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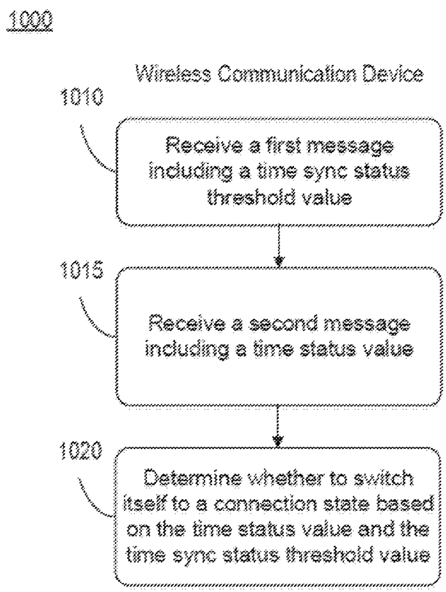

FIG. 10

(57) **Abstract:** Presented are systems and methods for notifying synchronization status. A wireless communication device (e.g., a UE) may receive a first message including a time sync status threshold value. The wireless communication device may receive a second message including a time status value. The wireless communication device may determine whether to switch itself to a connection state based on the time status value and the time sync status threshold value.

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SYSTEMS AND METHODS FOR NOTIFYING SYNCHRONIZATION STATUS

TECHNICAL FIELD

The disclosure relates generally to wireless communications, including but not limited to systems and methods for notifying synchronization status.

BACKGROUND

The standardization organization Third Generation Partnership Project (3GPP) is currently in the process of specifying a new Radio Interface called 5G New Radio (5G NR) as well as a Next Generation Packet Core Network (NG-CN or NGC). The 5G NR will have three main components: a 5G Access Network (5G-AN), a 5G Core Network (5GC), and a User Equipment (UE). In order to facilitate the enablement of different data services and requirements, the elements of the 5GC, also called Network Functions, have been simplified with some of them being software based, and some being hardware based, so that they could be adapted according to need.

SUMMARY

The example embodiments disclosed herein are directed to solving the issues relating to one or more of the problems presented in the prior art, as well as providing additional features that will become readily apparent by reference to the following detailed description when taken in conjunction with the accompany drawings. In accordance with various embodiments, example systems, methods, devices and computer program products are disclosed herein. It is understood, however, that these embodiments are presented by way of example and are not limiting, and it will be apparent to those of ordinary skill in the art who read the present disclosure that various modifications to the disclosed embodiments can be made while remaining within the scope of this disclosure.

At least one aspect is directed to a system, method, apparatus, or a computer-readable medium of the following. A wireless communication device (e.g., a UE) may receive a first message including a time sync status threshold value. The wireless communication device may receive a second message including a time status value. The wireless communication device may determine whether to switch itself to a connection state based on the time status value and the time sync status threshold value. The wireless communication device may receive the first message from an Access & Mobility Management Function (AMF) or a wireless communication node (e.g., a NG-RAN). The wireless communication device may receive the second message through broadcast from the wireless communication node.

In some embodiments, the AMF can be configured to create the time sync status threshold value. The first message can be a Non-Access Stratum (NAS) message sent directly from the AMF. The first message can be a Radio Resource Control (RRC) message sent from the wireless communication node. The second message can be a new Information Element of a System Information Block (SIB) or an existing Information Element of ReferenceTimeInfo.

In some embodiments, a Time Sensitive Communication Synchronization Function (TSCTSF) or a Time Sensitive Networking-Adaptation Function (TSN-AF) can be configured to create the time sync status threshold value. The TSCTSN or TSN AF can be configured to send the time sync status threshold value to the AMF.

In some embodiments, the wireless communication node can be configured to create the time sync status threshold value. The wireless communication node can be configured to send the time sync status threshold value to the AMF.

In some embodiments, a network entity may send a message including a time sync status threshold value to a wireless communication device. The wireless communication device can be configured to determine whether to switch itself to a connection state based on the time sync status threshold value and a received time status value. The network entity can be an Access & Mobility Management Function (AMF) or a wireless communication node. The time status value can be received from the wireless communication node through broadcast. The time sync status threshold value can be created by one of: the AMF, the wireless communication node, a Time Sensitive Communication Synchronization Function (TSCTSF), or a Time Sensitive Networking-Adaptation Function (TSN-AF).

In some embodiments, the AMF may receive the time sync status threshold value from Time Sensitive Communication Synchronization Function (TSCTSF), a Time Sensitive

Networking-Adaptation Function (TSN-AF), or the wireless communication node. The wireless communication node can be a NG-RAN.

BRIEF DESCRIPTION OF THE DRAWINGS

Various example embodiments of the present solution are described in detail below with reference to the following figures or drawings. The drawings are provided for purposes of illustration only and merely depict example embodiments of the present solution to facilitate the reader's understanding of the present solution. Therefore, the drawings should not be considered limiting of the breadth, scope, or applicability of the present solution. It should be noted that for clarity and ease of illustration, these drawings are not necessarily drawn to scale.

FIG. 1 illustrates an example cellular communication network in which techniques disclosed herein may be implemented, in accordance with an embodiment of the present disclosure;

FIG. 2 illustrates a block diagram of an example base station and a user equipment device, in accordance with some embodiments of the present disclosure;

FIG. 3 illustrates an example implementation of a 5GS architecture, in accordance with some embodiments of the present disclosure;

FIG. 4 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure;

FIG. 5 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure;

FIG. 6 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure;

FIG. 7 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure;

FIG. 8 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure;

FIG. 9 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure; and

FIG. 10 illustrates a flow diagram of an example method for notifying synchronization status, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

1. Mobile Communication Technology and Environment

FIG. 1 illustrates an example wireless communication network, and/or system, 100 in which techniques disclosed herein may be implemented, in accordance with an embodiment of the present disclosure. In the following discussion, the wireless communication network 100 may be any wireless network, such as a cellular network or a narrowband Internet of things (NB-IoT) network, and is herein referred to as "network 100." Such an example network 100 includes a base station 102 (hereinafter "BS 102"; also referred to as wireless communication node) and a user equipment device 104 (hereinafter "UE 104"; also referred to as wireless communication device) that can communicate with each other via a communication link 110 (e.g., a wireless communication channel), and a cluster of cells 126, 130, 132, 134, 136, 138 and 140 overlaying a geographical area 101. In Figure 1, the BS 102 and UE 104 are contained within a respective geographic boundary of cell 126. Each of the other cells 130, 132, 134, 136, 138 and 140 may include at least one base station operating at its allocated bandwidth to provide adequate radio coverage to its intended users.

For example, the BS 102 may operate at an allocated channel transmission bandwidth to provide adequate coverage to the UE 104. The BS 102 and the UE 104 may communicate via a downlink radio frame 118, and an uplink radio frame 124 respectively. Each radio frame 118/124 may be further divided into sub-frames 120/127 which may include data symbols 122/128. In the present disclosure, the BS 102 and UE 104 are described herein as non-limiting examples of "communication nodes," generally, which can practice the methods disclosed herein.

Such communication nodes may be capable of wireless and/or wired communications, in accordance with various embodiments of the present solution.

FIG. 2 illustrates a block diagram of an example wireless communication system 200 for transmitting and receiving wireless communication signals (e.g., OFDM/OFDMA signals) in accordance with some embodiments of the present solution. The system 200 may include components and elements configured to support known or conventional operating features that need not be described in detail herein. In one illustrative embodiment, system 200 can be used to communicate (e.g., transmit and receive) data symbols in a wireless communication environment such as the wireless communication environment 100 of Figure 1, as described above.

System 200 generally includes a base station 202 (hereinafter "BS 202") and a user equipment device 204 (hereinafter "UE 204"). The BS 202 includes a BS (base station) transceiver module 210, a BS antenna 212, a BS processor module 214, a BS memory module 216, and a network communication module 218, each module being coupled and interconnected with one another as necessary via a data communication bus 220. The UE 204 includes a UE (user equipment) transceiver module 230, a UE antenna 232, a UE memory module 234, and a UE processor module 236, each module being coupled and interconnected with one another as necessary via a data communication bus 240. The BS 202 communicates with the UE 204 via a communication channel 250, which can be any wireless channel or other medium suitable for transmission of data as described herein.

As would be understood by persons of ordinary skill in the art, system 200 may further include any number of modules other than the modules shown in Figure 2. Those skilled in the art will understand that the various illustrative blocks, modules, circuits, and processing logic described in connection with the embodiments disclosed herein may be implemented in hardware, computer-readable software, firmware, or any practical combination thereof. To clearly illustrate this interchangeability and compatibility of hardware, firmware, and software, various illustrative components, blocks, modules, circuits, and steps are described generally in terms of their functionality. Whether such functionality is implemented as hardware, firmware, or software can depend upon the particular application and design constraints imposed on the overall system. Those familiar with the concepts described herein may implement such functionality in a suitable manner for each particular application, but such implementation decisions should not be interpreted as limiting the scope of the present disclosure

In accordance with some embodiments, the UE transceiver 230 may be referred to herein as an "uplink" transceiver 230 that includes a radio frequency (RF) transmitter and a RF receiver each comprising circuitry that is coupled to the antenna 232. A duplex switch (not shown) may alternatively couple the uplink transmitter or receiver to the uplink antenna in time duplex fashion. Similarly, in accordance with some embodiments, the BS transceiver 210 may be referred to herein as a "downlink" transceiver 210 that includes a RF transmitter and a RF receiver each comprising circuity that is coupled to the antenna 212. A downlink duplex switch may alternatively couple the downlink transmitter or receiver to the downlink antenna 212 in time duplex fashion. The operations of the two transceiver modules 210 and 230 may be coordinated in time such that the uplink receiver circuitry is coupled to the uplink antenna 232 for reception of transmissions over the wireless transmission link 250 at the same time that the downlink transmitter is coupled to the downlink antenna 212. Conversely, the operations of the two transceivers 210 and 230 may be coordinated in time such that the downlink receiver is coupled to the downlink antenna 212 for reception of transmissions over the wireless transmission link 250 at the same time that the uplink transmitter is coupled to the uplink antenna 232. In some embodiments, there is close time synchronization with a minimal guard time between changes in duplex direction.

