(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 August 2020 (27.08.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/171802 A1

(51) International Patent Classification:
H04J 3/06 (2006.01) *H04W 88/10* (2009.01)

(21) International Application Number:
PCT/US2019/018644

(22) International Filing Date:
19 February 2019 (19.02.2019)

(25) Filing Language: English

(26) Publication Language: English

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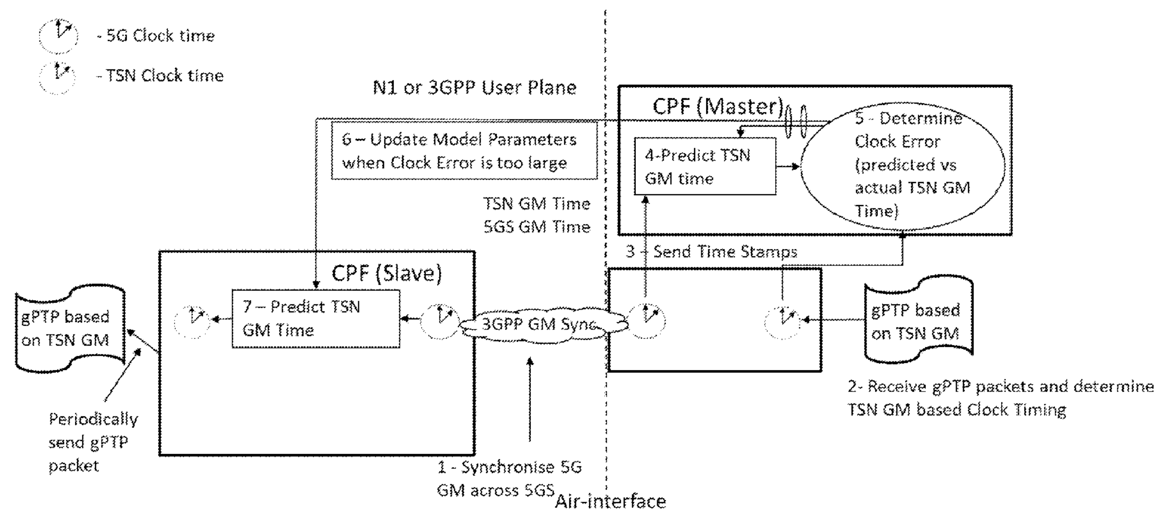
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: SYNCHRONIZATION FOR 5GS TIME SENSITIVE COMMUNICATIONS (TSC) USING MACHINE LEARNING

Figure 6



(57) Abstract: There is provided an apparatus, said apparatus comprising at least one processor and at least one memory including a computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the apparatus at least to: determine an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receive first network timing domain clock information at the first clock prediction function, determine, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain and, if so, provide the second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain.

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UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SYNCHRONIZATION FOR 5GS TIME SENSITIVE COMMUNICATIONS (TSC) USING MACHINE LEARNING

Field

[001] The present application relates to a method, apparatus, system and computer program and in particular but not exclusively to time synchronization in a 5GS-time sensitive networking (TSN) network using machine learning.

Background

[002] A communication system can be seen as a facility that enables communication sessions between two or more entities such as user terminals, base stations and/or other nodes by providing carriers between the various entities involved in the communications path. A communication system can be provided for example by means of a communication network and one or more compatible communication devices (also referred to as station or user equipment) and/or application servers. The communication sessions may comprise, for example, communication of data for carrying communications such as voice, video, electronic mail (email), text message, multimedia, content data, time-sensitive network (TSN) flows and/or data in an industrial application such as critical system messages between an actuator and a controller, critical sensor data (such as measurements, video feed etc.) towards a control system and so on. Non-limiting examples of services provided comprise two-way or multi-way calls, data communication or multimedia services and access to a data network system, such as the Internet.

[003] In a wireless communication system at least a part of a communication session, for example, between at least two stations or between at least one station and at least one application server (e.g. for video), occurs over a wireless link. Examples of wireless systems comprise public land mobile networks (PLMN) operating based on 3GPP radio standards such as E-UTRA, New Radio, satellite based communication systems and different wireless local networks, for example wireless local area networks (WLAN). The wireless systems can typically be divided into cells, and are therefore often referred to as cellular systems.

[004] A user can access the communication system by means of an appropriate communication device or terminal. A communication device of a user may be referred to as user equipment (UE) or user device. A communication device is provided with an appropriate signal receiving and transmitting apparatus for enabling communications, for example enabling access to a communication network or communications directly with other users. The communication device may access one or more carriers provided by the network, for example a base station of a cell, and transmit and/or receive communications on the one or more carriers.

[005] The communication system and associated devices typically operate in accordance with a given standard or specification which sets out what the various entities associated with the system are permitted to do and how that should be achieved. Communication protocols and/or parameters which shall be used for the connection are also typically defined. One example of a communications system is UTRAN (3G radio). Other examples of communication systems are the long-term evolution (LTE) of the Universal Mobile Telecommunications System (UMTS) based on the E-UTRAN radio-access technology, and so-called 5G system (5GS) including the 5G or next generation core (NGC) and the 5G Access network based on the New Radio (NR) radio-access technology. 5GS including NR are being standardized by the 3rd Generation Partnership Project (3GPP).

Summary

[006] In a first aspect there is provided an apparatus comprising: at least one processor and at least one memory including a computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the apparatus at least to:

[007] determine an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receive first network timing domain clock information at the first clock prediction function, determine, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain and, if so, provide the second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain.

[008] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[009] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[010] The first network timing domain clock information may comprise a first network timing domain clock time and the apparatus may be further configured to determine if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

[011] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[012] The apparatus may be further configured to cause the apparatus at least to provide the updated parameters using control signalling.

[013] The apparatus may be further configured to cause the apparatus at least to provide the updated parameters in a user plane packet.

[014] The apparatus may be further configured to cause the apparatus at least to receive the first network timing domain clock information from a network entity having an association with the first network timing domain.

[015] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[016] In a second aspect there is provided an apparatus comprising: at least one processor and at least one memory including a computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the apparatus at least to: receive, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[017] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[018] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[019] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[020] The apparatus may be further configured to receive the updated parameters using control signalling.

[021] The apparatus may be further configured to receive the updated parameters in a user plane packet.

[022] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[023] In a third aspect there is provided a method comprising determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receiving first network timing domain clock information at the first clock prediction function, determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain and, if so, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

[024] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[025] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[026] The first network timing domain clock information may comprise a first network timing domain clock time and determining whether to provide the second clock prediction function with updated parameters may comprise determining if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

[027] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[028] The method may comprise providing the updated parameters using control signalling.

[029] The method may comprise providing the updated parameters in a user plane packet.

[030] The method may comprise receiving the first network timing domain clock information from a network entity having an association with the first network timing domain.

[031] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[032] In a fourth aspect there is provided a method comprising receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[033] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[034] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[035] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[036] The method may comprise receiving the updated parameters using control signalling.

[037] The method may comprise receiving the updated parameters in a user plane packet.

[038] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[039] In a fifth aspect there is provided an apparatus comprising means for determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receiving first network timing domain clock information at the first clock prediction function, determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain and, if so, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

[040] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[041] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprises a new radio network.

[042] The first network timing domain clock information may comprise a first network timing domain clock time and means for determining whether to provide the second clock prediction function with updated parameters may comprise means for determining if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

[043] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[044] The apparatus may comprise means for providing the updated parameters using control signalling.

[045] The apparatus may comprise means for providing the updated parameters in a user plane packet.

[046] The apparatus may comprise means for receiving the first network timing domain clock information from a network entity having an association with the first network timing domain.

[047] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[048] In a sixth aspect there is provided an apparatus comprising means for receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[049] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[050] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[051] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[052] The apparatus may comprise means for receiving the updated parameters using control signalling.

[053] The apparatus may comprise means for receiving the updated parameters in a user plane packet.

[054] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[055] In a seventh aspect there is provided a computer readable medium comprising program instructions for causing an apparatus to perform at least the following: determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receiving first network timing domain clock information at the first clock prediction function, determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain and, if so, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

[056] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[057] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprises a new radio network.

[058] The first network timing domain clock information may comprise a first network timing domain clock time and the apparatus may be caused to perform determining if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

[059] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[060] The apparatus may be caused to perform providing the updated parameters using control signalling.

[061] The apparatus may be caused to perform providing the updated parameters in a user plane packet.

[062] The apparatus may be caused to perform receiving the first network timing domain clock information from a network entity having an association with the first network timing domain.

[063] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[064] In an eighth aspect there is provided a computer readable medium comprising program instructions for causing an apparatus to perform at least the following: receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[065] The first clock prediction function may be a master clock prediction function. The second clock prediction function may be a slave clock prediction function.

[066] The first network timing domain may comprise a time sensitive communications network. The second network timing domain may comprise a new radio network.

