



(51) International Patent Classification:

H04W 28/24 (2009.01) *H04W* 4/50 (2018.01)
H04W 4/18 (2009.01) *H04M* 1/72403 (2021.01)

(21) International Application Number:

PCT/US2021/056447

(22) International Filing Date:

25 October 2021 (25.10.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

63/109,197 03 November 2020 (03.11.2020) US

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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, IT, 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, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, 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, 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).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

(54) Title: COMMUNICATION OF SCHEDULING ASSISTANCE INFORMATION

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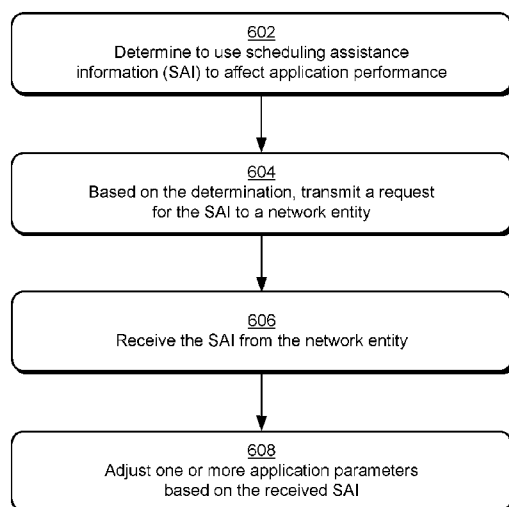


Fig. 6

(57) Abstract: This document describes methods, devices, systems, and means for managing application performance by a user equipment, UE, the user equipment determining to use scheduling assistance information, SAI, to affect application performance (702). Based on the determining, the UE transmits a request for the SAI to a network entity (704), receives the SAI from the network entity (706), and adjusts one or more application parameters based on the received SAI (708).

Published:

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

COMMUNICATION OF SCHEDULING ASSISTANCE INFORMATION

BACKGROUND

[0001] The evolution of wireless communication to fifth generation (5G) standards and technologies provides higher data rates and greater capacity, with improved reliability and lower latency, which enhances mobile broadband services. 5G technologies also provide new classes of services for vehicular networking, fixed wireless broadband, and the Internet of Things (IoT).

[0002] The performance of applications running on a user equipment (UE) is susceptible to variations in the communications link between the UE and a base station. Applications can react to changes in the communication link, such as adapting the data rate of a codec or changing a buffer size. These adaptations often rely on historical performance data for the communication link, assume a wired or otherwise stable communication link, and can be slow to change in light of quickly-changing wireless communication channels. Thus, there is an opportunity to improve the performance and responsiveness of applications to variations in wireless communication links.

SUMMARY

[0003] This summary is provided to introduce concepts of communication of scheduling assistance information. The concepts are further described below in the Detailed Description. This summary is not intended to identify essential features of the claimed subject matter, nor is it intended for use in determining the scope of the claimed subject matter.

[0004] In aspects, methods, devices, systems, and means for managing application performance by a user equipment (UE) describe the user equipment determining to use scheduling assistance information (SAI) to affect application performance. Based on the determining, the UE transmits a request for the SAI to a network entity, receives the SAI from the network entity, and adjusts one or more application parameters based on the received SAI.

[0005] In other aspects, methods, devices, systems, and means for providing scheduling assistance information (SAI) to a user equipment (UE) by a network entity describe the network

entity receiving a request for the SAI from the UE. In response to the received request, the network entity generates the SAI and transmits an indication of the generated SAI to the UE, the transmission assisting the UE to adjust one or more application parameters based on the SAI.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Aspects of communication of scheduling assistance information are described with reference to the following drawings. The same numbers are used throughout the drawings to reference like features and components:

FIG. 1 illustrates an example wireless network system in which various aspects of communication of scheduling assistance information can be implemented.

FIG. 2 illustrates an example device diagram that can implement various aspects of communication of scheduling assistance information.

FIG. 3 illustrates an example block diagram of a wireless network stack model in which various aspects of communication of scheduling assistance information can be implemented.

FIG. 4 illustrates an air interface resource that extends between a user equipment and a base station and with which various aspects of communication of scheduling assistance information can be implemented.

FIG. 5 illustrates example data and control transactions between a user equipment, a base station, and a core network in accordance with aspects of communication of scheduling assistance information.

FIG. 6 illustrates an example method in accordance with aspects of communication of scheduling assistance information.

FIG. 7 illustrates an example method in accordance with aspects of communication of scheduling assistance information.

DETAILED DESCRIPTION

[0007] With increasingly data- and compute-intensive applications on user devices, optimizing user experiences can be challenging for application software. These applications can benefit from data throughput or delay estimations to adapt their behaviors based on link quality.