The UE transceiver 230 and the base station transceiver 210 are configured to communicate via the wireless data communication link 250, and cooperate with a suitably configured RF antenna arrangement 212/232 that can support a particular wireless communication protocol and modulation scheme. In some illustrative embodiments, the UE transceiver 210 and the base station transceiver 210 are configured to support industry standards such as the Long Term Evolution (LTE) and emerging 5G standards, and the like. It is understood, however, that the present disclosure is not necessarily limited in application to a particular standard and associated protocols. Rather, the UE transceiver 230 and the base station transceiver 210 may be configured to support alternate, or additional, wireless data communication protocols, including future standards or variations thereof.

In accordance with various embodiments, the BS 202 may be an evolved node B (eNB), a serving eNB, a target eNB, a femto station, or a pico station, for example. In some embodiments, the UE 204 may be embodied in various types of user devices such as a mobile phone, a smart phone, a personal digital assistant (PDA), tablet, laptop computer, wearable computing device, etc. The processor modules 214 and 236 may be implemented, or realized, with a general purpose processor, a content addressable memory, a digital signal processor, an application specific integrated circuit, a field programmable gate array, any suitable programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof, designed to perform the functions described herein. In this manner, a processor may be realized as a microprocessor, a controller, a microcontroller, a state machine, or the like. A processor may also be implemented as a combination of computing devices, e.g., a combination of a digital signal processor and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a digital signal processor core, or any other such configuration.

Furthermore, the steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in firmware, in a software module executed by processor modules 214 and 236, respectively, or in any practical combination thereof. The memory modules 216 and 234 may be realized as RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. In this regard, memory modules 216 and 234 may be coupled to the processor modules 210 and 230, respectively, such that the processors modules 210 and 230 can read information from, and write information to, memory modules 216 and 234, respectively. The memory modules 216 and 234 may also be integrated into their respective processor modules 210 and 230. In some embodiments, the memory modules 216 and 234 may each include a cache memory for storing temporary variables or other intermediate information during execution of instructions to be executed by processor modules 210 and 230, respectively. Memory modules 216 and 234 may also each include non-volatile memory for storing instructions to be executed by the processor modules 210 and 230, respectively.

The network communication module 218 generally represents the hardware, software, firmware, processing logic, and/or other components of the base station 202 that enable bi-directional communication between base station transceiver 210 and other network components and communication nodes configured to communication with the base station 202. For example, network communication module 218 may be configured to support internet or WiMAX traffic. In a typical deployment, without limitation, network communication module 218 provides an 802.3 Ethernet interface such that base station transceiver 210 can communicate with a conventional Ethernet based computer network. In this manner, the network communication module 218 may include a physical interface for connection to the computer network (e.g., Mobile Switching Center (MSC)). The terms "configured for," "configured to" and conjugations thereof, as used herein with respect to a specified operation or function, refer to a device, component, circuit, structure, machine, signal, etc., that is physically constructed, programmed, formatted and/or arranged to perform the specified operation or function.

The Open Systems Interconnection (OSI) Model (referred to herein as, "open system interconnection model") is a conceptual and logical layout that defines network communication used by systems (e.g., wireless communication device, wireless communication node) open to interconnection and communication with other systems. The model is broken into seven subcomponents, or layers, each of which represents a conceptual collection of services provided to the layers above and below it. The OSI Model also defines a logical network and effectively describes computer packet transfer by using different layer protocols. The OSI Model may also be referred to as the seven-layer OSI Model or the seven-layer model. In some embodiments, a first layer may be a physical layer. In some embodiments, a second layer may be a Medium Access Control (MAC) layer. In some embodiments, a third layer may be a Radio Link Control (RLC) layer. In some embodiments, a fourth layer may be a Packet Data Convergence Protocol (PDCP) layer. In some embodiments, a fifth layer may be a Radio Resource Control (RRC) layer. In some embodiments, a sixth layer may be a Non Access Stratum (NAS) layer or an Internet Protocol (IP) layer, and the seventh layer being the other layer.

Various example embodiments of the present solution are described below with reference to the accompanying figures to enable a person of ordinary skill in the art to make and use the present solution. As would be apparent to those of ordinary skill in the art, after reading the present disclosure, various changes or modifications to the examples described herein can be made without departing from the scope of the present solution. Thus, the present solution is not limited to the example embodiments and applications described and illustrated herein. Additionally, the specific order or hierarchy of steps in the methods disclosed herein are merely example approaches. Based upon design preferences, the specific order or hierarchy of steps of the disclosed methods or processes can be re-arranged while remaining within the scope of the present solution. Thus, those of ordinary skill in the art will understand that the methods and techniques disclosed herein present various steps or acts in a sample order, and the present solution is not limited to the specific order or hierarchy presented unless expressly stated otherwise.

2. Systems and Methods for Notifying Synchronization Status

In a 5G system, a time synchronization service to a UE may have been supported. A next-generation radio access network (NG-RAN) (e.g., a gNB or an NG-eNB) may obtain a precise time from a 5G internal time source and may provide precise time information to a UE via a 5G access stratum (AS) signaling (e.g., a 5G access stratum time distribution).

In order to support a disaster tolerance, a 5G system (5GS) may support a timing resiliency. When a 5G internal time source (e.g., 5G grand master (GM)) fails/degrades/upgrades/switches, it may lead to changes in time synchronization performance parameters of NG-RAN. The NG-RAN may inform the UE a time status.

For a connection management (CM)-idle mode UE or CM-connected with radio resource control (RRC) inactive mode UE, the UE may enter a CM-connected mode to get time status information details. However, this may cause high load to the NG-RAN when lot of UEs enter the CM-connected mode in the same time because of NG-RAN time status changes. The high load may have a negative impact to NG-RAN performance and stability. The systems and methods presented herein can include novel approaches for avoiding all UEs going to connected at the same time.

FIG. 3 illustrates an example implementation of a 5GS architecture to support a time synchronization service, in accordance with some embodiments of the present disclosure. For simplicity, network functions (NFs) that are not related to the time synchronization may not be described. The architecture may include at least one of following functions: a user equipment (UE), 5G access network (5G-AN), an access and mobility management function (AMF), a session management function (SMF), a user plane function (UPF), a policy control function (PCF), a network exposure function (NEF), a time sensitive communication and time synchronization function (TSCTSF), and a time sensitive network adaptation function (TSN AF).

The user equipment (UE) can be accessing the 5GS and may obtain services via NG-RAN. The UE may interact with an access and mobility control function (AMF) of a core network via a non-access stratum (NAS) signaling.

The 5G-AN (e.g., 5G radio access network) can be called NG-RAN. The NG-RAN may be responsible for an air interface resource scheduling and air interface connection management of a network to which the UE is accessing to.

The access and mobility management function (AMF) may include at least one of following functionalities: a registration management, a connection management, or a reachability management and mobility management. The AMF may also perform an access authentication and access authorization. The AMF can be a NAS security termination and may relay a session management (SM) non-access stratum (NAS) between a UE and a session management function (SMF).

The session management function (SMF) may include at least one of following functionalities: a session management (e.g., session establishment, modify and/or release), a UE IP address allocation and management (e.g., optional authorization), a selection and control of user plane (UP) function, or a downlink data notification.

The user plane function (UPF) may include at least one of following functionalities: an anchor point for intra-/inter-radio access technology (RAT) mobility, a packet routing and forwarding, a traffic usage reporting, a quality of service (QoS) handling for user plane, or a downlink packet buffering and downlink data notification triggering.

The policy control function (PCF) may include at least one of following functionalities: an unified policy framework to govern network behavior, policy rules to control plane function(s) to enforce the policy rules, or a front end to access subscription information relevant for policy decisions in a user data repository (UDR).

The network exposure function (NEF) may be deployed optionally for exchanging information between 5G core (5GC) and an external application function (AF). In this disclosure, NEF/AF may present the NEF and the AF for brief.

The time sensitive communication and time synchronization function (TSCTSF) may control a time synchronization service by controlling the NG-RAN to enable the 5G access stratum time distribution and may configure a device-side time sensitive networking (TSN) translator (DS-TT) and network-side time sensitive networking (TSN) translator (NW-TT) when the 5GS is not integrated with TSN network.

The time sensitive network adaptation function (TSN AF) may provide an interworking and adaptation with computer numerical control (CNC) in an external TSN network.

There can be a 5G internal grand master (GM) clock as a time source (e.g., global positioning system (GPS), or GM clock in a transport network). The NG-RAN and UPF may perform time synchronization with a 5G internal GM clock separately.

In existing 5G system, a NG-RAN can provide precise time information to a UE via a 5G AS signaling (e.g., 5G access stratum time distribution (ASTI)).

FIG. 4 illustrates a sequence diagram illustrating a time synchronization between a UE and a NG-RAN, in accordance with some embodiments of the present disclosure. FIG. 4 shows how a UE obtains 5G precise time over an air interface from a NG-RAN.

In step 401, a NG-RAN may send ReferenceTimeInfo to a UE in a system information block 9 (SIB9) or radio resource control (RRC) message.

In step 402, there can be three information elements (IEs) in the ReferenceTimeInfo.

referenceSFN: This field may indicate a reference system frame number (SFN) corresponding to reference time information.