[067] The first clock prediction function may be associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

[068] The apparatus may be caused to perform receiving the updated parameters using control signalling.

[069] The apparatus may be caused to perform receiving the updated parameters in a user plane packet.

[070] The updated parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[071] In a ninth aspect there is provided a non-transitory computer readable medium comprising program instructions for causing an apparatus to perform at least the method according to the third or fourth aspect.

[072] In the above, many different embodiments have been described. It should be appreciated that further embodiments may be provided by the combination of any two or more of the embodiments described above.

Description of Figures

[073] Embodiments will now be described, by way of example only, with reference to the accompanying Figures in which:

[074] Figure 1 shows a schematic diagram of an example communication system comprising a base station and a plurality of communication devices;

[075] Figure 2 shows a schematic diagram of an example mobile communication device;

[076] Figure 3 shows a schematic diagram of an example control apparatus;

[077] Figure 4 shows a flowchart of a method according to an example embodiment;

[078] Figure 5 shows a flowchart of a method according to an example embodiment;

[079] Figure 6 shows a schematic diagram of a TSN Clock synchronisation across the 5GS according to an example embodiment;

[080] Figure 7 shows a schematic diagram of a TSN Clock synchronisation across the 5GS according to an example embodiment; and

[081] Figure 8 shows a schematic diagram of a TSN Clock synchronisation across the 5GS according to an example embodiment.

Detailed description

[082] Before explaining in detail the examples, certain general principles of a wireless communication system and mobile communication devices are briefly explained with reference to Figures 1 to 3 to assist in understanding the technology underlying the described examples.

[083] In a wireless communication system 100, such as that shown in figure 1, mobile communication devices or user equipment (UE) 102, 104, 105 are provided wireless access via at least one base station (e.g. next generation NB, gNB) or similar wireless transmitting and/or receiving node or point. Base stations may be controlled or assisted by at least one appropriate controller apparatus, so as to enable operation thereof and management of mobile communication devices in communication with the base stations. The controller apparatus may be located in a radio access network (e.g. wireless communication system 100) or in a core network (CN) (not shown) and may be implemented as one central apparatus or its functionality may be distributed over several apparatuses. The controller apparatus may be part of the base station and/or provided by a separate entity such as a Radio Network Controller. In Figure 1 control apparatus 108 and 109 are shown to control the respective macro level base stations 106 and 107. The control apparatus of a base station can be interconnected with other control entities. The control apparatus is typically provided with memory capacity and at least one data processor. The control apparatus and functions may be distributed between a plurality of control units. In some systems, the control apparatus may additionally or alternatively be provided in a radio network controller.

[084] In Figure 1 base stations 106 and 107 are shown as connected to a wider communications network 113 via gateway 112. A further gateway function may be provided to connect to another network.

[085] The smaller base stations 116, 118 and 120 may also be connected to the network 113, for example by a separate gateway function and/or via the controllers of the macro level stations. The base stations 116, 118 and 120 may be pico or femto level base stations or the like. In the example, stations 116 and 118 are connected via a gateway 111 whilst station 120 connects via the controller apparatus 108. In some embodiments, the smaller stations may not be provided. Smaller base stations 116, 118 and 120 may be part of a second network, for example WLAN and may be WLAN APs.

[086] The communication devices 102, 104, 105 may access the communication system based on various access techniques, such as code division multiple access (CDMA), or wideband CDMA (WCDMA). Other non-limiting examples comprise time division multiple access (TDMA), frequency division multiple access (FDMA) and various schemes thereof such as the interleaved frequency division multiple access (IFDMA), single carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access (OFDMA), space division multiple access (SDMA) and so on.

[087] An example of wireless communication systems are architectures standardized by the 3rd Generation Partnership Project (3GPP). One3GPP based development is often referred to as the long term evolution (LTE) of the Universal Mobile Telecommunications System (UMTS) radio-access technology. The various development stages of the 3GPP specifications are referred to as releases. More recent developments of the LTE are often referred to as LTE Advanced (LTE-A). The LTE (LTE-A) employs a radio mobile architecture known as the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and a core network known as the Evolved Packet Core (EPC). Base stations of such systems are known as evolved or enhanced Node Bs (eNBs) and provide E-UTRAN features such as user plane Packet Data Convergence/Radio Link Control/Medium Access Control/Physical layer protocol (PDCP/RLC/MAC/PHY) and control plane Radio Resource Control (RRC) protocol terminations towards the communication devices. Other examples of radio access system comprise those provided by base stations of systems that are based on technologies such as wireless local area network (WLAN) and/or WiMax (Worldwide Interoperability for

Microwave Access). A base station can provide coverage for an entire cell or similar radio service area. Core network elements include Mobility Management Entity (MME), Serving Gateway (S-GW) and Packet Gateway (P-GW).

[088] An example of a suitable communications system is the 5G or NR concept. Network architecture in NR may be similar to that of LTE-advanced. Base stations of NR systems may be known as next generation Node Bs (gNBs). Changes to the network architecture may depend on the need to support various radio technologies and finer QoS support, and some on-demand requirements for e.g. QoS levels to support QoE of user point of view. New functions are defined in the 5G system architecture, including an Access Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), among other network functions in the Next Generation Core (NGC). The 5G System supports new capabilities, including network slicing to better tailor networks to application requirements and provide virtual networks for tenants. It also uses a services-based architecture the provides greater flexibility for introducing new services and features compared to the EPC which relied on fixed, peer-peer reference points. NR may use multiple input – multiple output (MIMO) antennas, many more base stations or nodes than the LTE (a so-called small cell concept), including macro sites operating in co-operation with smaller stations and perhaps also employing a variety of radio technologies for better coverage and enhanced data rates. MR may also support lower latency for air-interface transmission due to revisions in physical and MAC layer protocols.

[089] Future networks may utilise network functions virtualization (NFV) which is a network architecture concept that proposes virtualizing network node functions into “building blocks” or entities that may be operationally connected or linked together to provide services. A virtualized network function (VNF) may comprise one or more virtual machines running computer program codes using standard or general type servers instead of customized hardware. Cloud computing or data storage may also be utilized. In radio communications this may mean node operations to be carried out, by a Centralized Unit (CU) at least partly, in a server, host or node operationally coupled to Distributed Unit (DU), which may connect to a remote radio head (RRH). It is also possible that node operations will be distributed among a plurality of servers, nodes or hosts. It should also be understood that the distribution of labour between core network operations and base station operations may differ from that of the LTE or even be non-existent.

[090] An example 5G core network (CN) comprises functional entities. The CN is connected to a UE via the radio access network (RAN). An UPF (User Plane Function) which may be a PSA (PDU Session Anchor) providing an anchor point for user IP, Ethernet or Unstructured user data sessions. The UPF may be responsible for forwarding frames back and forth between the DN (data network) and the gNBs through tunnels established over transport networks towards the UE(s) that want to exchange traffic with the DN.

[091] The UPF is controlled by an SMF (Session Management Function) that receives policies from a PCF (Policy Control Function). The CN may also include an AMF (Access & Mobility Function) which terminates the control plane interface with the RAN and manages UE registrations and mobility.

[092] A possible mobile communication device will now be described in more detail with reference to Figure 2 showing a schematic, partially sectioned view of a communication device 200. Such a communication device is often referred to as user equipment (UE) or terminal. An appropriate mobile communication device may be provided by any device capable of sending and receiving radio signals. Non-limiting examples comprise a mobile station (MS) or mobile device such as a mobile phone or what is known as a 'smart phone', a computer provided with a wireless interface card or other wireless interface facility (e.g., USB dongle), personal data assistant (PDA) or a tablet provided with wireless communication capabilities, or any combinations of these or the like. A mobile communication device may provide, for example, communication of data for carrying communications such as voice, electronic mail (email), text message, multimedia and so on. Users may thus be offered and provided numerous services via their communication devices. Non-limiting examples of these services comprise two-way or multi-way calls, data communication or multimedia services or simply an access to a data communications network system, such as the Internet. Users may also be provided broadcast or multicast data. Non-limiting examples of the content comprise downloads, television and radio programs, videos, advertisements, various alerts and other information.

[093] In an industrial application a communication device may be a modem integrated into an industrial actuator (e.g. a robot arm) and/or a modem acting as an Ethernet-hub that will act as a connection point for one or several connected Ethernet devices (which connection may be wired or unwired).

[094] A mobile device is typically provided with at least one data processing entity 201, at least one memory 202 and other possible components 203 for use in software and hardware aided execution of tasks it is designed to perform, including control of access to and communications with access systems and other communication devices. The data processing, storage and other relevant control apparatus can be provided on an appropriate circuit board and/or in chipsets. This feature is denoted by reference 204. The user may control the operation of the mobile device by means of a suitable user interface such as key pad 205, voice commands, touch sensitive screen or pad, combinations thereof or the like. A display 208, a speaker and a microphone can be also provided. Furthermore, a mobile communication device may comprise appropriate connectors (either wired or wireless) to other devices and/or for connecting external accessories, for example hands-free equipment, thereto.