[0008] To improve the ability of application-layer software running on a user equipment (UE) to adapt to variations in a wireless communications link between the UE and a base station, the base station can send scheduling assistance information to the UE. The scheduling assistance information is scheduling-related and network performance-related information that assists the UE in managing the performance of applications executing on the UE. The scheduling assistance information may include any one or more of: available downlink (DL) and/or uplink (UL) air interface resources that are unassigned, a DL packet delay value, a DL packet jitter value, an UL interference value, an UL Signal to Interference and Noise Ratio (SINR) value, or the like. The scheduling assistance information can be associated with a time window (*e.g.*, the next 100 milliseconds). An application on the UE uses the scheduling assistance information to modify application settings, for example adapting a streaming codec resolution (4K versus 720P), changing a video frame rate (*e.g.*, 60 fps versus 24.976 fps), selecting an online gaming quality or bit rate (10 Mbps versus 5 Mbps), shifting from edge or cloud computing to local processing, and so forth.

[0009] While features and concepts of the described devices, systems, and methods for communication of scheduling assistance information can be implemented in any number of different environments, systems, devices, and/or various configurations, aspects of communication of scheduling assistance information are described in the context of the following example devices, systems, and configurations.

Example Environment

[0010] FIG. 1 illustrates an example environment 100 in which various aspects of communication of scheduling assistance information can be implemented. The example environment 100 includes a user equipment 110 (UE 110) that communicates with one or more base stations 120 (illustrated as base stations 121 and 122), through one or more wireless communication links 130 (wireless link 130), illustrated as wireless links 131 and 132. In this example, the user equipment 110 is implemented as a smartphone. Although illustrated as a smartphone, the user equipment 110 may be implemented as any suitable computing or electronic device, such as a mobile communication device, a modem, cellular phone, gaming device, navigation device, media device, laptop computer, desktop computer, tablet computer, smart appliance, or vehicle-based communication system. The base stations 120 (*e.g.*, an Evolved Universal Terrestrial Radio Access Network Node B, E-UTRAN Node B, evolved Node B, eNodeB, eNB, Next Generation Node B, gNode B, gNB, ng-eNB, a 6G node B, or the like) may be implemented in a macrocell, microcell, small cell, picocell, distributed base station, and the like, or any combination or future evolution thereof.

[0011] The base stations 120 communicate with the user equipment 110 via the wireless links 131 and 132, which may be implemented as any suitable type of wireless link. The wireless links 131 and 132 can include a downlink of data and control information communicated from the base stations 120 to the user equipment 110, an uplink of other data and control information communicated from the user equipment 110 to the base stations 120, or both. The wireless links 130 may include one or more wireless links or bearers implemented using any suitable communication protocol or standard, or combination of communication protocols or standards such as 3rd Generation Partnership Project Long-Term Evolution (3GPP LTE), Fifth Generation New Radio (5G NR), 6G, and so forth. Multiple wireless links 130 may be aggregated in a carrier aggregation to provide a higher data rate for the user equipment 110. Multiple wireless links 130 from multiple base stations 120 may be configured for Coordinated Multipoint (CoMP)

communication with the user equipment 110. Additionally, multiple wireless links 130 may be configured for single-radio access technology (RAT) (single-RAT) dual connectivity (single-RAT-DC) or multi-RAT dual connectivity (MR-DC).

[0012] The base stations 120 are collectively a Radio Access Network 140 (RAN, Evolved Universal Terrestrial Radio Access Network, E-UTRAN, 5G NR RAN or NR RAN). The base stations 121 and 122 in the RAN 140 are connected to a core network 150, such as a Fifth Generation Core (5GC) or 6G core network. The base stations 121 and 122 connect, at 102 and 104 respectively, to the core network 150 via an NG2 interface (or a similar 6G interface) for control-plane signaling and via an NG3 interface (or a similar 6G interface) for user-plane data communications. In addition to connections to core networks, base stations 120 may communicate with each other via an Xn Application Protocol (XnAP), at 112, to exchange user-plane and control-plane data. The user equipment 110 may also connect, via the core network 150, to public networks, such as the Internet 160 to interact with a remote service 170.

Example Devices

[0013] FIG. 2 illustrates an example device diagram 200 of the user equipment 110, the base stations 120, and a core network server 280. The user equipment 110 and the base stations 120 may include additional functions and interfaces that are omitted from FIG. 2 for the sake of clarity. The user equipment 110 includes antennas 202, a radio frequency front end 204 (RF front end 204), an LTE transceiver 206, a 5G NR transceiver 208, and a 6G transceiver 210 for communicating with base stations 120 in the RAN 140. The RF front end 204 of the user equipment 110 can couple or connect the LTE transceiver 206, the 5G NR transceiver 208, and the 6G transceiver 210 to the antennas 202 to facilitate various types of wireless communication. The antennas 202 of the user equipment 110 may include an array of multiple antennas that are configured similarly to or differently from each other. The antennas 202 and the RF front end 204 can be tuned to, and/or be tunable to, one or more frequency bands defined by the 3GPP LTE,

5G NR, and 6G communication standards and implemented by the LTE transceiver 206, the 5G NR transceiver 208, and/or the 6G transceiver 210. Additionally, the antennas 202, the RF front end 204, the LTE transceiver 206, the 5G NR transceiver 208, and/or the 6G transceiver 210 may be configured to support beamforming for the transmission and reception of communications with the base stations 120. By way of example and not limitation, the antennas 202 and the RF front end 204 can be implemented for operation in sub-gigahertz bands, sub-6 GHz bands, and/or above 6 GHz bands that are defined by the 3GPP LTE, 5G NR, and 6G communication standards.