Time (ReferenceTime): the time field may indicate the time at the SFN (e.g., referenceSFN) boundary.

Uncertainty: This field may indicate an uncertainty of the reference time information in the time field. The uncertainty can be 25ns multiplied by this field.

The UE may use the above received information to synchronize time with the NG-RAN. After this procedure, we can consider that the UE and the NG-RAN are time synchronized (e.g., the UE and the NG-RAN share/have the same 5G clock time).

When the 5G time status is changed (e.g., the original GM clock degrades, the original GM clock upgrades, the original GM clock is down, and/or a new 5G GM clock is used), this may lead to changes in the time synchronization performance parameters of the NG-RAN. The NG-RAN may notify the latest status to the UE.

FIG. 5 illustrates a sequence diagram illustrating a time synchronization, in accordance with some embodiments of the present disclosure. FIG. 5 show how a UE is notified about time status. A NG-RAN may notify time status to a UE.

In step 501, a time synchronization can be the same sequence diagram as shown in FIG. 4.

In step 502, the NG-RAN may detect a 5G internal GM event (e.g., current GM clock degrades/upgrades, the original GM clock is down, and/or a new 5G GM clock is used). This may lead to changes in the time synchronization performance parameters of the NG-RAN.

In step 503, the NG-RAN may notify UEs in a coverage area of the cells of NG-RAN by a SIB. The notification may include a time synchronization status event/report.

In step 504, for an IDLE UE, or CM-connected with RRC inactive mode UE which performs the time synchronization, the UE may initiate a RRC connection establishment procedure with the NG-RAN when the UE receives the time synchronization status event/report indication in the step 503.

In step 505, after the RRC connection is established, the NG-RAN may notify the UE with time synchronization status details (e.g., clock accuracy, traceability to UTC, or frequency stability).

The SIB resources can be very limited in the air interface. In the step 503, the NG-RAN may broadcast that something happened. Specific details can be provided to the UE in the RRC message in the step 505.

This procedure may cause an issue: all the IDLE mode UEs, or CM-connected with RRC inactive mode UEs which are receiving the time information may enter a CM-connected mode simultaneously. This procedure may cause high load to the NG-RAN, which may have a negative impact to a performance and stability of the NG-RAN.

However, it may be not necessary for all UEs to know the detail when there is a time synchronization status change. Those conditions (not necessary for all UEs to be notified) may include: (1) an idle mode UE-A's clock synchronization accuracy requirement is 800 ns; (2) a current time synchronization accuracy provided by NG-RAN is 500 ns; (3) a 5G internal GM event happens: a time synchronization accuracy provided by NG-RAN becomes/changes to 400 ns (upgrade), or 600 ns (downgrade). For the UE-A, it may not need to move into Connected mode to obtain the status details because the time synchronization QoS is still fulfilled. A mechanism may be needed to ensure that a UE only goes/switches/changes into a connected mode to obtain status details when required. The mechanism may minimize an impact to a NG-RAN.

Implementation Example 1

FIG. 6 shows a procedure where an AMF creates and sends a time synchronization status threshold value. An AMF may create a time synchronization status threshold value and may send the time synchronization status threshold value to a UE via a NAS message.

In step 601, an AMF may receive a service operation which carries a 5G access stratum time distribution requirement for a UE. The AMF may receive this request from a unified data management (UDM) or a policy control function (PCF).

In step 602, the AMF may create a time synchronization status threshold value for the UE (e.g., according to the time synchronization error budget for the UE in step 601, or according to local configuration).

In step 603, the AMF may send the time synchronization status threshold value to the UE via a NAS message. For a CM connected mode UE, the AMF can send the NAS message directly. For an IDLE UE, the AMF can either wait for the UE entering the CM connected mode, or page the UE. After the UE enters the CM connected mode, the AMF may then send the time synchronization status threshold value to the UE via a NAS message.

In step 604, the AMF may (optionally) send the time synchronization status threshold value to NG-RAN in a N2 message. This NAS message may be in a N1 container in the step 604. The NG-RAN may forward the N1 container to the UE after receiving the N2 message.

In step 605, the NG-RAN may broadcast the 5G time status value in the SIB according to current 5G clock status. The time status value may be a new IE in the SIB, or reuse the existing uncertainty IE in the ReferenceTimeInfo.

In step 606, the NG-RAN may detect a 5G internal GM event (e.g., current GM clock degrades/upgrades, the original GM clock is down, and/or a new 5G GM clock is used). This may lead to changes in the time synchronization performance parameters of the NG-RAN.

In step 607, the NG-RAN may broadcast the 5G time status value in the SIB which reflects the change.

In step 608, according to the time synchronization status threshold value received in the step 603 and current 5G time status value received in the step 607, the IDLE or RRC inactive UE may initiate the RRC connection establishment procedure with the NG-RAN. The UE may compare the time synchronization status threshold value and 5G time status value directly. For example, the UE can be configured to enter RRC connection mode when the 5G time status value is large than time synchronization status threshold value. For another example, the UE can be configured to enter RRC connection mode when the 5G time status value is less than time synchronization status threshold value. The UE may formulate a conversion on time synchronization status threshold value and 5G time status value. After formulating the conversion, the UE may compare the time synchronization status threshold value and the 5G time status value. For example, the 5G time status value can be transformed into “real status value”, such as multiplying by 25. The UE can be configured to enter RRC connection mode when the “real status value” is large than the time synchronization status threshold value. For another example, the UE can be configured to enter RRC connection mode when the “real status value” is less than time the synchronization status threshold value.

In step 609, after the RRC connection is established, the NG-RAN may notify the UE with time synchronization status details (e.g., clock accuracy, traceability to UTC, or frequency stability).

Implementation Example 2

FIG. 7 shows a procedure where an AMF creates a time synchronization status threshold value and a UE receives the time synchronization status threshold value via an access stratum (AS) (e.g., RRC) signaling. An AMF may create a time synchronization status threshold value. A UE may receive the time synchronization status threshold value via an AS signaling.

In step 701, an AMF may receive a service operation which carries a 5G access stratum time distribution requirement for a UE. The AMF may receive the request from a UDM or a PCF.

In step 702, the AMF may create a time synchronization status threshold value for the UE (e.g., according to a time synchronization error budget for the UE in step 701, or according to a local configuration).

In step 703, the AMF may send the time sync status threshold value to a NG-RAN via a N2 message. For a CM connected mode UE, the AMF can send the N2 message directly. For an IDLE UE, the AMF can either wait for the UE entering the CM connected mode, or page the UE. After the UE enters the CM connected mode, the AMF may send the time synchronization status threshold value to the NG-RAN.

In step 704, the NG-RAN may send the time synchronization status threshold value to the UE via an AS (e.g., RRC) message. If the UE is in a RRC inactive mode, the NG-RAN may perform a RAN paging first.

In step 705, the NG-RAN may broadcast a 5G time status value in a system information block (SIB) according to current 5G clock status. The time status value may be a new IE in the SIB, or may reuse the existing uncertainty IE in the ReferenceTimeInfo.

In step 706, the NG-RAN may detect a 5G internal GM event (e.g., current GM clock degrades/upgrades, the original GM clock is down, or a new 5G GM clock is used). This may lead to changes in time synchronization performance parameters of the NG-RAN.

In step 707, the NG-RAN may broadcast a 5G time status value in the SIB which reflect the change.

In step 708, according to the time synchronization status threshold value received in the step 704 and current time status value, the IDLE or RRC inactive UE may initiate a RRC connection establishment procedure with the NG-RAN. This step can be similar with the step 608.

In step 709, after the RRC connection is established, the NG-RAN may notify the UE with time synchronization status details (e.g., a clock accuracy, a traceability to UTC, or a frequency stability).

Implementation Example 3

FIG. 8 shows a procedure where a NG-RAN creates a time synchronization status threshold value and a UE receives the time synchronization status threshold value via an access stratum (AS) (e.g., RRC) or a NAS signaling. A NG-RAN may create a time synchronization status threshold value, and may send the time synchronization status threshold value to a UE via an access stratum (AS) (e.g., RRC) or a NAS signaling.

In step 801, an AMF may receive a service operation which carries a 5G access stratum time distribution requirement for a UE. The AMF may receive the request from a UDM or a PCF.

In step 802, the AMF may send a N2 message with a 5G access stratum time distribution requirement to a NG-RAN. For a CM connected mode UE, the AMF may send the N2 message to the NG-RAN directly. For an IDLE UE, the AMF may either wait for the UE entering the CM connected mode, or may page the UE. After the UE enter CM connected mode, the AMF may send a N2 message to the NG-RAN.

In step 803, the NG-RAN may create a time synchronization status threshold value for the UE (e.g., according to a time synchronization error budget for the UE in step 802, or according to a local configuration).

In step 804, the NG-RAN may send the time synchronization status threshold value to the UE via an AS (e.g., RRC) message. If the UE is in a RRC inactive mode, the NG-RAN may perform a RAN paging first.

Another option for step 804 can be step 804a. In step 804a, the NG-RAN may send the time synchronization status threshold value to the AMF in a N2 message. The AMF may send the time synchronization status threshold value to the UE via a NAS message.

In step 805, the NG-RAN may broadcast a 5G time status value in a SIB according to current 5G clock status. The time status value may be a new IE in the SIB, or may reuse the existing uncertainty IE in the ReferenceTimeInfo.

In step 806, the NG-RAN may detect a 5G internal GM event (e.g., current GM clock degrades/upgrades, the original GM clock is down, or a new 5G GM clock is used). This may lead to changes in time synchronization performance parameters of the NG-RAN.

In step 807, the NG-RAN may broadcast a 5G time status value in a SIB which may reflect the change.