[095] The mobile device 200 may receive signals over an air or radio interface 207 via appropriate apparatus for receiving and may transmit signals via appropriate apparatus for transmitting radio signals. In Figure 2 transceiver apparatus is designated schematically by block 206. The transceiver apparatus 206 may be provided for example by means of a radio part and associated antenna arrangement. The antenna arrangement may be arranged internally or externally to the mobile device.

[096] Figure 3 shows an example embodiment of a control apparatus for a communication system, for example to be coupled to and/or for controlling a station of an access system, such as a RAN node, e.g. a base station, eNB or gNB, a relay node or a core network node such as an MME or S-GW or P-GW, or a core network function such as AMF/SMF, or a server or host. The method may be implanted in a single control apparatus or across more than one control apparatus. The control apparatus may be integrated with or external to a node or module of a core network or RAN. In some embodiments, base stations comprise a separate control apparatus unit or module. In other embodiments, the control apparatus can be another network element such as a radio network controller or a spectrum controller. In some embodiments, each base station may have such a control apparatus, such as a CU Control Plane (CU-CP) as well as a control apparatus being provided in a radio network controller. The control apparatus 300 can be arranged to provide control on communications in the service area of the system. The control apparatus 300 comprises at least one memory 301, at least one data processing unit 302, 303 and an input/output interface 304. Via the interface the control apparatus can be coupled to a receiver and a transmitter of the base station. The receiver and/or the transmitter may be implemented as a radio front end or a remote radio head.

[097] 5G Time Sensitive Communications (TSC) to support industrial verticals has been studied in 3GPP under the recently concluded Release 16 FS_Vertical and URLLC_5G study items. TSC related work is now moving to the phase in 3GPP where technical specifications are written. Industrial networks have unique requirements for low latency deterministic data transmission and high reliability. With deterministic data transmission, the data transmission characteristics are known, and end-points, such as an industrial controller can send bursts with low latency. Interrupted transmission may be tolerated only for a limited period known as the Survival Time. Periodic deterministic data transmission is an important sub-category of deterministic data transmission For periodic deterministic data, the traffic burst size, initial transmission time and periodicity are known. Provided that network relay elements are precisely synchronized, this allows for ultra-low latency network communication via careful coordination of transmission at each hop through the network.

[098] The following may be applicable in the tactile industrial network, also known as Industrial IoT (IIoT) or Industry 4.0 networks. Here, 3GPP technologies are applied, in addition to wired time sensitive networking (TSN) networks, in industrial environments.

[100] Time sensitive communication (TSC) provides industrial networks with deterministic delay to handle time sensitive traffic. Currently, wired links are assumed for connecting sensors and controllers of an industrial network. Moving from wired to wireless sensors and actuators may provide mobility, scalability (in terms of number of sensors or actuators) and/or low cost maintenance. To connect the wireless devices (e.g. sensors and actuators) to a TSC network, wireless transmission mechanisms such as the ones defined in 3GPP may be used.

[101] TSN is currently standardized as the mechanism for communication within wired industrial networks. IEEE has developed a suite of TSN specifications to allow synchronization of bridges to Grand Master (GM) clocks (IEEE1588, 802.1AS), link layer bridge discovery (802.1AB), provisioning of streams, including gate schedules along the path between TSN endpoints (802.1Qcc), frame replication for reliability (802.1CB) and other protocols to enable isochronous transmission to connect endpoints across Ethernet bridges. For configuration of TSC, the so-called fully centralized configuration model of IEEE TSN has been adopted as the main starting point in 3GPP. In summary, end-station requirements for transmissions are provided through a Central User Configuration (CUC) function to a Central Network Configuration (CNC) function that has discovered the synchronized bridged network topology and bridge latencies. The CNC then formulates gate schedules that are provisioned by the CNC at each synchronized bridge in a path between the end-station talker and listener. The gate schedule at each bridge specifies absolute times and periodicity for transmission of user plane frames.

[102] Using a 5GS as a bridge and as a self-contained end-to-end network has been proposed to support deterministic traffic, and these models are expected to be supported by 3GPP standards. A key enabler of deterministic communication in a network is synchronizing the network elements to a master clock. A common attribute for both the approaches described above is that clock synchronization is required among elements outside of the 5GS such as end-stations and/or wired network bridges, some of which may reside on the UE side of the 5GS, and some of which may reside on the UPF side. In addition, clock synchronization between these elements and the ingress/egress points in the 5GS is required. Synchronization of all the communication entities is a key requirement for TSN.

[103] Independent of 5G, the IEEE has developed a suite of TSN specifications that rely on synchronization of bridges to Grand Master (GM) clocks. Based on IEEE1588, 802.1AS uses generalized Precision Time Protocol (gPTP) frames to synchronize bridges and end stations to a TSN GM clock. Within each TSN timing Domain, gPTP frames containing TSN GM timing information are propagated to elements that require clock synchronization.

[104] In a network, there may be more than one TSN timing domain and a bridge may require clock synchronization to more than one domain. This clock synchronization may be needed in a TSN network so that at each bridge, gate schedules can specify absolute times for contention free, isochronous transmission of user plane frames. This enables very low latency communication for deterministic traffic between endpoints, supporting industrial applications such as real-time machine control.

[105] Independent of IEEE TSN, in 5G, the UE and RAN are synchronized using low layer structure on the Uu interface (though not absolute time). In the RAN, IEEE1588 may be used to propagate PTP packets, originating from a 5G GM, to synchronize both RAN nodes and transport layer nodes. In addition, in 3GPP Release 15 LTE, System Information Block (SIB)/RRC signaling was defined to send to the UE UTC time based on radio frames boundaries, and a similar mechanism has been defined for NR.

[106] Based on these capabilities, several proposals have been put forward in the 3GPP FS_Vertical study item (see TR23.734) to support clock synchronization between nodes on the UE and NGC side of the 5GS. Paraphrasing the TR, they include:

[107] Transport of 802.1AS messages over the 5G system to convey timing to the UE. In this case the gPTP packets are sent over the 5GS user plane. The UE may then forward the gPTP packets to downstream nodes. Due to asymmetry and jitter due to scheduling on the air interface, this option may not provide acceptable timing.

[108] An alternative proposal is to convey timing to the UE via 5G specific signaling, e.g. via 5G broadcast/5G unicast for timing of frame structure. In this option, the 5G RAN utilizes its fine-frame structure (e.g. below PHY symbol level) to convey timing to the UE. This is similar to the approach used in R15 LTE where a “TimeReferenceInfo”, which specifies a clock time associated with a reference System Frame Number (SFN) is sent by RRC signaling to the UE. The UE may then act as boundary master clocks towards connected TSN devices.

[109] This mechanism may work when there is only one GM (i.e. when the 5G GM is the TSN GM). However, scalability to support the 5G GM plus possibly multiple TSN GMs may be difficult as it affects RRC signaling, and new capabilities are required in the RAN to support this option. In addition, clock synchronization via SIB is only possible from the RAN to the UE, not from the UE to the RAN.

[110] An alternative proposal is to have only the network elements at the edges of the 5G system (the UE and the UPF) support the synchronization with the TSN Clock via IEEE 802.1AS. In addition, the 5GS is synchronized internally using the 5G GM, so the UE and UPF clocks are synchronized. The UPF puts a 5G GM time stamp in received TSN GM gPTP packets that convey the TSN GM timing. The 5G GM timing may be made available to the UE with signaling of time information related to absolute timing of radio frames (i.e. using SIB/RRC based methods described for R15 LTE). The timing information (gPTP messages, including the information on the incoming sync message timestamping) can be carried from the UPF to the UE as data packets (e.g payload). When the timing information arrives at the UE, the UE makes an adjustment based on the difference between time stamp of the UPF and of the UE. The time stamp of UPF and UE are based on the 5G internal system clock.

[111] In this solution, a constant stream of gPTP packets are sent from UPF to the UE in the user plane, which may make it impossible for the UE to transition to the idle state, even when scheduled Tx/Rx is not occurring or is not necessary, and when clock synchronisation is not necessary because of prior synchronization signaling. Note that a UE in idle state uses less battery power, and hence this issue may affect the viability of some use cases.

[112] Figure 4 shows a flowchart of a method according to an example embodiment.

[113] In a first step, S1, the method comprises determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters.

[114] In a second step, S2, the method comprises receiving first network timing domain clock information at the first clock prediction function.

[115] In a third step, S3, the method comprises determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for a clock of a first network timing domain based on the clock of the second network timing domain.

[116] If so, the method comprises in a fourth step, S4, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for a clock of a first network timing domain based on the clock of the second network timing domain.

