}$ $x_{u_2}[n]$ on different time and frequency resources.

[0228] FIG. **21**A is a flowchart showing the PRACH-detection procedure **400** corresponding to the PRACH-signaling procedure **300** shown in FIG. **20**A. FIG. **21**B is a flow diagram showing steps **406** to **410** of the flowchart shown in FIG. **21**A.

[0229] When the procedure **400** starts (step **402**), the TRP **102** receives the PRACH signal (step **404**). At step **406**, the TRP **102** obtains the scaling factor parameter p and the pre-formed matrices of the pre-assigned and broadcasted PRACH preambles. Next, the TRP **102** detects two PRACH sequences $x_{r1}[n]$ and $y_{r2}[n]=Re^{j\theta}$ $x_{r2}[n]$ (corresponding to the sequences $x_{u_1}[n]$ and $Re^{j\theta}$ $x_{u_2}[n]$ transmitted from the UE **114**).

[0230] At step **408**, the TRP **102** searches for and determines a pair of ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ corresponding to the PRACH sequences $x_{r1}[n]$ and $y_{r2}[n]$.

[0231] More specifically, the TRP **102** configures the PRACH search window at step **424**. Then, the TRP **102** selects two candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ from a pool or a set of ZC sequences (step **426**) and calculates their complex conjugates $x_{u_1}^*[n]$ and $y_{u_2}^*[n]$ (step **428**).

[0232] For each of $x_{u_1}^*[n]$ and $x_{u_2}^*[n]$ (the operations thereof being represented by box **430**), the TRP **102** calculates the cross-correlation between $x_{u_1}^*[n]$ (or $x_{u_2}^*[n]$) and the detected PRACH sequence $x_{r1}[n]$ (or $y_{r2}[n]$) (step **432**), and checks if any peak exists in the calculated cross-correlation (step **434**). If no peak exists in the calculated cross-correlation, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0233] If at step **434**, one or more true peaks are detected, the TRP **102** then checks if any of the detected peaks is a true peak (step **436**). If the detected peaks are not true peaks, the procedure **400** goes back to step **426** to select another pair of candidate ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$.

[0234] If both cross-correlations have true peaks, the selected candidate ZC sequences are the ZC sequences used by the UE **114**. The TRP **102** then estimates the TD and/or CFO based on the selected ZC sequences $x_{u_1}[n]$ and $x_{u_2}[n]$ and the detected PRACH sequence $z_r[n]$ as described above (step **410**), and establishes uplink synchronization with the UE **114** (step **412**). The procedure **400** then ends (step **414**).

[0235] In some embodiments, the modified sequence may be generated from a Zadoff-Chu (ZC) sequence rotated by an angle θ (that is, not scaled).

[0236] In some embodiments, the PRACH preamble may only comprise the modified sequence generated from a Zadoff-Chu (ZC) sequence rotated by an angle θ. Accordingly, the above-described PRACH-detection procedure **400** only uses one candidate ZC sequence in the search step **408**.

[0237] In some embodiments wherein the communications environment suffers a large differential delay and a long cyclic prefix is needed, the PRACH-signaling procedure **300** may concatenate multiple copies of the $z_u[n]$ sequence in a sequential (or aggregated) manner for accommodating the large differential delay.

[0238] The sequentially concatenated sequence S[n] may be generated as following:

$$S[n] = \sum_{d=0}^{D} z_u\left[n - d\left(N_u + N_{CP}^{RA} + N_G\right)\right] \tag{15}$$

where $z_u[n]$ is the superimposed sequence of $x_u[n]$ and $Re^{j\theta}$ $x_u^*[n]$, Nu is the duration of the PRACH sequence, N_{CP}^{RA} is the cyclic-prefix duration of the PRACH preamble, NG is the guard-interval duration of the PRACH preamble (which may be only for TTD (FR-2)), and D is the number of concatenated copies of the $z_u[n]$ sequence. D may be selected to ensure consistency that generated sequences work in both TN and NTN (or both terrestrial TRPs **102**A and non-terrestrial TRPs **102**B) as:

$$D = \left\lceil \frac{Delay_{NTN}}{\text{Maximum Delay}_{TN}} \right\rceil - 1 \tag{16}$$

where Delay_{NTN} is the TD of the non-terrestrial TRPs **102**B or the TD of the NTN system, and $\text{Maximum Delay}_{TN}$ is the maximum TD of the terrestrial TRPs **102**A or the maximum TD of the TN system.