In step 808, according to the time synchronization status threshold value received in the step 804/804a and current time status value, the IDLE or RRC inactive UE may initiate a RRC connection establishment procedure with the NG-RAN. This step can be similar with step 608.

In step 809, after the RRC connection is established, the NG-RAN may notify the UE with time synchronization status details (e.g., a clock accuracy, a traceability to UTC, a frequency stability).

Implementation Example 4

FIG. 9 shows a procedure where a TSCTSF / TSN AF creates a time synchronization status threshold value and sends the time synchronization status threshold value to an AMF.

In step 901, a TSCTSF / TSN AF may receive a service operation which carries a 5G access stratum time distribution request for a UE. The TSCTSF / TSN AF may receive the request from a NEF or an AF.

In step 902, the TSCTSF / TSN AF may create a time synchronization status threshold value for the UE (e.g., according to a time synchronization error budget for the UE in step 901, or according to a local configuration).

In step 903, the TSCTSF / TSN AF may search/determine a PCF for the UE using a Nbsf service operation. The TSCTSF / TSN AF may send an AM policy of the UE using a Npcf_AMPolicyAuthorization request (containing the time synchronization status threshold value) to a PCF.

In step 904, the PCF may initiate an AM Policy Association Modification procedure for the UE to provide the time synchronization status threshold value to the AMF.

In step 905, the AMF may send the time synchronization status threshold value to the UE. The AMF may send the time synchronization status threshold value via a NAS message (same with step 603 in FIG. 6), or send the time synchronization status threshold value to a NG-RAN. The NG-RAN may send the time synchronization status threshold value to the UE via an AS (e.g., RRC) message (same with step 703/704 in FIG. 7).

In step 906, the AMF may (optional) send the time synchronization status threshold value to the NG-RAN in a N2 message. The NAS message may be in a N1 container in the step 905. The NG-RAN may forward the N1 container to UE after receiving the N2 message.

Step 907~911 can be the same with the step 605~609.

In some embodiments, a time synchronization status threshold value and a time status value may be in the same dimension, or different dimensions. The UE may compare the time synchronization status threshold value and the 5G time status value directly. The time synchronization status threshold value and a time status value may be in the different dimensions. The UE may formulate a conversion on time synchronization status threshold value and 5G time status value. After formulating the conversion, the UE may compare the time synchronization status threshold value and the 5G time status value.

It should be understood that one or more features from the above implementation examples are not exclusive to the specific implementation examples, but can be combined in any manner (e.g., in any priority and/or order, concurrently or otherwise).

FIG. 10 illustrates a flow diagram of a method 1000 for notifying synchronization status. The method 1000 may be implemented using any one or more of the components and devices detailed herein in conjunction with FIGs. 1–9. In overview, the method 1000 may be performed by a wireless communication device (e.g., a UE), in some embodiments. Additional, fewer, or different operations may be performed in the method 1000 depending on the embodiment. At least one aspect of the operations is directed to a system, method, apparatus, or a computer-readable medium.

A wireless communication device (e.g., a UE) may receive a first message including a time sync status threshold value. The wireless communication device may receive a second message including a time status value. The wireless communication device may determine whether to switch itself to a connection state based on the time status value and the time sync status threshold value. The wireless communication device may receive the first message from an Access & Mobility Management Function (AMF) or a wireless communication node (e.g., a NG-RAN). The wireless communication device may receive the second message through broadcast from the wireless communication node.

In some embodiments, the AMF can be configured to create the time sync status threshold value. The first message can be a Non-Access Stratum (NAS) message sent directly from the AMF. The first message can be a Radio Resource Control (RRC) message sent from the wireless communication node. The second message can be a new Information Element of a System Information Block (SIB) or an existing Information Element of ReferenceTimeInfo.

In some embodiments, a Time Sensitive Communication Synchronization Function (TSCTSF) or a Time Sensitive Networking-Adaptation Function (TSN-AF) can be configured to create the time sync status threshold value. The TSCTSN or TSN AF can be configured to send the time sync status threshold value to the AMF.

In some embodiments, the wireless communication node can be configured to create the time sync status threshold value. The wireless communication node can be configured to send the time sync status threshold value to the AMF.

In some embodiments, a network entity may send a message including a time sync status threshold value to a wireless communication device. The wireless communication device can be configured to determine whether to switch itself to a connection state based on the time sync status threshold value and a received time status value. The network entity can be an Access & Mobility Management Function (AMF) or a wireless communication node. The time status value can be received from the wireless communication node through broadcast. The time sync status threshold value can be created by one of: the AMF, the wireless communication node, a Time Sensitive Communication Synchronization Function (TSCTSF), or a Time Sensitive Networking-Adaptation Function (TSN-AF).

In some embodiments, the AMF may receive the time sync status threshold value from Time Sensitive Communication Synchronization Function (TSCTSF), a Time Sensitive Networking-Adaptation Function (TSN-AF), or the wireless communication node. The wireless communication node can be a NG-RAN.

While various embodiments of the present solution have been described above, it should be understood that they have been presented by way of example only, and not by way of limitation. Likewise, the various diagrams may depict an example architectural or configuration, which are provided to enable persons of ordinary skill in the art to understand example features and functions of the present solution. Such persons would understand, however, that the solution is not restricted to the illustrated example architectures or configurations, but can be implemented using a variety of alternative architectures and configurations. Additionally, as would be understood by persons of ordinary skill in the art, one or more features of one embodiment can be combined with one or more features of another embodiment described herein. Thus, the breadth and scope of the present disclosure should not be limited by any of the above-described illustrative embodiments.

It is also understood that any reference to an element herein using a designation such as "first," "second," and so forth does not generally limit the quantity or order of those elements. Rather, these designations can be used herein as a convenient means of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements can be employed, or that the first element must precede the second element in some manner.

Additionally, a person having ordinary skill in the art would understand that information and signals can be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits and symbols, for example, which may be referenced in the above description can be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

A person of ordinary skill in the art would further appreciate that any of the various illustrative logical blocks, modules, processors, means, circuits, methods and functions described in connection with the aspects disclosed herein can be implemented by electronic hardware (e.g., a digital implementation, an analog implementation, or a combination of the two), firmware, various forms of program or design code incorporating instructions (which can be referred to herein, for convenience, as "software" or a "software module), or any combination of these techniques. To clearly illustrate this interchangeability of hardware, firmware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware, firmware or software, or a combination of these techniques, depends upon the particular application and design constraints imposed on the overall system. Skilled artisans can implement the described functionality in various ways for each particular application, but such implementation decisions do not cause a departure from the scope of the present disclosure.

Furthermore, a person of ordinary skill in the art would understand that various illustrative logical blocks, modules, devices, components and circuits described herein can be implemented within or performed by an integrated circuit (IC) that can include a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, or any combination thereof. The logical blocks, modules, and circuits can further include antennas and/or transceivers to communicate with various components within the network or within the device. A general purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, or state machine. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other suitable configuration to perform the functions described herein.

If implemented in software, the functions can be stored as one or more instructions or code on a computer-readable medium. Thus, the steps of a method or algorithm disclosed herein can be implemented as software stored on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program or code from one place to another. A storage media can be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer.

In this document, the term "module" as used herein, refers to software, firmware, hardware, and any combination of these elements for performing the associated functions described herein. Additionally, for purpose of discussion, the various modules are described as discrete modules; however, as would be apparent to one of ordinary skill in the art, two or more modules may be combined to form a single module that performs the associated functions according embodiments of the present solution.

Additionally, memory or other storage, as well as communication components, may be employed in embodiments of the present solution. It will be appreciated that, for clarity purposes, the above description has described embodiments of the present solution with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processing logic elements or domains may be used without detracting from the present solution. For example, functionality illustrated to be performed by separate processing logic elements, or controllers, may be performed by the same processing logic element, or controller. Hence, references to specific functional units are only references to a suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

Various modifications to the embodiments described in this disclosure will be readily apparent to those skilled in the art, and the general principles defined herein can be applied to other embodiments without departing from the scope of this disclosure. Thus, the disclosure is not intended to be limited to the embodiments shown herein, but is to be accorded the widest scope consistent with the novel features and principles disclosed herein, as recited in the claims below.

CLAIMS

What is claimed is:

1. A wireless communication method, comprising:

receiving, by a wireless communication device, a first message including a time sync status threshold value;

receiving, by the wireless communication device, a second message including a time status value; and

determining, by the wireless communication device, whether to switch itself to a connection state based on the time status value and the time sync status threshold value.

2. The wireless communication method of claim 1, further comprising:

receiving, by the wireless communication device from an Access & Mobility Management Function (AMF) or a wireless communication node, the first message; and

receiving, by the wireless communication device from the wireless communication node, the second message through broadcast.

3. The wireless communication method of claim 2, wherein the AMF is configured to create the time sync status threshold value.

4. The wireless communication method of claim 2, wherein the first message is a Non-Access Stratum (NAS) message sent directly from the AMF.

5. The wireless communication method of claim 2, wherein the first message is a Radio Resource Control (RRC) message sent from the wireless communication node.

6. The wireless communication method of claim 2, wherein the second message is a new Information Element of a System Information Block (SIB) or an existing Information Element of ReferenceTimeInfo.

7. The wireless communication method of claim 2, wherein a Time Sensitive Communication Synchronization Function (TSCTSF) or a Time Sensitive Networking-

Adaptation Function (TSN-AF) is configured to create the time sync status threshold value.

8. The wireless communication method of claim 7, wherein the TSCTSN or TSN AF is configured to send the time sync status threshold value to the AMF.

9. The wireless communication method of claim 2, wherein the wireless communication node is configured to create the time sync status threshold value.

10. The wireless communication method of claim 9, wherein the wireless communication node is configured to send the time sync status threshold value to the AMF.