[117] Figure 5 shows a flowchart of a method according to an example embodiment.

[118] In a first step, T1, the method comprises receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[119] The clock of the first network timing domain may be a TSN GM clock, residing in a TSN network. The clock of the second network timing domain may be a 5GS GM clock, residing in a 5GS.

[120] The first Clock Prediction Function (CPF) may be referred to as a Master CPF. The second CPF may be referred to as a slave CPF.

[121] The first network timing domain clock information may comprise a first network timing domain clock time. Determining whether to provide the second clock prediction function with updated parameters may comprises determining if the difference between the estimated clock time and the first network clock time is higher than a threshold (i.e. whether the estimated clock time is accurate within acceptable bounds).

[122] The method assumes that the second network timing domain is synchronized between the UE and RAN using the second network timing domain clock (e.g., 5G GM). 5G GM clock information may be sent to a UE in a manner similar to that used in R15 LTE (via RRC SIB or unicast signalling). Hence the UE, and RAN (gNB) are 5G GM time-aware. In this method, the first network clock (e.g., TSN GM) may be on either the UE or the UPF side of the 5GS. Note that the 5G GM and the TSN GM are represent example embodiments of the GMs that supply timing for the first and second network timing domains. In an alternative embodiment, the TSN GM may be the second network timing domain clock, and a 5GS GM may be a first network timing domain clock.

[123] The CPF is executed independently and asynchronously for Master and Slave 5GS Network Nodes (5GNN) that reside on opposite sides of Uu (the Air-interface). A CPF may reside in a 5GNN, or elsewhere, with the candidate locations depending on the type of 5GNN node. For example, the 5GNN may be the UE, RAN, SMF or UPF. Examples of 5GNN associated nodes are an xRAN Controller, an external network exposure function (NEF) connected function, or a UE based application.

[124] Both the first (slave) CPF and the second (master) CPF are aware of the clock of the second network timing domain, but only the first CPF directly receives first network timing domain clock information. The first network timing domain clock information may be received from a network entity having an association with the first network timing domain. The first network timing domain clock information may comprises a gPTP packet associated with a (external) TSN GM. The first network timing domain clock information may be received via 802.1AS/1588 or via connection to a 5G GM.

[125] In normal operation the second, or Slave, CPF may autonomously calculate a first network timing domain clock time (P_TSN GM Clock time) to be used for locally generated gPTP packets sent to downstream nodes (e.g., end-stations). Independently the first, or Master, CPF calculates an identical first network timing domain clock time (P_TSN GM Clock time) and determines whether it is accurate within acceptable bounds. Only when it is not accurate within acceptable bounds is signaling for Clock Correction required. Hence if the model is matched well to the clock characteristics, Clock Correction should be needed infrequently.

[126] When the first network timing domain clock information is received at a Master 5GNN, the 5GNN records both the received TSN GM time and the 5G GM time. The 5GNN sends the time information to its CPF (if separate from the receiving 5GNN). For example, a UPF 5GNN may send the information over N4 to an SMF that hosts the CPF. The Master CPF executes the same algorithm used in the Slave CPF to calculate the same P-TSN GM Clock time as the Slave CPF. If the P-TSN GM Clock time differs sufficiently from the TSN GM Clock time obtained from the gPTP packet, Clock Correction for the Slave CPF is triggered.

[127] Both CPFs calculate a predicted TSN GM Clock (P_TSN GM) from the 5G GM clock time, a common prediction model and identical model parameters. In the Slave CPF, the P_TSN GM Clock time is calculated periodically and used as the TSN GM Clock time in 802.1AS synchronization of downstream nodes (e.g., UE connected end-stations).

[128] The CPF algorithm in the first CPF and the second CPF may assume a model for prediction of a first network timing domain clock time from second network timing domain GM Clock time. The model is the same in the first CPF and the second CPF. The first CPF determines whether the model predicted first network timing domain clock time is within acceptable bounds of the actual first network timing domain clock time learned from the received first network clock timing domain information.

[129] The initial parameters and updated parameters are the model parameters. The model parameters may comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

[130] For example, the algorithm model may be a constant offset model. For example, the two clocks have a constant offset, that is P_TSN GMclock= 〖5GS〗 _ GMclock+offset, where the offset is learned in the first CPF by simply comparing the received first network clock time from the first network clock information with the second network clock time.

[131] The first CPF determines if the current difference between two clock times, adjusted for a previously learned offset, exceeds a threshold ϵ associated with TSC Clock synchronization required for end-station applications. If |TSN G 〖Mclock〗 _ - 〖5GS〗 _ GMclock-offset|> ϵ, then Clock Correction is triggered and offset is updated for the next iteration (which may occur when a subsequent gPTP packet is received) to: offset= TSN G 〖Mclock〗 _ - 〖5GS〗 _ GMclock. Note this model is useful when the 5G GM and TSN GM are mostly syntonized (have the same frequency but not the same clock time).

[132] Note that within the bounds of this solution is the option that the UPF or SMF Master simply calculates Offset= TSN G 〖Mclock〗 _ - 〖5GS〗 _ GMclock, for each TSN GM gPTP packet arrival at the UPF, and sends Offset to the UE as a “modeling parameter”, either with the gPTP packet or via 3GPP signaling. The UE Slave may then simply add the Offset to its 5G Clock to obtain the P_TSN Clock time for propagation via 802.1AS to connected devices. This option allows for a stateless CPF.

[133] An alternative mode is the constant Drift Model. The clocks of the first network timing domain and the second network timing domain are modelled to have a constant frequency offset, which means the clock times drift apart linearly, that is drift(t)=offset+ at, where “a” is the drift slope. Then if the time difference between the two clocks, adjusted for a previously learned drift slope, exceeds a threshold ϵ associated with TSC clock synchronization required for end-station applications, (|TSN G 〚Mclock〛 _ - 〚5GS〛 _ GMclock-drift(t)|> ϵ) then Clock Correction is triggered and “a” and “offset” are updated for the next iteration (for example, when a subsequent gPTP packet is received).

[134] Other models. e.g., machine learning models, using more complex model functions, linear prediction and machine learning may be applied. Generally, the more accurate the model, the less frequent Clock Correction needs to be triggered.

[135] Providing the second clock prediction function with updated parameters for use in determining an estimated clock time for a clock of a first network timing domain may be referred to as clock correction. Clock correction is the process of updating model parameters (such as Offset) in the slave CPF so the slave P_TSN GM timing matches that calculated in the master CPF. This ensures that the TSN GM timing propagated from the slave to downstream nodes is accurate within the bounds (ϵ) tested at the master CPF. Two possible methods are proposed:

[136] The updated parameters may be provided to the second CPF directly from the first CPF or via a network node, e.g., RAN node or CN node, or UE.

[137] Model parameters may be sent via 3GPP signaling. If the UE or UPF/SMF/NEF application is the master or slave, then NAS signaling may be used. If the RAN/xRAN controller is the master or slave, then RRC (N2 interface) signaling may be used.

[138] Model parameters may be sent in a user plane packet. If the CPF is thought of as an application (interfacing with NEF, in the UE or xRAN controller associated), then a user plane packet containing the model parameters may be sent between the Master and Slave CPF. The packet may also contain the gPTP packet from the UPF ingress.

[139] The method may provide an alternative to the proposals described above for synchronization of one or more TSN GMs (associated with a wired TSN network) across the 5GS, once synchronization has been achieved with a 5GS GM.

[140] A clock prediction algorithm, uses the 5GS synchronization information and a model of the difference between the TSN GM and the 5GS GM to determine when sending TSN GM Clock Synchronization information over the air-interface is necessary. The method also provides two alternatives for efficiently conveying the TSN GM synchronization information across the 5GS.

[141] A schematic diagram illustrating TSN clock synchronisation across a 5GS according to an example embodiment is shown in Figure 6. The 5G GM is synchronised across the 5GS. First network timing domain information comprising gPTP packets based on TSN GM are received at a network entity and time stamps are provided to the first (Master) CPF.

[142] The master CPF predicts TSN GM time based on the 5G GM time stamp and compares the predicted (or estimated) TSN GM time to the actual TSN GM time. If the clock error is too large, the Master CPF updates the model parameters at the second (or Slave) CPF using the N1 or 3GPP User plane, depending on where the Master CPF is located. The Slave CPF then uses the parameters to predicted TSN GM time based on the 5G GM time. The second CPF is then able to provide gPTP packets based on the TSN GM.

[143] Figure 7 illustrates a first example embodiment.

[144] In this example, a TSN GM is located on the UPF side of the 5GS, the UPF/SMF is the CPF Master and the UE/mobile terminal (MT) is the CPF Slave. As described previously, 802.1AS/IEEE1588 gPTP is used within the 5GS to synchronize the 5GS network functions, including the UPF and RAN nodes, and a 3GPP native protocol similar to that used in LTE R15 is used to convey the 5G GM clock information over the air-interface to the UE.