[0239] FIG. **22**A shows the PRACH preamble **600** with the sequence S[n] formed by two copies of $z_u[n]$ concatenated in the sequential manner, wherein CP represents the cyclic prefix **602**, G represents the guard interval **606**, and S[n] is the combination of the two copies of $z_u[n]$ **604** which sandwich a guard interval **606** and a cyclic prefix **602**.

[0240] FIG. **22**B shows the PRACH preamble **600** with the sequence S[n] formed by two copies of $z_u[n]$ concatenated in the aggregated manner. The PRACH preamble **600** in these embodiments comprises two aggregated cyclic prefix **602**, two aggregated two copies of $z_u[n]$ **604**, and two aggregated guard intervals **606**.

[0241] As those skilled in the art will appreciate, the above-described superimposed rotated PRACH sequence $z_u[n]$ may be easily adopted in both TN systems and NTN systems (or terrestrial TRPs **102**A and non-terrestrial TRPs **102**B), and provides a backward compatibility with NR. In some embodiments, the above-described superimposed rotated PRACH sequence is tunable by adjusting the design parameters such as the rotation angle θ and the scaling factor R. In these embodiments, each UE **114** in the NTN system (or to communicate with a non-terrestrial TRP **102**B) generates $z_u[n]$ as a normalized PRACH sequence which in some embodiments is the normalized summation of a selected ZC sequence $x_u[n]$ and the weighted and rotated complex-conjugate thereof, that is,

$$z_u[n] = \frac{x_u[n] + Re^{j\theta}x_u^*[n]}{\sqrt{1^2 + R^2}} \tag{17}$$

or is the normalized summation of a first selected ZC sequence $x_{u_1}[n]$ and the weighted and rotated version of a second selected ZC sequence $x_{u_2}[n]$, that is,

$$z_u[n] = \frac{x_{u_1}[n] + e^{j\theta}Rx_{u_2}[n]}{\sqrt{1^2 + R^2}} \tag{18}$$

[0242] As described above, R is a design parameter used in both TN systems and NTN systems (or terrestrial TRPs **102**A and non-terrestrial TRPs **102**B), where 0<R<1. The optimal value of R in an NTN system (or a non-terrestrial TRP **102**B) depends on the communications environment and configurations thereof. If the value of R=0, then, $z_u[n]=x_u[n]$ or $z_u[n]=x_{u_1}[n]$, which is the ZC sequence in NR for TN systems, thereby providing the backward compatibility with NR while at the same time allowing its use in TN systems of 6G as TN systems only need a simple PRACH ZC sequence for estimating TD and fractional CFO.

[0243] As those skilled in the art will appreciate, the above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and PRACH-detection procedures **300** and **400** require a low implementation complexity at the TRP **102**, and require reduced computational resources for PRACH detection. In the embodiments as shown in FIGS. **12**A-**12**B, **16**A-**16**B, **19**A-**19**B and **21**A-**21**B, each correlator of the TRP **102** only requires one ZC sequence or its complex conjugate as an input. In the embodiments as shown in FIGS. **10**A-**10**B and **18**A-**18**B, the TRP **102** only requires a single correlator.

[0244] On the UE side, the above-described PRACH preamble having modified ZC sequences and related PRACH-signaling **300** provide a simplicity in generation of PRACH sequences. The above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and procedure **300** also give rise to a reduced PAPR at the UE side, which may preserve the energy efficiency at UEs **114** and may reduce the cost of the UEs **114** as the UEs **114** may use low-cost amplifiers with reduced linear ranges.

[0245] The level of PAPR may be tuned by adjusting the rotation angle θ and/or the scaling factor R. For example, the PAPR of the PRACH signal increases as the value of the scaling factor R increases. Table 1 below shows the PAPR for various values of R, where the rotation angle θ is fixed and set to θ=π/2, L_{RA}=571, and u=7.

TABLE 1

the PAPR of $z_u[n]$

R	PAPR of $z_u[n]$ in dB
0	0
0.1	1.8195
0.2	3.2801
0.3	4.4222
0.4	5.2913
0.5	5.9315
0.6	6.064
0.7	6.6875
0.8	6.8734
0.9	6.9707
1	6.9982

[0246] FIG. **23** shows how R affects the constellations of the entries of the superimposed sequence $z_u[n]$ (having the ZC sequence $x_u[n]$ and its rotated complex-conjugate $e^{j\theta}$ $x_u^*[n]$) with comparison to the conventional ZC sequence $x_u[n]$ and its rotated complex-conjugate $e^{j\theta}$ $x_u^*[n]$.