11. A wireless communication method, comprising:

sending, by a network entity to a wireless communication device, a message including a time sync status threshold value;

wherein the wireless communication device is configured to determine whether to switch itself to a connection state based on the time sync status threshold value and a received time status value.

12. The wireless communication method of claim 11, wherein the network entity is an Access & Mobility Management Function (AMF) or a wireless communication node, and wherein the time status value is received from the wireless communication node through broadcast.

13. The wireless communication method of claim 12, wherein the time sync status threshold value is created by one of: the AMF, the wireless communication node, a Time Sensitive Communication Synchronization Function (TSCTSF), or a Time Sensitive Networking-Adaptation Function (TSN-AF).

14. The wireless communication method of claim 12 or 13, wherein the AMF receives the time sync status threshold value from Time Sensitive Communication Synchronization Function (TSCTSF), a Time Sensitive Networking-Adaptation Function (TSN-AF), or the wireless communication node.

15. The wireless communication method of claim 11, wherein the wireless communication node is a NG-RAN.

16. A wireless communications apparatus comprising a processor and a memory, wherein the processor is configured to read code from the memory and implement a method recited in any of claims 1 to 15.

17. A computer program product comprising a computer-readable program medium code stored thereupon, the code, when executed by a processor, causing the processor to implement a method recited in any of claims 1 to 15.

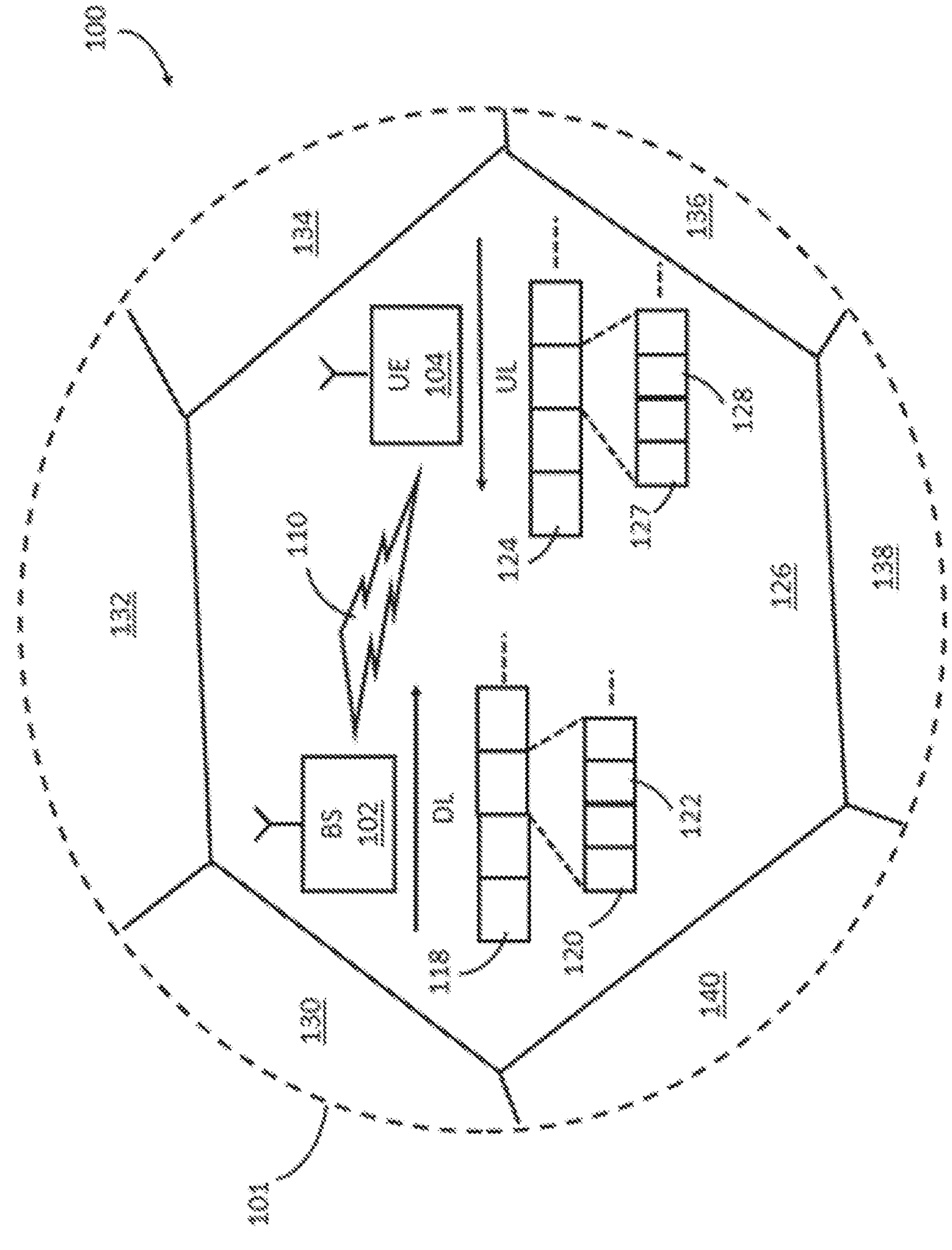
100
101
BS
102
UE
104
DL
UL
110
118
120
122
124
126
127
128
130
132
134
136
138
140

FIG. 1

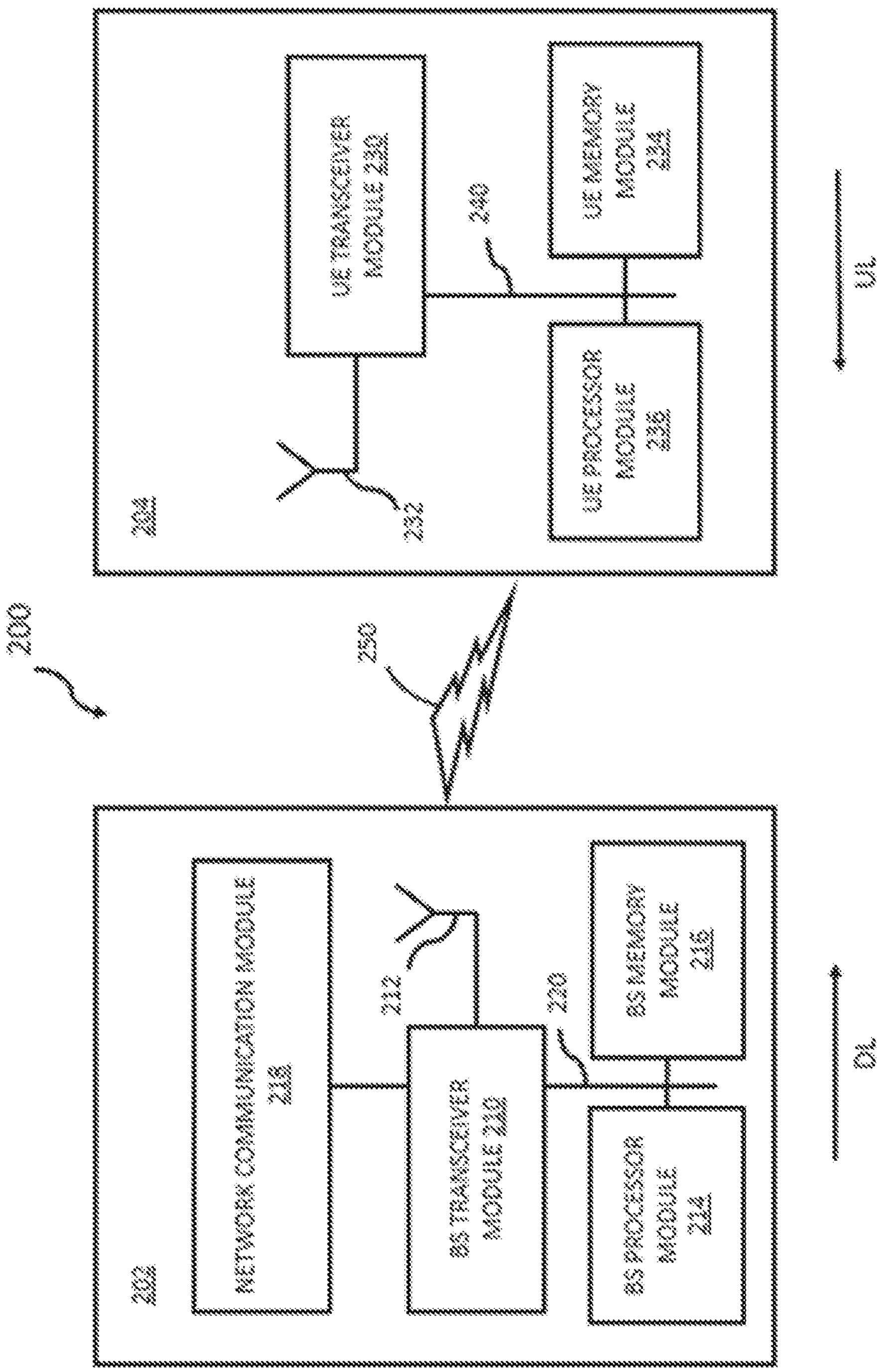
200
250
204
232
UE TRANSCEIVER MODULE 230
240
UE MEMORY MODULE 234
UE PROCESSOR MODULE 236
UL
202
NETWORK COMMUNICATION MODULE 218
212
BS TRANSCEIVER MODULE 210
220
BS MEMORY MODULE 216
BS PROCESSOR MODULE 214
DL