[145] In a first step, the MT/UE CPF uses a model to predict a TSN GM Clock time from 5G GM Clock time. In the simplest embodiment, the P_TSN GM Clock time = 5G GM time + Offset, though other more complex models may be used. This time is used to synchronize downstream nodes such as the robot/end-station in figure 7.

[146] In a second step, a gPTP packet with TSN GM timing is received at the UPF.

[147] In a third step, the UPF sends the TSN GM timing information and 5G GM timing information to its CPF. Though in figure 7 the CPF is shown in the SMF, it may alternatively reside in the UPF, or in an external function connected to the NEF.

[148] In a fourth step, the SMF CPF computes a predicted TSN GM time from the 5G GM time and the same prediction model used by the MT CPF in step 1. The P_TSN GM Clock time calculated in this step should match the P_TSN GM Clock time calculated by the MT/UE CPF in the first step.

[149] In a fifth step, if the predicted TSN GM time differs sufficiently from the actual TSN GM time provided by the UPF in the third step, the CPF sends an update of the model parameters to the MT (slave) CPF. In its simplest form, the model parameters may comprise the current offset between the TSN GM and the 5G GM.

[150] In a sixth step, the MT/UE uses the new model parameters to calculate the next Predicted TSN GM Clock time.

[151] A second example embodiment is shown in Figure 8. In this example the Master CPF is associated with the RAN. The CPF may for example be in the RAN, an xRAN controller or another processing function associated with the RAN. The operation is the same as described with reference to Figure 6, except that the TSN GM clock synchronization is propagated over the 5GS wired N3 interface from the UPF to the RAN, the RAN provides the TSN GM and 5G GM time stamps to the CPF and updated clock model parameters are sent to the UE via RAN (eg: RRC) signaling.

[152] The method may be implemented in a user equipment as described with reference to Figure 2 or a control apparatus as described with reference to figure 3.

[153] An apparatus may comprise means for determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters, receiving first network timing domain clock information at the first clock prediction function, determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain and, if so, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

[154] Alternatively, or in addition, an apparatus may comprise means for receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain, wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

[155] It should be understood that the apparatuses may comprise or be coupled to other units or modules etc., such as radio parts or radio heads, used in or for transmission and/or reception. Although the apparatuses have been described as one entity, different modules and memory may be implemented in one or more physical or logical entities.

[156] It is noted that whilst embodiments have been described in relation to LTE and 5G NR, similar principles can be applied in relation to other networks and communication systems where clock synchronization is required. Therefore, although certain embodiments were described above by way of example with reference to certain example architectures for wireless networks, technologies and standards, embodiments may be applied to any other suitable forms of communication systems than those illustrated and described herein.

[157] It is also noted herein that while the above describes example embodiments, there are several variations and modifications which may be made to the disclosed solution without departing from the scope of the present invention.

[158] In general, the various example embodiments may be implemented in hardware or special purpose circuits, software, logic or any combination thereof. Some aspects of the invention may be implemented in hardware, while other aspects may be implemented in firmware or software which may be executed by a controller, microprocessor or other computing device, although the invention is not limited thereto. While various aspects of the invention may be illustrated and described as block diagrams, flow charts, or using some other pictorial representation, it is well understood that these blocks, apparatus, systems, techniques or methods described herein may be implemented in, as non-limiting examples, hardware, software, firmware, special purpose circuits or logic, general purpose hardware or controller or other computing devices, or some combination thereof.

[159] Example embodiments of this invention may be implemented by computer software executable by a data processor of the mobile device, such as in the processor entity, or by hardware, or by a combination of software and hardware. Computer software or program, also called program product, including software routines, applets and/or macros, may be stored in any apparatus-readable data storage medium and they comprise program instructions to perform particular tasks. A computer program product may comprise one or more computer-executable components which, when the program is run, are configured to carry out embodiments. The one or more computer-executable components may be at least one software code or portions of it.

[160] Further in this regard it should be noted that any blocks of the logic flow as in the Figures may represent program steps, or interconnected logic circuits, blocks and functions, or a combination of program steps and logic circuits, blocks and functions. The software may be stored on such physical media as memory chips, or memory blocks implemented within the processor, magnetic media such as hard disk or floppy disks, and optical media such as for example DVD and the data variants thereof, CD. The physical media is a non-transitory media.

[161] The memory may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The data processors may be of any type suitable to the local technical environment, and may comprise one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASIC), FPGA, gate level circuits and processors based on multi core processor architecture, as non-limiting examples.

[162] Example embodiments of the inventions may be practiced in various components such as integrated circuit modules. The design of integrated circuits is by and large a highly automated process. Complex and powerful software tools are available for converting a logic level design into a semiconductor circuit design ready to be etched and formed on a semiconductor substrate.

[163] The foregoing description has provided by way of non-limiting examples a full and informative description of the exemplary embodiment of this invention. However, various modifications and adaptations may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings and the appended claims. However, all such and similar modifications of the teachings of this invention will still fall within the scope of this invention as defined in the appended claims. Indeed, there is a further embodiment comprising a combination of one or more embodiments with any of the other embodiments previously discussed.

Claims

1. An apparatus comprising: at least one processor and at least one memory including a computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the apparatus at least to:

determine an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters;

receive first network timing domain clock information at the first clock prediction function;

determine, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain; and, if so,

provide the second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain.

2. An apparatus according to claim 1, wherein the first clock prediction function is a master clock prediction function and the second clock prediction function is a slave clock prediction function.

3. An apparatus according to claim 1 or claim 2, wherein the first network timing domain comprises a time sensitive communications network and the second network timing domain comprises a new radio network.

4. An apparatus according to any of claims 1 to 3, wherein the first network timing domain clock information comprises a first network timing domain clock time and the apparatus is further configured to determine if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

5. An apparatus according to any of claims 1 to 4, wherein the first clock prediction function is associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

6. An apparatus according to any of claims 1 to 5, wherein the apparatus is further configured to provide the updated parameters using control signalling.

7. An apparatus according to any of claims 1 to 4, wherein the apparatus is further configured to provide the updated parameters in a user plane packet.

8. An apparatus according to claims 1 to 7, wherein the apparatus is further configured to receive the first network timing domain clock information from a network entity having an association with the first network timing domain.

9. An apparatus according to any of claims 1 to 8, wherein the updated parameters comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

10. An apparatus comprising: at least one processor and at least one memory including a computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the apparatus at least to:

receive, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain,

wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

11. An apparatus according to claim 10, wherein the first clock prediction function is a master clock prediction function and the second clock prediction function is a slave clock prediction function.

12. An apparatus according to claim 10 or claim 11, wherein the first network timing domain comprises a time sensitive communications network and the second network timing domain comprises a new radio network.

13. An apparatus according to any of claims 10 to 12, wherein the first clock prediction function is associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

An apparatus according to any of claims 10 to 13, wherein the apparatus is further configured to receive the updated parameters using control signalling.

14. An apparatus according to any of claims 10 to 14, wherein the apparatus is further configured to receive the updated parameters in a user plane packet.

15. An apparatus according to any of claims 10 to 15, wherein the updated parameters comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

16. A method comprising:

determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters;

receiving first network timing domain clock information at the first clock prediction function;

determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain; and, if so,

providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

17. A method according to claim 17, wherein the first clock prediction function is a master clock prediction function and the second clock prediction function is a slave clock prediction function.

18. A method according to claim 17 or claim 18, wherein the first network timing domain comprises a time sensitive communications network and the second network timing domain comprises a new radio network.

19. A method according to any of claims 17 to 19, wherein the first network timing domain clock information comprises a first network timing domain clock time and determining whether to provide the second clock prediction function with updated parameters comprises determining if the difference between the estimated clock time and the first network timing domain clock time is higher than a threshold.

20. A method according to any of claims 17 to 20, wherein the first clock prediction function is associated with one of a user equipment, a core network function, a radio access network controller and a network exposure function.

21. A method according to any of claims 17 to 21, comprising providing the updated parameters using control signalling.

22. A method according to any of claims 17 to 20, comprising providing the updated parameters in a user plane packet.

23. A method according to claims 17 to 23, comprising receiving the first network timing domain clock information from a network entity having an association with the first network timing domain.

24. An method according to any of claims 17 to 24, wherein the updated parameters comprise an offset between the clock of the first network timing domain and the clock of the second network timing domain.

25. A method comprising:

receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain,

wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

26. An apparatus comprising means for:

determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters;

receiving first network timing domain clock information at the first clock prediction function;

determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain; and, if so,

providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

27. An apparatus comprising means for:

receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain,

wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

28. A computer readable medium comprising program instructions for causing an apparatus to perform at least the following:

determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters;

receiving first network timing domain clock information at the first clock prediction function;

determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain; and, if so,

providing the second clock prediction function with updated parameters for use in determining an estimated clock time for the first network timing domain based on the clock of the second network timing domain.