[0247] FIG. **24** shows the comparison of the constellations of the superimposed sequence $z_u[n]$, conventional ZC sequence $x_u[n]$, its rotated complex-conjugate $e^{j\theta}$ $x_u^*[n]$, and the prior-art method of Category 2 using two ZC sequences.

[0248] Table 2 and Table 3 below illustrate how the rotated angle θ may be tuned for a given ZC-sequence root that produces the minimum PAPR values of the corresponding superimposed sequence $z_u[n]$ at a given value of the scaling factor R. The tables also show a comparison of the PAPR of the two of the generated sequences with the PAPR of another sequence that can be generated via one of the prior-art Category-2 methods. Moreover, as can be seen from Table 2, the methods disclosed herein provide a flexibility in assigning different ZC-sequence roots for the used sequences while achieving almost the same PAPR (which is lower than that of prior-art methods), thereby guaranteeing fairness to all served UEs **114**.

TABLE 2

PAPR for various values of u with optimal θ, when R = 1 and L_{RA} = 571

u	Optimal θ	PAPR (in dB) of $z_u[n]$ in dB	PAPR of the prior-art method of Category 2 using two ZC sequences
17	180	6.5216	6.9061
61	15	6.5231	
7	0	6.5215	6.9291
11	180	6.5214	
5	0	6.5215	6.9292
9	0	6.5216	
6	90	6.5215	6.9383
18	270	6.5218	
55	195	6.5238	7.2073
110	285	6.5218	
37	0	6.5235	6.9291
41	180	6.5238	
67	15	6.5227	6.9292
71	15	6.5222	
20	270	6.5221	6.9084
60	105	6.5234	
271	225	6.5218	6.5214
277	225	6.5216	
250	315	6.5234	6.5432
500	345	6.5222	
300	135	6.5218	7.2437
271	225	6.5218	
200	120	6.5216	6.6388
199	210	6.5216	

TABLE 3

PAPR for various values of u with optimal θ, when R = 0.5 and L_{RA} = 571

u	Optimal θ	PAPR (in dB) of $z_u[n]$ in dB	PAPR of the prior-art method of Category 2 using two ZC sequences
17	180	5.5486	6.9061
61	15	5.5499	
7	0	5.5486	6.9291
11	180	5.5484	
5	0	5.5485	6.9292
9	0	5.5486	
6	90	5.5486	6.9383
18	270	5.5488	
55	195	5.5504	7.2073
110	285	5.5488	
37	0	5.5502	6.9291
41	180	5.5503	
67	15	5.5495	6.9292
71	15	5.5491	
20	270	5.549	6.9084
60	105	5.5501	
271	225	5.5488	6.5214
277	225	5.5486	
250	315	5.5501	6.5432
500	345	5.5491	
300	135	5.5488	7.2437
271	225	5.5488	
200	120	5.5487	6.6388
199	210	5.5486	

[0249] The above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and PRACH-detection procedures **300** and **400** save frequency and time resources with significant improvement of resources utilizations, where the normalized superimposed PRACH sequence $z_u[n]$ (see Equation (17)) may be sent on the same time and frequency resources. As a result, the above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and PRACH-detection procedures **300** and **400** enable TRPs **102** to serve more UEs **114** simultaneously as the number of PRACH sequences per UE is minimized.

[0250] As the above-described PRACH preamble having modified ZC sequences is tunable, it may accommodate a wide range of implementation scenarios by modifying the rotation angle θ and the scaling factor R.

[0251] The superimposed sequence disclosed herein has a low level of the cross-correlation with its cyclically shifted versions in both cases of using a single correlator or two correlators. The technical features and benefits of above-described embodiments may include:

- **[0252]** Providing at least two linearly independent measurements as the inputs of the estimator (or more than two linearly independent measurements when concatenation is used), which improves the estimation accuracy of TD and/or CFO;
- **[0253]** Using a single root to generate the ZC sequence and its complex conjugate, which simplifies the receiver circuitry and PRACH detection at the TRP **102**;
- **[0254]** Enabling detection of large CFOs in various environments (such as up to half of the used PRACH bandwidth), which facilitates the establishment of uplink synchronization between the UE **114** and the TRP **102**;
- **[0255]** The design parameter R, wherein, when R=0, the above-described PRACH preamble having modified ZC sequences and related PRACH-signaling and PRACH-detection procedures **300** and **400** may operate for TN systems or the terrestrial TRPs **102**A, which provides backward compatible with NR;
- **[0256]** The tunable design parameters R and **0**, which facilitate adapting of various communications environments;
- **[0257]** Having a rotational angle that eliminates the ambiguity and adds an independency to the components of PRACH preamble, which may be used instead of using two non-complex conjugate PRACH preambles with different roots for the same UE **114**, thereby giving the TRP **102** the capability to efficiently use the allocated PRACH preambles to simultaneously serve a large number of UEs **114**, as the number of PRACH sequences per UE is minimized.
- **[0258]** Providing an ability to control the PAPR at UEs **114** using R and θ to select the minimum optimal PAPR. At the TRP **102**, the receiver thereof may only use one root to generate the ZC sequence with its complex conjugate and subsequently their cyclically shifted versions, which minimizes the number of correlation operations and consequently reduces the computational complexity, thereby improving the energy efficiency in both UEs **114** (through lowering the PAPRs) and at TRPs **102** (through lowered receiver complexity with a fast searching algorithm);
- **[0259]** Option of transmitting the PRACH preamble using the PRACH sequence and its complex conjugate on same time and frequency resources with the capa-

bility to estimate TD and/or CFO, thereby preserving time/frequency resources and improving the PRACH occasions utilizations;

[0260] Having a concatenated sequential version either on the same or different PRACH occasions, thereby expanding the ability to accommodate multiple communications configurations and also ensuring orthogonality.

[0261] In above embodiments, the communication system **100** is a system combining terrestrial communication networks with non-terrestrial communication networks, such as combining cellular networks with satellite communication networks. In some embodiments, the terrestrial communication networks may comprise, or alternatively be, other radio access networks such as WI-FI® networks (WI-FI is a registered trademark of Wi-Fi Alliance, Austin, TX, USA).

C. Acronym Key

[0262] 4G: Fourth generation
[0263] 5G: Fifth generation
[0264] 6G: Sixth Generation
[0265] ASIC: Application Specific Integrated Circuit
[0266] BSC: Base Station Controller
[0267] CDMA: Code Division Multiple Access
[0268] CFO: Carrier Frequency Offset
[0269] CP: Cyclic Prefix
[0270] EDGE: Enhanced Data Rates for GSM Evolution
[0271] FDMA: Frequency Division Multiple Access
[0272] FFT: Fast Fourier Transform
[0273] FPGA: Field Programmable Gate Array
[0274] FR2: Frequency Range 2
[0275] GERAN: GSM EDGE Radio Access Network
[0276] GLONASS: Global'naya Navigatsionnaya Sputnikovaya Sistema
[0277] gNodeB or gNB: Next Generation Node of Base Station
[0278] GNSS: Global Navigation Satellite System
[0279] GPS: Global Positioning System
[0280] GSM: Global System for Mobile Communications
[0281] HAPS: High Altitude Platform Station
[0282] HSDPA: High Speed Downlink Packet Access
[0283] HSPA: High Speed Packet Access
[0284] HSUPA: High-Speed Uplink Packet Access
[0285] IRNSS: Indian Regional Navigation Satellite System
[0286] IoT: Internet-of-Things
[0287] IR: Infrared
[0288] LTE: Long-Term Evolution
[0289] MIMO: Multiple-Input Multiple-Output
[0290] mmWave: Millimeter-Wave
[0291] MTC: Machine Type Communication
[0292] NIC: Network Interface Controller
[0293] NR: New Radio
[0294] NTN: Non-Terrestrial Networks
[0295] OFDM: Orthogonal Frequency Division Multiplexing
[0296] OFDMA: Orthogonal Frequency Division Multiple Access
[0297] PAPR: Peak to Average Power Ratio
[0298] PDA: Personal Digital Assistant
[0299] POTS: Plain Old Telephone Service
[0300] PRACH: Physical Random-Access Channel
[0301] PSTN: Public Switched Telephone Network
[0302] QZSS: Quasi-Zenith Satellite System
[0303] RACH: Random-Access Channel
[0304] RAM: Random Access Memory
[0305] RAN: Radio Access Network
[0306] RF: Radio Frequency
[0307] RNC: Radio Network Controller
[0308] RNSS: Regional Navigation Satellite System
[0309] ROM: Read Only Memory
[0310] RRC: Radio Resource Control
[0311] RTD: Round-Trip Delay
[0312] SC-FDMA: Single-Carrier Frequency Division Multiple Access
[0313] SD: Secure Digital
[0314] SIB: System Information Block
[0315] SIM: Subscriber Identity Module
[0316] SNR: Signal-To-Noise Ratio
[0317] TD: Time Delay
[0318] TDMA: Time Division Multiple Access
[0319] TN: Terrestrial Networks
[0320] TRP: Transmit-Receive Point
[0321] UE: User Equipment
[0322] UMTS: Universal Mobile Telecommunication System
[0323] WCDMA: Wideband Code Division Multiple Access
[0324] WTRU: Wireless Transmit/Receive Unit
[0325] ZC Sequences: Zadoff-Chu sequences
[0326] ZCZ: Zero-Correlation Zone