FIG. 2

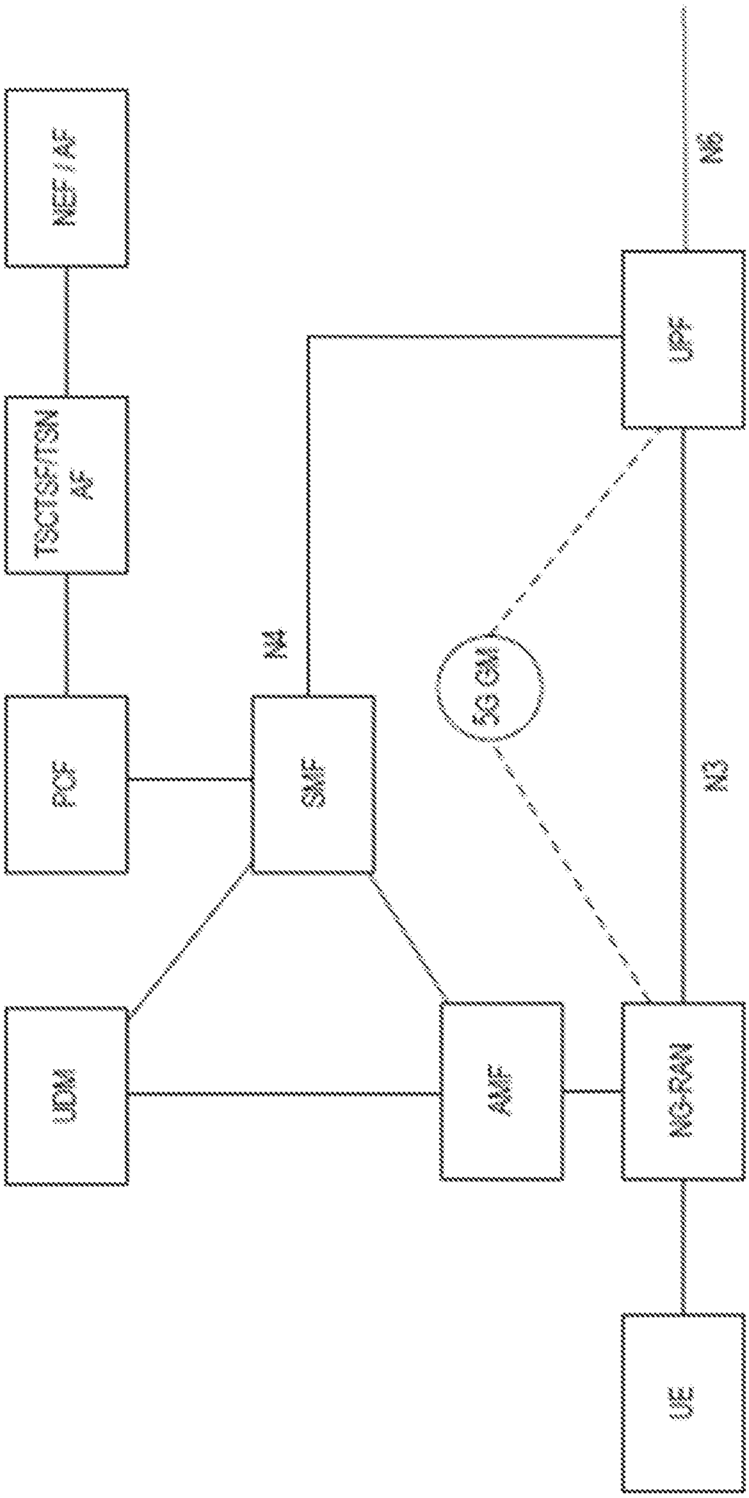

FIG. 3

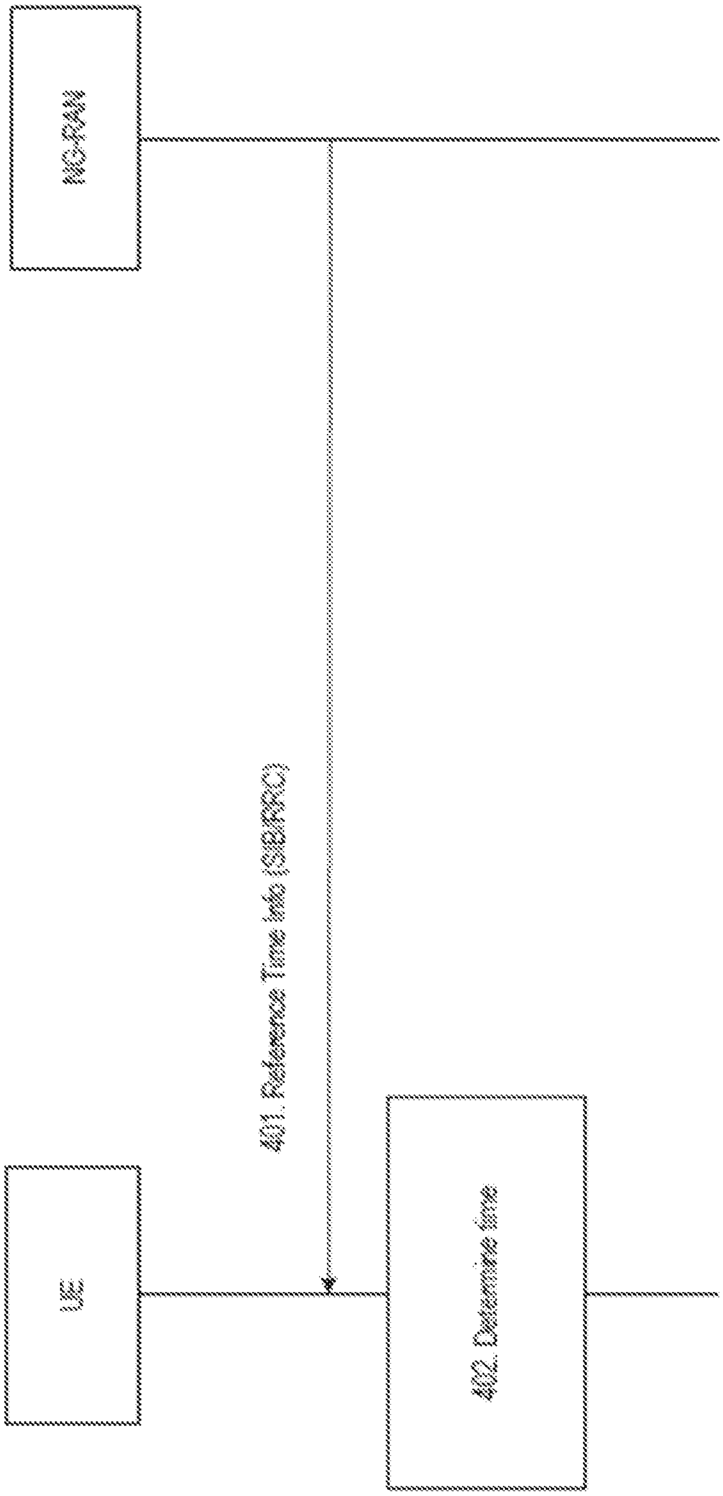

FIG. 4

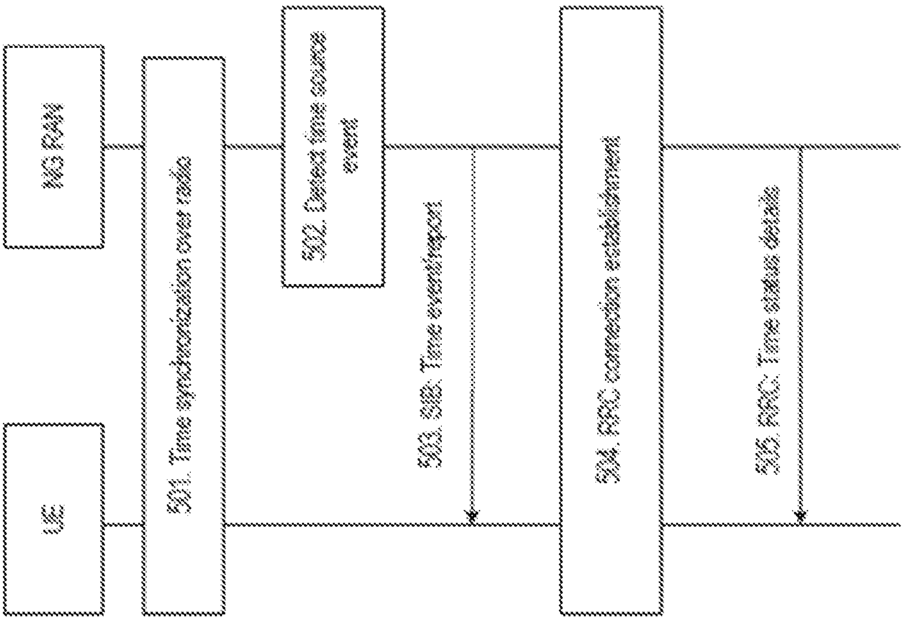
UE
NG RAN
501. Time synchronization over radio
502. Detect time source event
503. SIB: Time event/report
504. RRC connection establishment
505. RRC: Time status details