29. A computer readable medium comprising program instructions for causing an apparatus to perform at least the following:

receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain,

wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function.

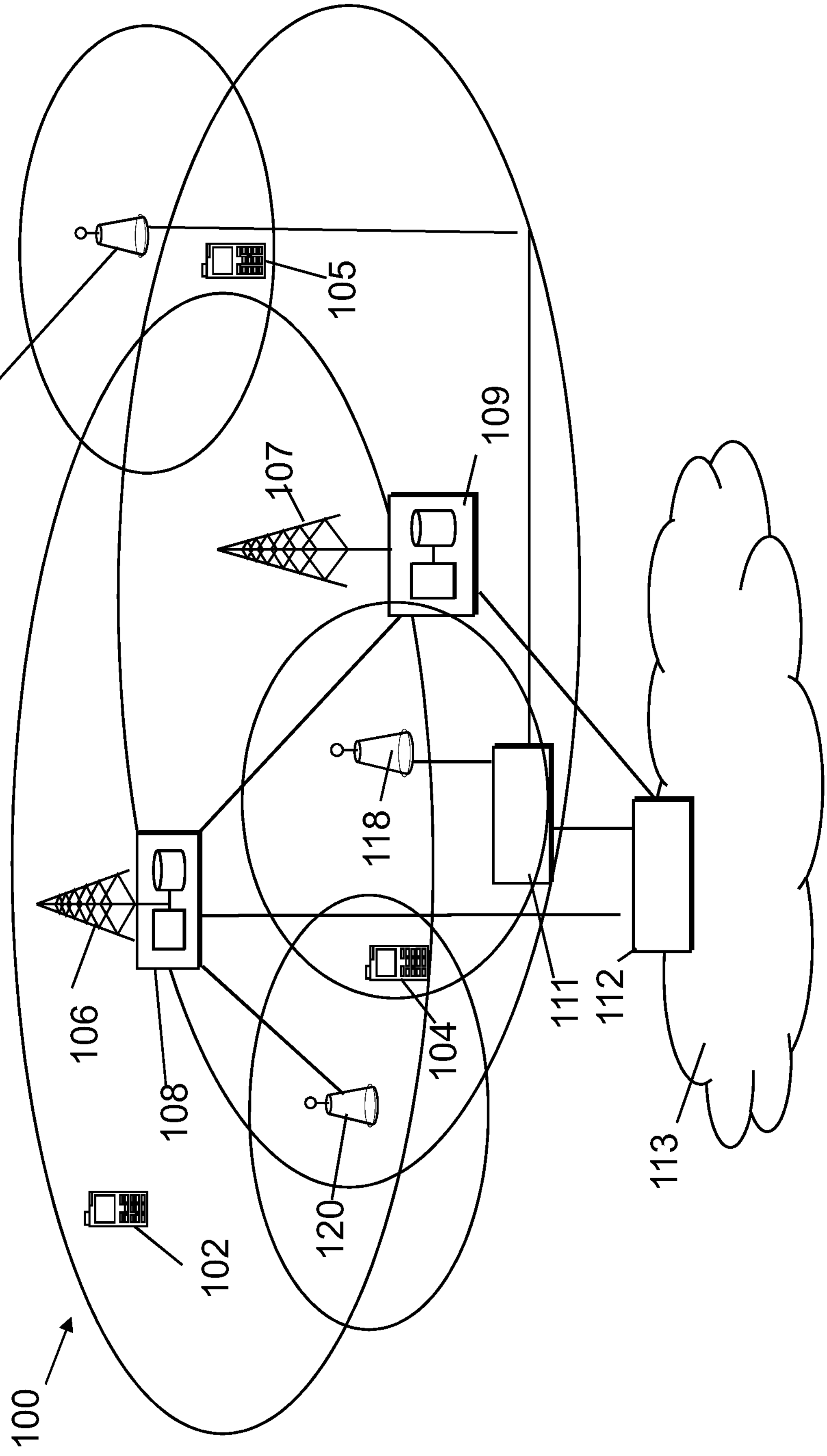


Figure 1

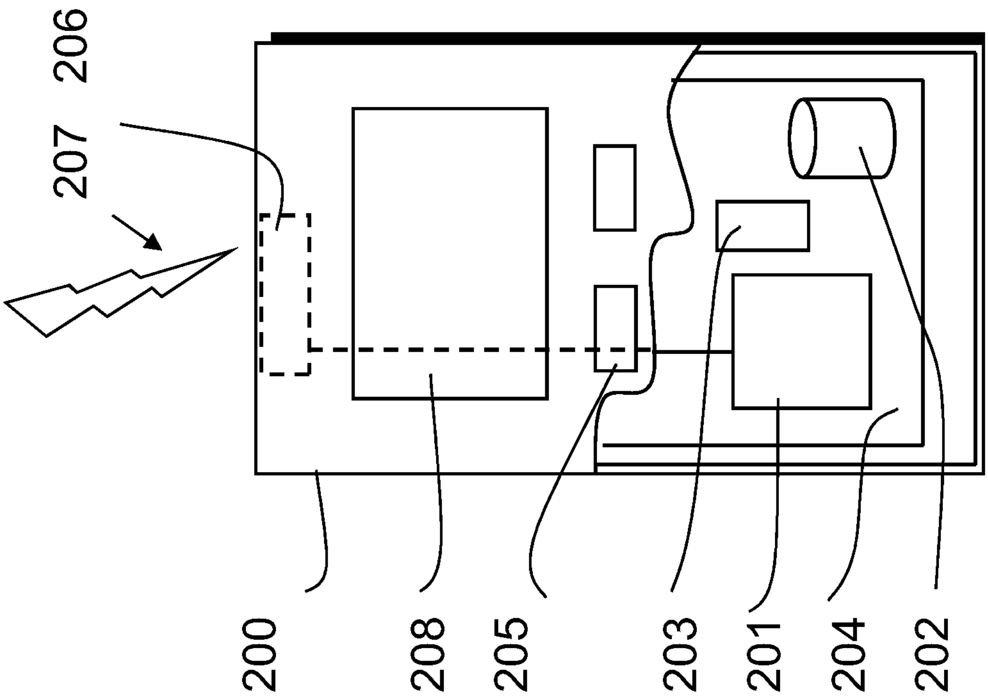


Figure 2

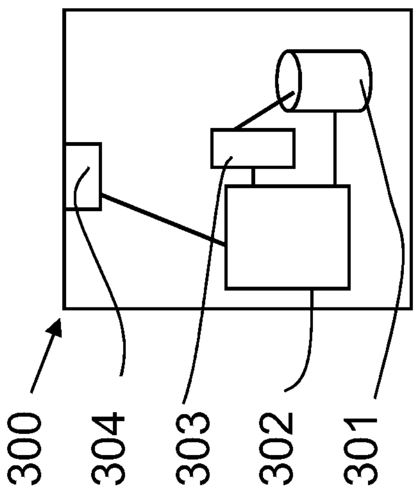


Figure 3

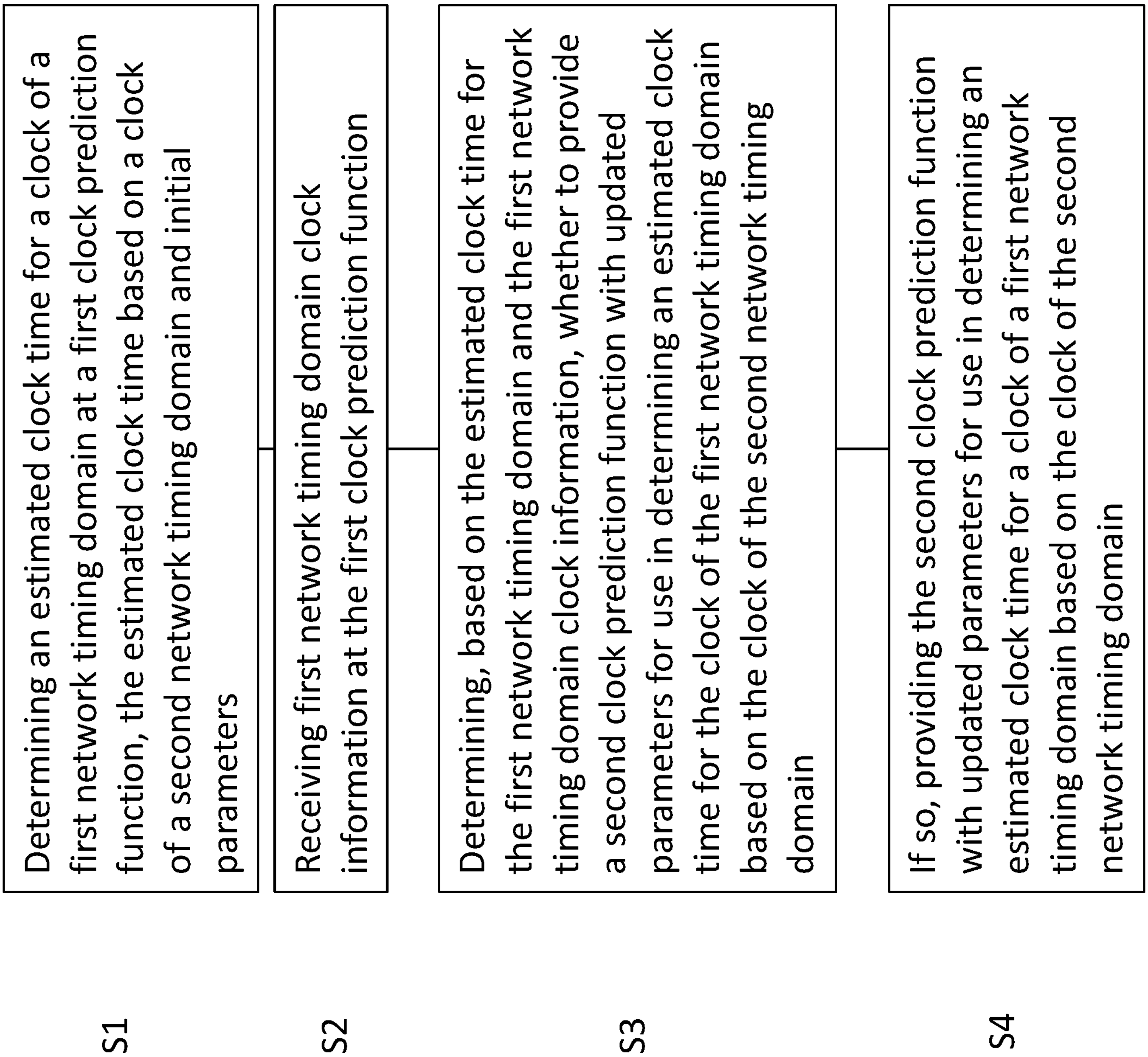
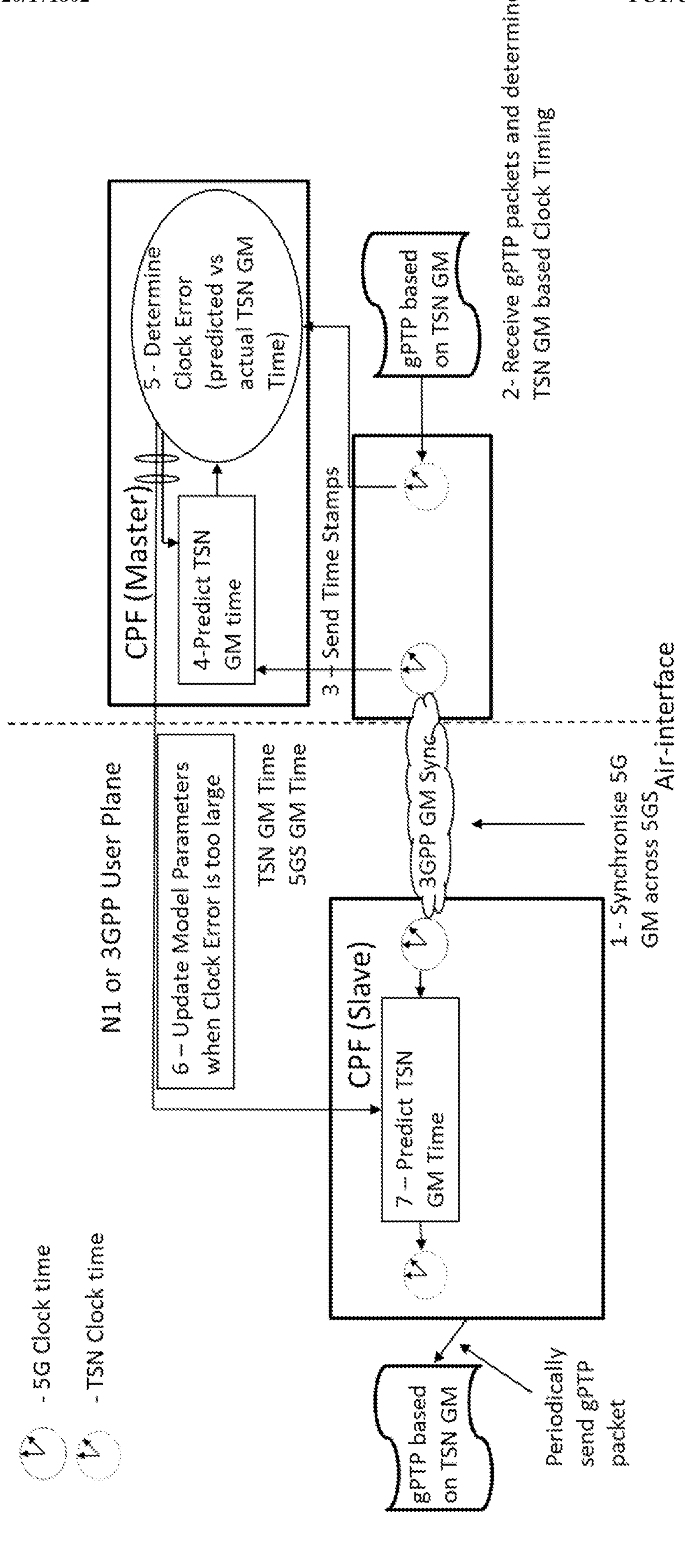

S1
Determining an estimated clock time for a clock of a first network timing domain at a first clock prediction function, the estimated clock time based on a clock of a second network timing domain and initial parameters
S2
Receiving first network timing domain clock information at the first clock prediction function
S3
Determining, based on the estimated clock time for the first network timing domain and the first network timing domain clock information, whether to provide a second clock prediction function with updated parameters for use in determining an estimated clock time for the clock of the first network timing domain based on the clock of the second network timing domain
S4
If so, providing the second clock prediction function with updated parameters for use in determining an estimated clock time for a clock of a first network timing domain based on the clock of the second network timing domain

Figure 4

Figure 5

T1

Receiving, from a network node or a user equipment, at a second clock prediction function, updated parameters for use in the second clock prediction function to determine an estimated clock time for a clock of a first network timing domain based on a clock of a second network timing domain,
wherein whether the updated parameters are provided is determined at a first clock prediction function based on an estimated clock time for the first network timing domain based on the clock of the second network timing domain and initial parameters and first network timing domain clock information received at the first clock prediction function



- 5G Clock time
- TSN Clock time
N1 or 3GPP User Plane
CPF (Master)
4-Predict TSN GM time
5 - Determine Clock Error (predicted vs actual TSN GM Time)
3 – Send Time Stamps
gPTP based on TSN GM
2- Receive gPTP packets and determine TSN GM based Clock Timing
6 – Update Model Parameters when Clock Error is too large
TSN GM Time
5GS GM Time
3GPP GM Sync
Air-interface
1 - Synchronise 5G GM across 5GS
CPF (Slave)
7 – Predict TSN GM Time
gPTP based on TSN GM
Periodically send gPTP packet