D. Definitions of Some Technical Terms

[0327] 6th Generation: is the next generation of mobile networks that may combine both Terrestrial Networks and Non-Terrestrial Networks.

[0328] A sequence: is a vector that have multiple entries, the number of entries is known as the length of the sequences. The entries values are generally complex numbers.

[0329] Terrestrial Network: is the network that may be built on the ground either using wired connections or wireless connections. Each network node stands on the ground. Base stations are grounded base stations.

[0330] Non-Terrestrial Network: is the network that may be built using base stations that are flying on the air or in the space. It requires wireless connections and, in some cases, the flying base-station may be fed through a wired connection such as using a tethered drone. Base stations may be low earth-orbit (LEO) satellites, middle earth-orbit (MEO) satellites, high-altitude platforms stations (HAPS), unmanned aerial vehicles (UAV) platforms, drones, and/or the like.

[0331] Zadoff-Chu sequences: special type of sequences that have a unity magnitude of their entries, zero cross-correlation with their cyclic shifted versions, and constant cross-correlation with other Zadoff-Chu sequences that are generated using different roots.

[0332] Random Access Channel: is a shared channel that may be accessed randomly by multiple users either simultaneously or non-simultaneously.

[0333] Physical Random-Access Channel: is a physical-layer shared channel that may be accessed randomly by multiple users either simultaneously or non-simultaneously.

[0334] Round-Trip Delay: is the time required for the signal to propagate through the communication channel after originating the signal from the transmitter until the signal reach the receiver and then to propagate through the communication channel again from the receiver to come back to the original transmitter.

[0335] Carrier Frequency Offset: is the deviation that may happen on the frequency subcarriers due to the Doppler shift of the communication channel and due to the local oscillators' synchronization mismatching between the transmitter and the receiver.

[0336] Zero-Correlation Zone: is the zone where the cross-correlation of the cyclically shifted versions of Zadoff-Chu sequences are equal to zero.

[0337] Time Delay: is the difference between the starting time of the sequence at the transmitter and the starting time of the sequence at the receiver, which is induced by the communication channel due to the propagation time requirement for the signal to propagate from the transmitter to the receiver.

[0338] User Equipment: is the user equipment in the cellular communications network at both TN and NTN.

[0339] gNB: is the radio base station in 5G NR networks and is herein used to denote the radio base station of existing or future TN or NTN cellular network.

[0340] New Radio: refers to the 5G air interface between UE and gNB as specified by 3GPP.

[0341] Frequency Range (FR) 1, 2: FR1 refers to bands in the sub-6 GHz spectrum (although 7125 MHz is defined as the maximum) and FR2 refers to bands in the mmWave spectrum.

[0342] Peak to Average Power Ratio: is the quantity that equals to the maximum power of the signal divided by the average power of the signal.

[0343] Although embodiments have been described above with reference to the accompanying drawings, those of skill in the art will appreciate that variations and modifications may be made without departing from the scope thereof as defined by the appended claims.

1. A method comprising:

transmitting a random-access preamble comprising at least a modified sequence generated from a first Zadoff-Chu (ZC) sequence rotated by an angle, the first ZC sequence belonging to a set of ZC sequences.

2. The method of claim **1**, wherein the modified sequence is the first ZC sequence rotated by the angle and scaled by a scaling factor.