FIG. 5

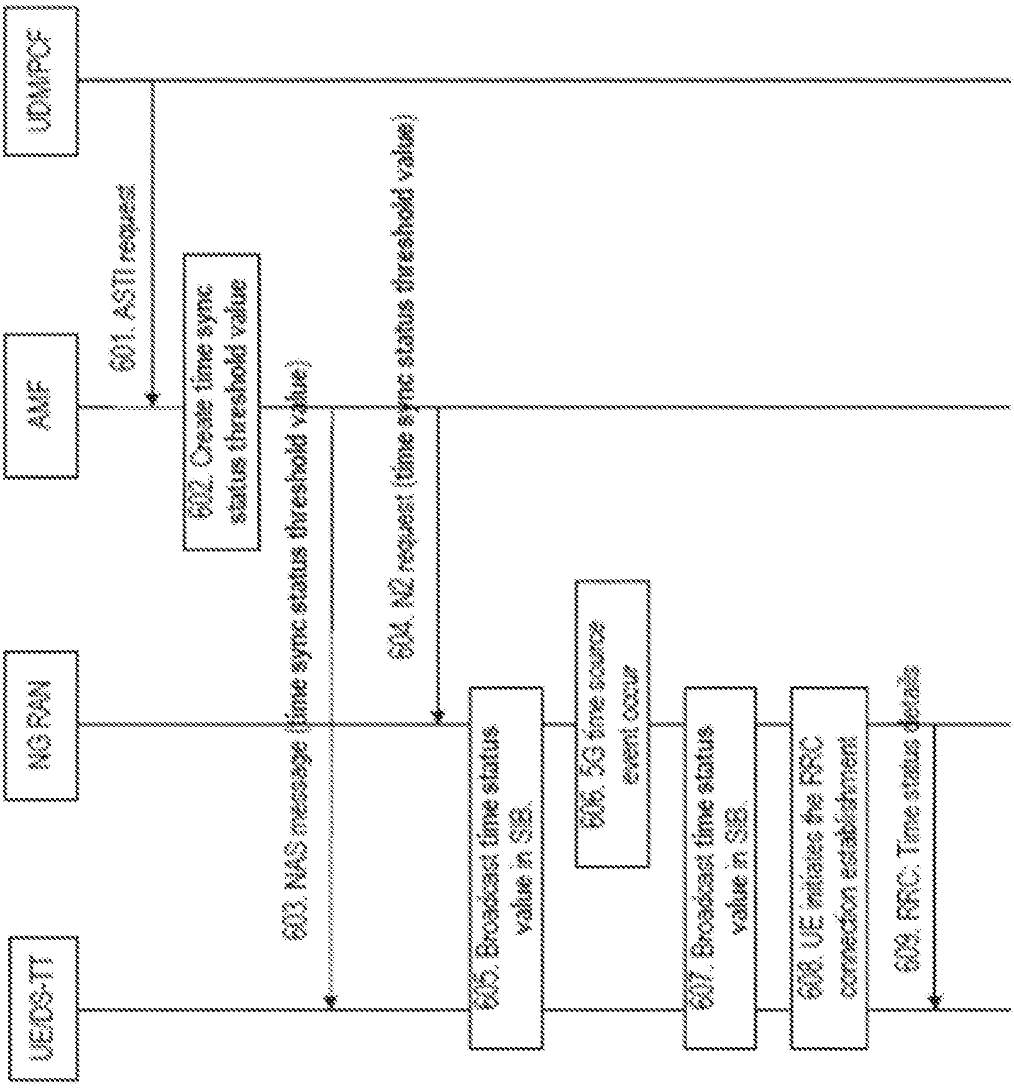
UE/DS-TT
NG RAN
AMF
UDM/PCF
601. ASTI request
602. Create time sync status threshold value
603. NAS message (time sync status threshold value)
604. N2 request (time sync status threshold value)
605. Broadcast time status value in SIB.
606. 5G time source event occur
607. Broadcast time status value in SIB.
608. UE initiates the RRC connection establishment
609. RRC. Time status details

FIG. 6

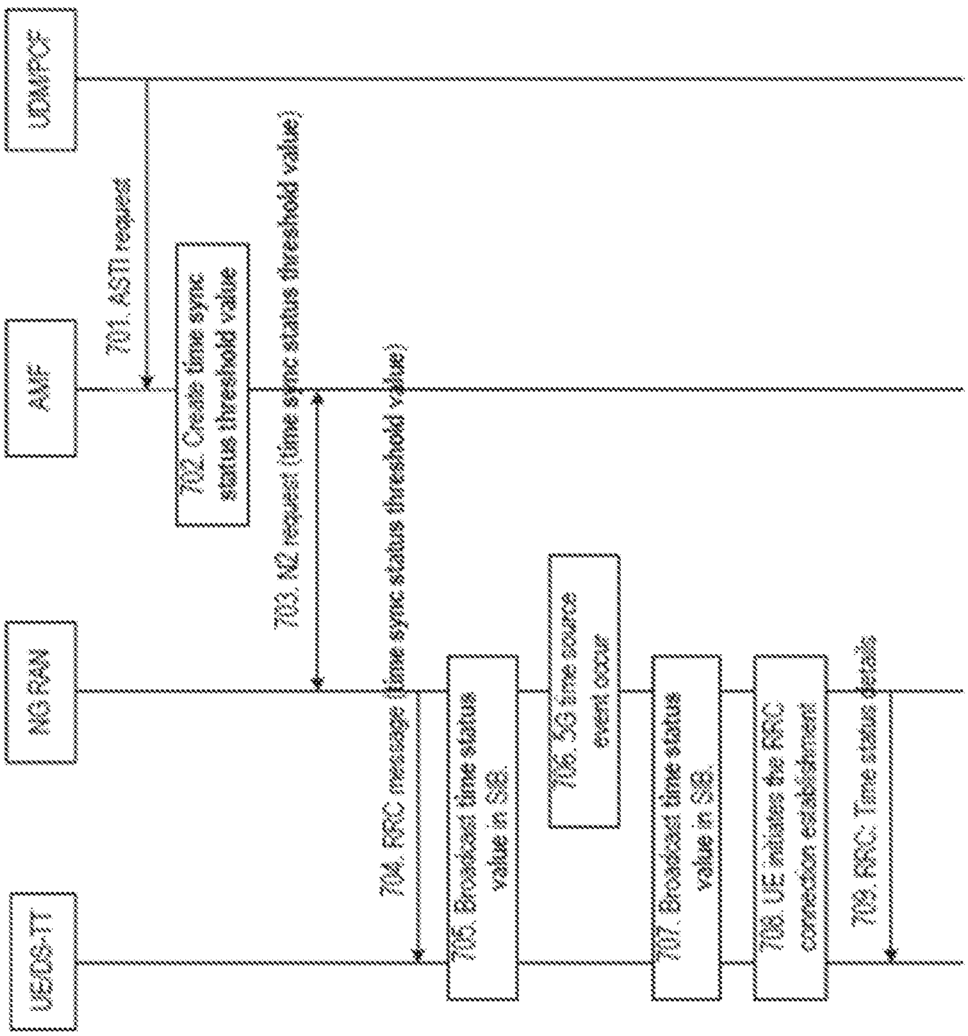
UE/DS-TT
NG RAN
AMF
UDM/PCF
701. ASTI request
702. Create time sync status threshold value
703. N2 request (time sync status threshold value)
704. RRC message (time sync status threshold value)
705. Broadcast time status value in SIB.
706. 5G time source event occur
707. Broadcast time status value in SIB.
708. UE initiates the RRC connection establishment
709. RRC: Time status details

FIG. 7

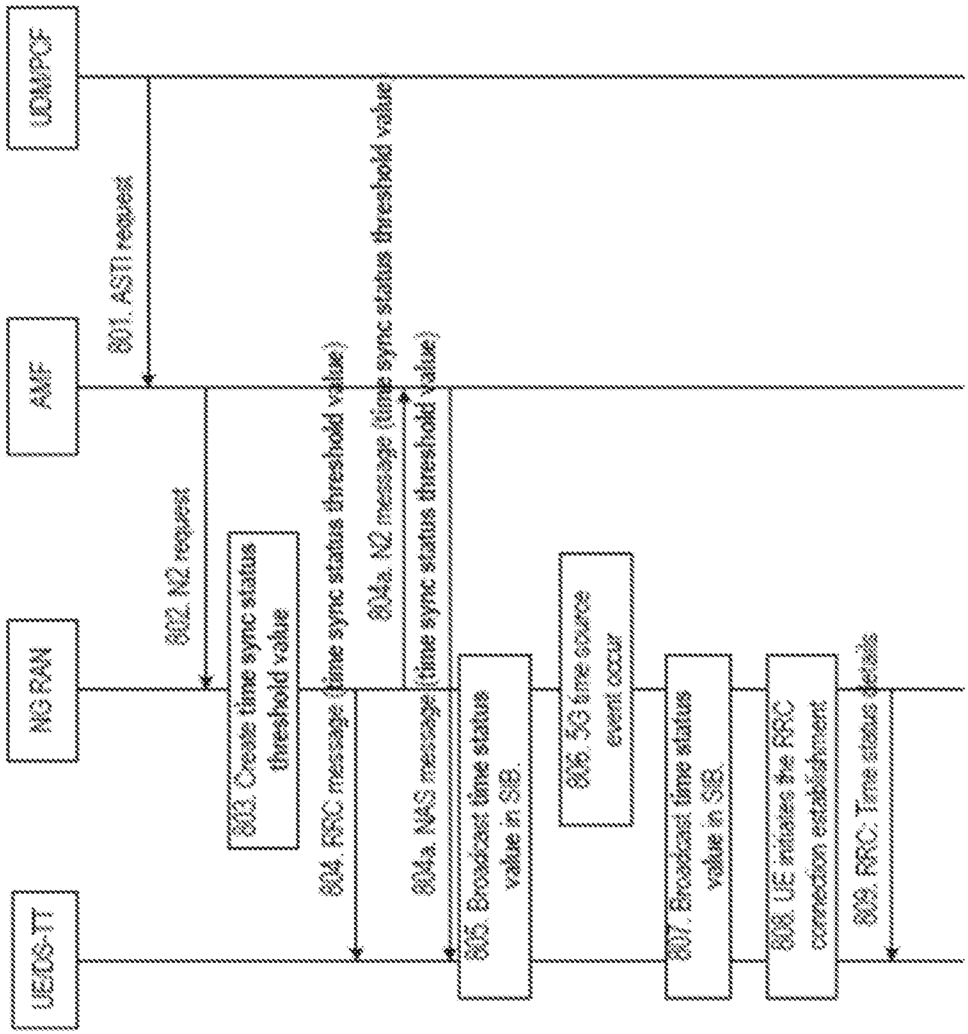
UE/DS-TT
NG RAN
AMF
UDM/PCF
801. ASTI request
802. N2 request
803. Create time sync status threshold value
804. RRC message (time sync status threshold value)
804a. N2 message (time sync status threshold value)
804a. NAS message (time sync status threshold value)
805. Broadcast time status value in SIB.
806. 5G time source event occur
807. Broadcast time status value in SIB.
808. UE initiates the RRC connection establishment
809. RRC: Time status details