Figure 6

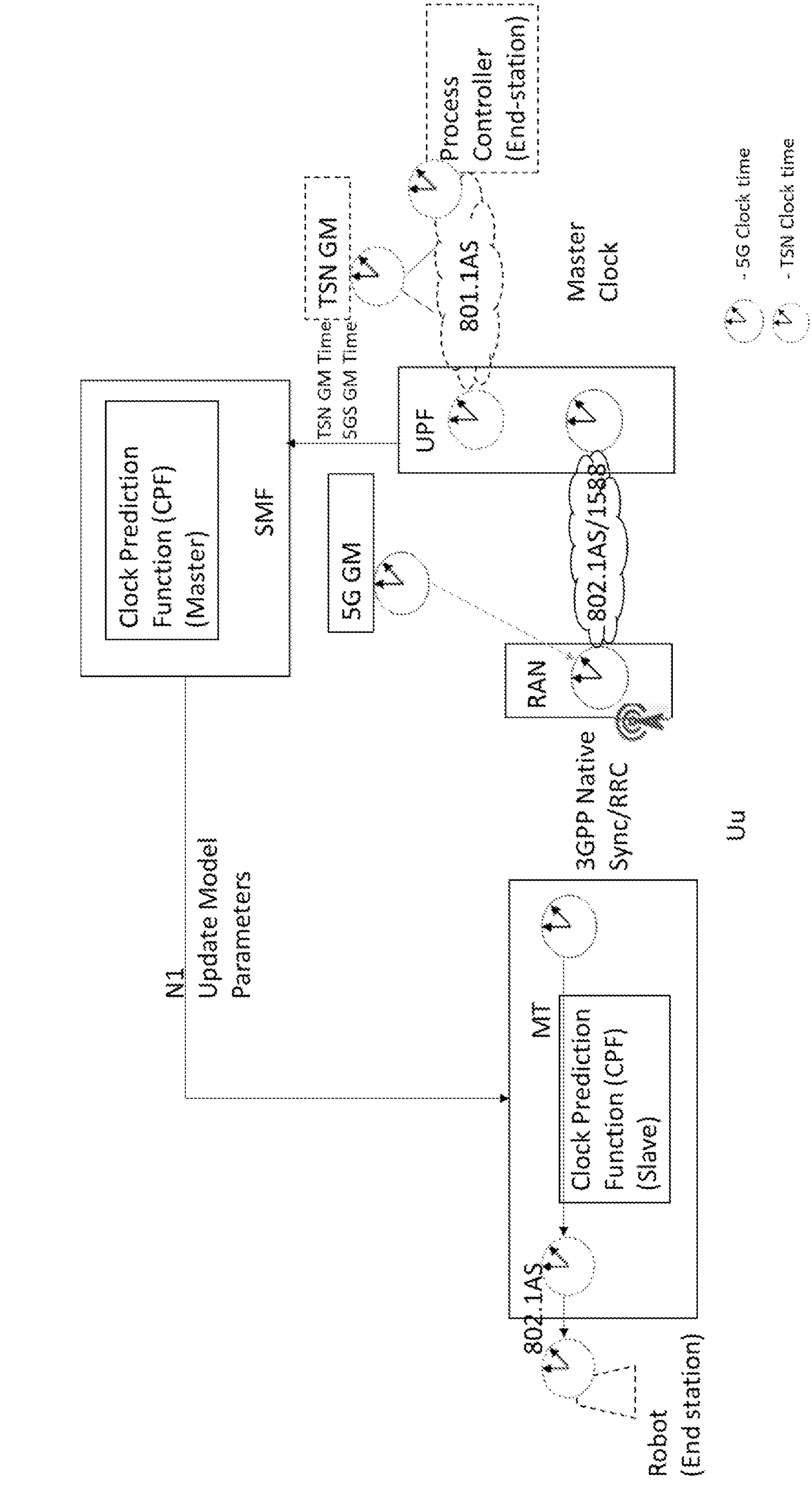

Process
Controller
(End-station)
TSN GM
801.1AS
Master
Clock
- 5G Clock time
- TSN Clock time
Clock Prediction
Function (CPF)
(Master)
SMF
TSN GM Time
5GS GM Time
UPF
5G GM
802.1AS/1588
RAN
3GPP Native
Sync/RRC
Uu
N1
Update Model
Parameters
MT
Clock Prediction
Function (CPF)
(Slave)
802.1AS
Robot
(End station)

Figure 7

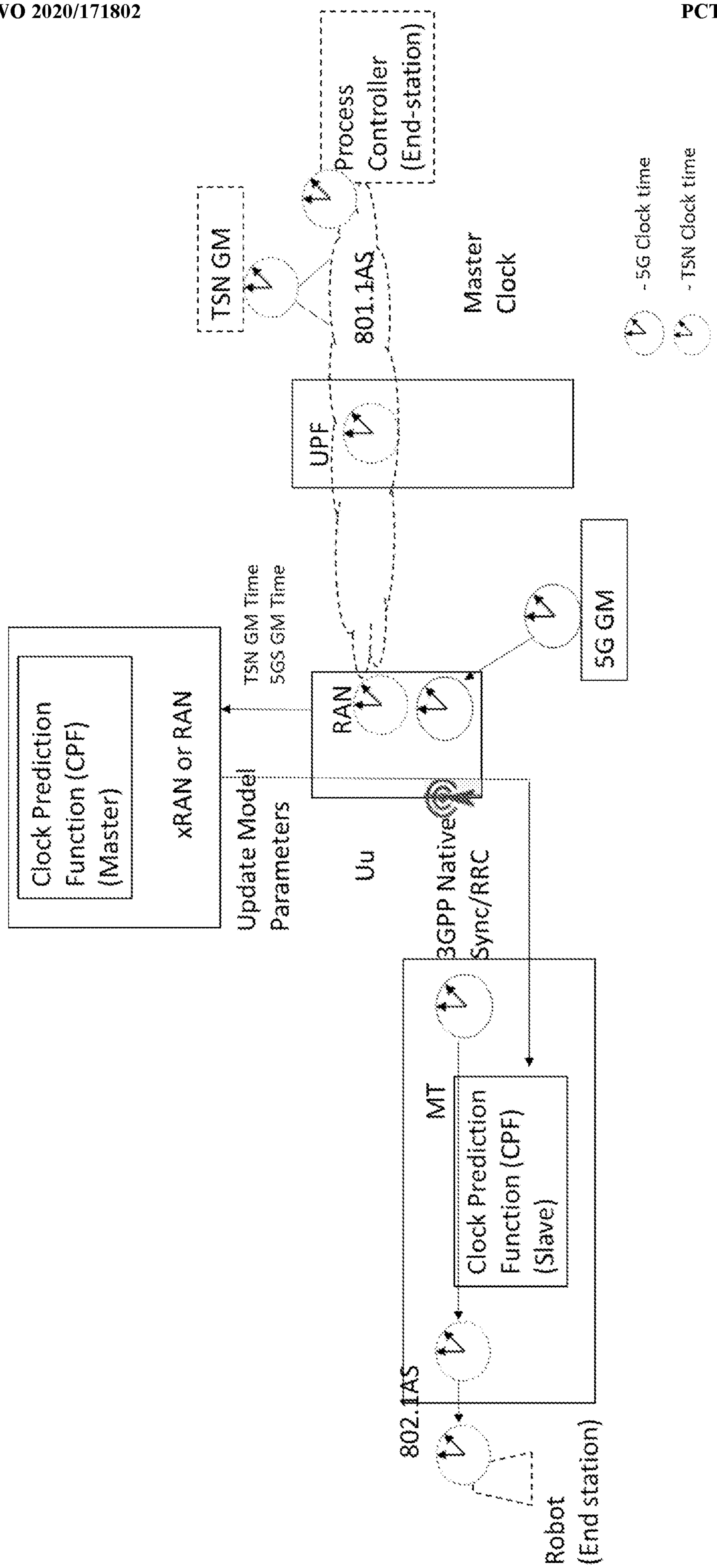

Process
Controller
(End-station)
TSN GM
801.1AS
Master
Clock
- 5G Clock time
- TSN Clock time
UPF
5G GM
RAN
TSN GM Time
5GS GM Time
Clock Prediction
Function (CPF)
(Master)
xRAN or RAN
Update Model
Parameters
Uu
3GPP Native
Sync/RRC
MT
Clock Prediction
Function (CPF)
(Slave)
802.1AS
Robot
(End station)

Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/018644

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04J3/06 H04W88/10
ADD.

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)
H04J H04W

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ERICSSON: "Clarification of 5G clock in relation to TSN time synchronization", 3GPP DRAFT; S2-1812417_5GCLOCK IN TIMESYNC SOLUTIONS_PA2, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. SA WG2, no. West Palm Beach, Florida; 20181126 - 20181130 20 November 2018 (2018-11-20), XP051499120, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg%5Fsa/WG2%5FArch/TSGS2%5F129BIS%5FWest%5FPalm%5FBeach/Docs/S2%2D1812417%2Ezip [retrieved on 2018-11-20] page 1 - page 5 figure 1 -/--	1-29

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2019	04/10/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Marongiu, M

2

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HUAWEI ET AL: "Solution of Time Synchronization in Multiple TSN Clock Domains", 3GPP DRAFT; S2-1813067 WAS12413 TSN TIME SYNCHRONIZATION IN MULTIPLE DOMAINS_R7, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLI , vol. SA WG2, no. West Palm Beach, Florida, US; 20181126 - 20181130 29 November 2018 (2018-11-29), XP051564362, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings%5F3GPP%5FSYNC/SA2/Docs/S2%2D1813067%2Ezip [retrieved on 2018-11-29] page 1 - page 4 page 7	1-29
A	US 2016/065358 A1 (ZHANG JINFANG [CN] ET AL) 3 March 2016 (2016-03-03) paragraph [0178] - paragraph [0179]	1-28
A	US 2017/359137 A1 (BUTTERWORTH ASHLEY I [US] ET AL) 14 December 2017 (2017-12-14) paragraph [0072] paragraph [0076] - paragraph [0077] figure 2	1-29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2019/018644

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016065358 A1	03-03-2016	CN 104144047 A	12-11-2014
		US 2016065358 A1	03-03-2016
		WO 2014180347 A1	13-11-2014
US 2017359137 A1	14-12-2017	US 2017359137 A1	14-12-2017
		US 2017359138 A1	14-12-2017
		US 2017359139 A1	14-12-2017