3. The method of claim **1**, wherein the random-access preamble further comprises a second ZC sequence.

4. The method of claim **3**, wherein the first ZC sequence and the second ZC sequence are ZC sequences of different roots.

5. The method of claim **3**, wherein the first ZC sequence is a complex conjugate of the second ZC sequence.

6. The method of claim **3**, wherein the random-access preamble comprises a superimposed physical random-access channel (PRACH) sequence being a superimposition of the modified sequence and the second ZC sequence.

7. The method of claim **6**, wherein the random-access preamble comprises a first copy and a second copy of the superimposed PRACH sequence; and

wherein a cyclic prefix (CP) is between the first copy and the second copy; or

wherein the second copy is directly concatenated to the first copy.

8. An apparatus comprising:

at least one processor coupled with a non-transitory computer-readable medium storing instructions, when the instructions are executed by the at least one processor, cause the apparatus to perform operations comprising:

receiving a random-access preamble;

determining from the random-access preamble at least a modified sequence, the modified sequence being a first Zadoff-Chu (ZC) sequence rotated by an angle, the first ZC sequence belonging to a set of ZC sequences; and

estimating at least one of a time delay (TD) or a carrier frequency offset (CFO) based on the random-access preamble and the modified sequence.

9. The apparatus of claim **8**, wherein the modified sequence is the first ZC sequence rotated by the angle and scaled by a scaling factor.

10. The apparatus of claim **8**, wherein the random-access preamble further comprises a second ZC sequence, and wherein the random-access preamble comprises a superimposed physical random-access channel (PRACH) sequence being a superimposition of the modified sequence and the second ZC sequence.

11. The apparatus of claim **10**, wherein the determining from the random-access preamble at least the modified sequence comprises:

obtaining at least a candidate modified sequence based on the set of ZC sequences;

calculating a candidate PRACH sequence at least based on the candidate modified sequence;

calculating a cross-correlation between the candidate PRACH sequence and the superimposed PRACH sequence;

using correlation peak detection to detect one or more peaks of the cross-correlation greater than other values of the cross-correlation by at least a threshold value; and

determining the candidate modified sequence as the modified sequence.

12. The apparatus of claim **11**, wherein the using the correlation peak detection comprises:

using the correlation peak detection to detect a peak of the cross-correlation greater than the other values of the cross-correlation by the at least threshold value; and

wherein the estimating the at least one of the TD or the CFO comprises:

estimating the TD based on the peak.

13. The apparatus of claim **11**, wherein the using the correlation peak detection comprises:

using the correlation peak detection to detect a plurality of peaks of the cross-correlation greater than the other values of the cross-correlation by the at least threshold value; and

wherein the estimating the at least one of the TD or the CFO comprises:

estimating the TD and the CFO based on the plurality of peaks.

14. The apparatus of claim **10**, wherein the determining from the random-access preamble at least the modified sequence comprises:

obtaining a candidate modified sequence and a second candidate ZC sequence based on the set of ZC sequences;

calculating a first cross-correlation between the superimposed PRACH sequence and the modified sequence;

calculating a second cross-correlation between the superimposed PRACH sequence and the second candidate ZC sequence; and

using correlation peak detection to detect one or more peaks of the first cross-correlation and the second cross-correlation respectively greater than other values of the first cross-correlation and the second cross-correlation by at least a threshold value; and

determining the candidate modified sequence and the second candidate ZC sequence as the modified sequence and the second ZC sequence, respectively.

15. An apparatus comprising:

at least one processor coupled with a non-transitory computer-readable medium storing instructions, when the instructions are executed by the at least one processor, cause the apparatus to perform operations comprising:

transmitting a random-access preamble comprising at least a modified sequence generated from a first Zadoff-Chu (ZC) sequence rotated by an angle, the first ZC sequence belonging to a set of ZC sequences.

16. The apparatus of claim **15**, wherein the modified sequence is the first ZC sequence rotated by the angle and scaled by a scaling factor.

17. The apparatus of claim **15**, wherein the random-access preamble further comprises a second ZC sequence.

18. The apparatus of claim **17**, wherein the first ZC sequence and the second ZC sequence are ZC sequences of different roots.

19. The apparatus of claim **17**, wherein the first ZC sequence is a complex conjugate of the second ZC sequence.

20. The apparatus of claim **17**, wherein the random-access preamble comprises a superimposed physical random-access channel (PRACH) sequence being a superimposition of the modified sequence and the second ZC sequence.

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