FIG. 8

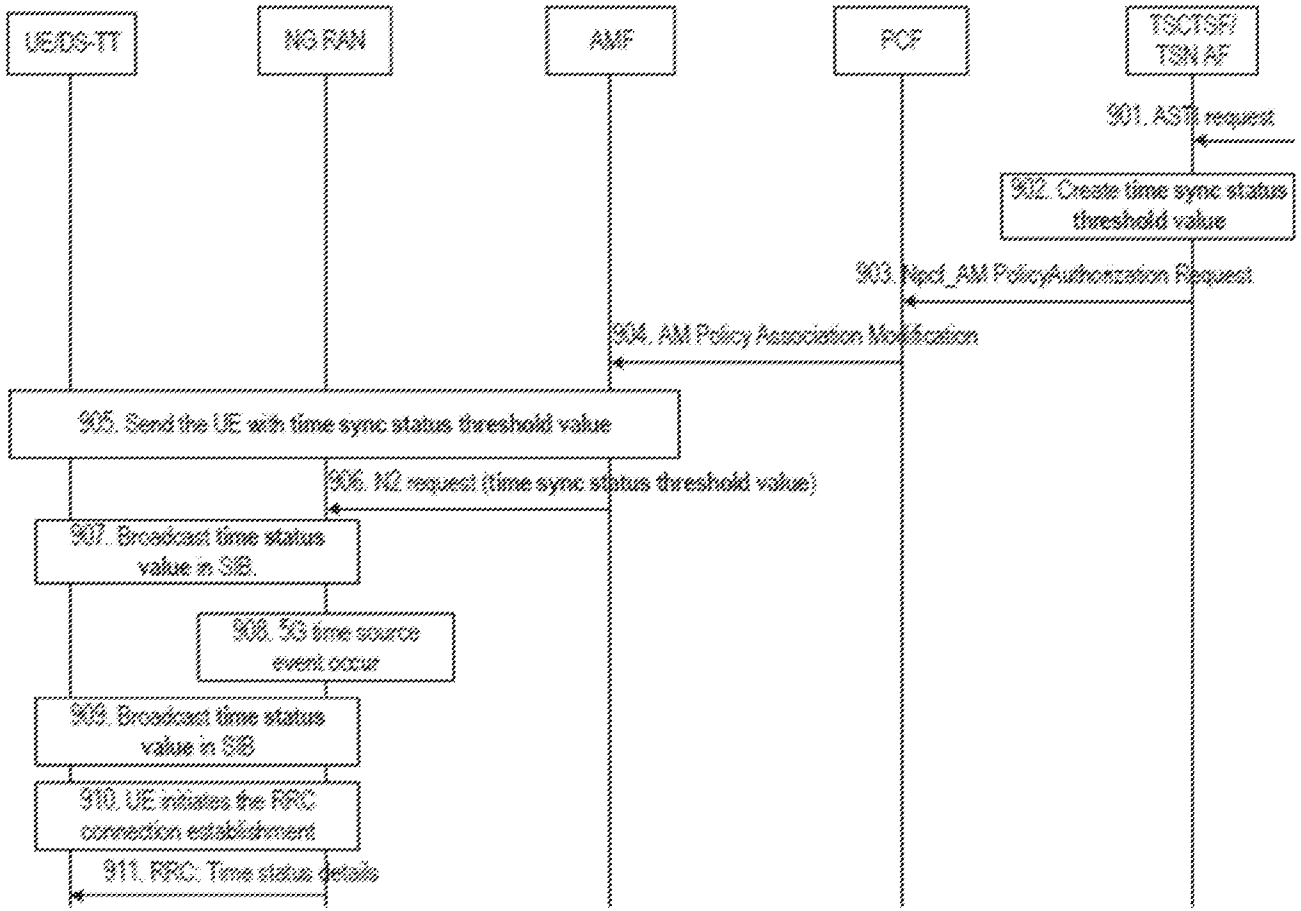
UE/DS-TT
NG RAN
AMF
PCF
TSCTSF/
TSN AF
901. ASTI request
902. Create time sync status
threshold value
903. Npcf_AM PolicyAuthorization Request
904. AM Policy Association Modification
905. Send the UE with time sync status threshold value
906. N2 request (time sync status threshold value)
907. Broadcast time status
value in SIB.
908. 5G time source
event occur
909. Broadcast time status
value in SIB
910. UE initiates the RRC
connection establishment
911. RRC: Time status details

FIG. 9

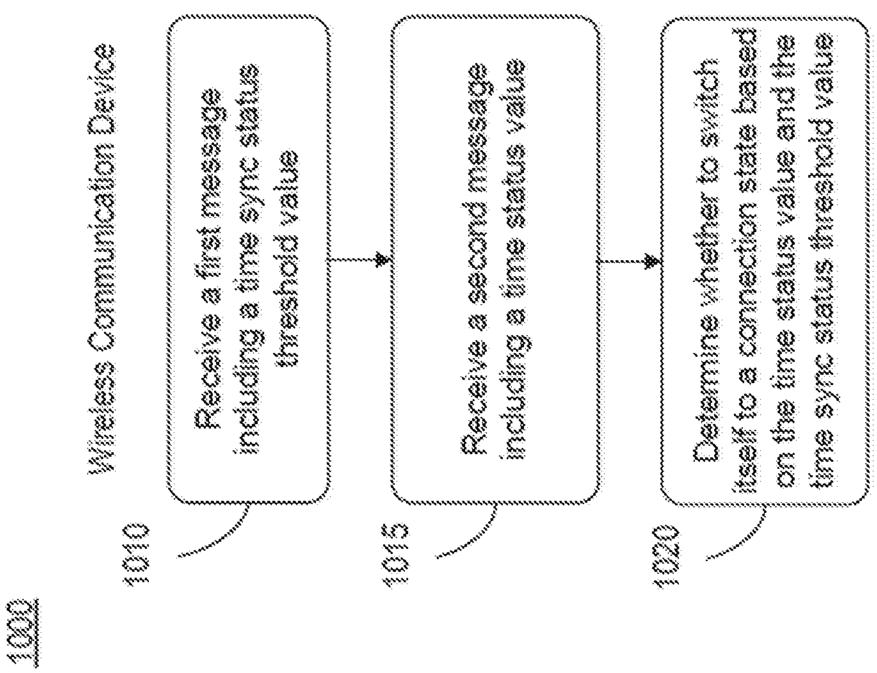
1000
Wireless Communication Device
1010
Receive a first message including a time sync status threshold value
1015
Receive a second message including a time status value
1020
Determine whether to switch itself to a connection state based on the time status value and the time sync status threshold value

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/070284

A. CLASSIFICATION OF SUBJECT MATTER

H04L47/00(2022.01)i; H04W 56/00(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H04W H04B H04Q H04L

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

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

3GPP,CNTXT,DWPI,ENTXT,WPABS: communication, time synchronization status, time status, time synchronization error budget, RRC, connection, inactive, active, idle, NAS, TSCTSF, AMF

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	3GPP. "Study on timing resiliency and TSC and URLLC enhancements (Release 18)" *3GPP TR 23.700-25 V18.0.0,* 21 December 2022 (2022-12-21), section 6.1	1-17
A	CN 102948225 A (MOTOROLA MOBILITY INC.) 27 February 2013 (2013-02-27) the whole document	1-17
A	CN 113438143 A (CHINESE AERONAUTICAL RADIO ELECTRONICS RESEARCH INSTITUTE) 24 September 2021 (2021-09-24) the whole document	1-17
A	HUAWEI et al. "Discussion on Time Synchronization Status notification towards UE(s)" *3GPP TSG-RAN WG2 Meeting #120 R2-2211559,* 18 November 2022 (2022-11-18), the whole document	1-17
A	NOKIA et al. "Discussion on SA2 LS on Time Synchronization Status notification towards UE(s)" *3GPP TSG-RAN WG2 Meeting #120 R2-2211777,* 14 November 2022 (2022-11-14), the whole document	1-17

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "D" document cited by the applicant in the international application
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 September 2023	**11 September 2023**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**GUO,Jing** Telephone No. **(+86) 010-53961671**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ZTE CORPORATION et al. "Consideration on Time Synchronization Status notification towards UE(s)" *3GPP TSG-RAN WG2 Meeting#120 R2-2211994,* 18 November 2022 (2022-11-18), the whole document	1-17
A	US 2021243797 A1 (ALTIOSTAR NETWORKS INC.) 05 August 2021 (2021-08-05) the whole document	1-17

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/070284

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	102948225	A	27 February 2013	US	2013301504	A1	14 November 2013
				US	2011319064	A1	29 December 2011
				KR	20130031853	A	29 March 2013
				WO	2011162934	A1	29 December 2011
CN	113438143	A	24 September 2021	None			
US	2021243797	A1	05 August 2021	EP	4101195	A1	14 December 2022
				WO	2021158665	A1	12 August 2021
				US	2022287078	A1	08 September 2022
				JP	2023514551	A	06 April 2023