[0014] The user equipment 110 also includes processor(s) 212 and computer-readable storage media 214 (CRM 214). The processor 212 may be a single core processor or a multiple core processor composed of a variety of materials, such as silicon, polysilicon, high-K dielectric, copper, and so on. The computer-readable storage media described herein excludes propagating signals. CRM 214 may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), or Flash memory useable to store device data 216 of the user equipment 110. The device data 216 includes user data, multimedia data, beamforming codebooks, applications, and/or an operating system of the user equipment 110, which are executable by processor(s) 212 to enable user-plane communication, control-plane signaling, and user interaction with the user equipment 110.

[0015] In some implementations, the CRM 214 may also include an application manager 218. The application manager 218 can communicate with the antennas 202, the RF front end 204, the LTE transceiver 206, the 5G NR transceiver 208, and/or the 6G transceiver 210 to monitor the quality of the wireless communication links 130. Based on this monitoring and scheduling assistance information, the application manager 218 can determine to adjust application-related parameters of applications running on the UE 110. In one option, the application manager 218 may be included in the operating system of the UE 110.

[0016] The device diagram for the base stations 120, shown in FIG. 2, includes a single network node (*e.g.*, a gNode B). The functionality of the base stations 120 may be distributed across multiple network nodes or devices and may be distributed in any fashion suitable to perform the functions described herein. The nomenclature for this split base station functionality varies and includes terms such Central Unit (CU), Distributed Unit (DU), Baseband Unit (BBU), Remote Radio Head (RRH), and/or Remote Radio Unit (RRU). The base stations 120 include antennas 252, a radio frequency front end 254 (RF front end 254), one or more LTE transceivers 256, one or more 5G NR transceivers 258, and/or one or more 6G transceivers 260 for communicating with the UE 110. The RF front end 254 of the base stations 120 can couple or connect the LTE transceivers 256, the 5G NR transceivers 258, and/or the 6G transceivers 260 to the antennas 252 to facilitate various types of wireless communication. The antennas 252 of the base stations 120 may include an array of multiple antennas that are configured similarly to or differently from each other. The antennas 252 and the RF front end 254 can be tuned to, and/or be tunable to, one or more frequency band defined by the 3GPP LTE, 5G NR, and 6G communication standards, and implemented by the LTE transceivers 256, one or more 5G NR transceivers 258, and/or one or more 6G transceivers 260. Additionally, the antennas 252, the RF front end 254, the LTE transceivers 256, one or more 5G NR transceivers 258, and/or one or more 6G transceivers 260 may be configured to support beamforming, such as Massive-MIMO, for the transmission and reception of communications with the UE 110.

[0017] The base stations 120 also include processor(s) 262 and computer-readable storage media 264 (CRM 264). The processor 262 may be a single core processor or a multiple core processor composed of a variety of materials, such as silicon, polysilicon, high-K dielectric, copper, and so on. CRM 264 may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), or Flash memory useable to store device data 266 of the base stations 120. The device data 266 includes network scheduling data, radio resource

management data, beamforming codebooks, applications, and/or an operating system of the base stations 120, which are executable by processor(s) 262 to enable communication with the user equipment 110.

[0018] CRM 264 also includes a base station scheduler 268. Alternately or additionally, the base station manager 268 may be implemented in whole or part as hardware logic or circuitry integrated with or separate from other components of the base stations 120. In at least some aspects, the base station manager 268 configures the LTE transceivers 256, the 5G NR transceivers 258, and the 6G transceiver(s) 260 for communication with the user equipment 110, as well as communication with a core network, such as the core network 150, and routing user-plane and control-plane data for joint communication. Additionally, the base station scheduler 268 may allocate air interface resources, schedule communications, and determine future availability of air interface resources for the UE 110.

[0019] The base stations 120 include an inter-base station interface 270, such as an Xn and/or X2 interface, which the base station manager 268 configures to exchange user-plane and control-plane data between other base stations 120, to manage the communication of the base stations 120 with the user equipment 110. The base stations 120 include a core network interface 272 that the base station manager 268 configures to exchange user-plane and control-plane data with core network functions and/or entities.

[0020] The core network server 280 may provide all or part of a function, entity, service, and/or gateway in the core network 150. Each function, entity, service, and/or gateway in the core network 150 may be provided as a service in the core network 150, distributed across multiple servers, or embodied on a dedicated server. For example, the core network server 280 may provide all or a portion of the services or functions of a User Plane Function (UPF), a Session Management Function (SMF), or an Access and Mobility Function (AMF). The core network server 280 is illustrated as being embodied on a single server that includes processor(s) 282 and computer-readable storage media 284 (CRM 284). The processor 282 may be a single core processor or a

multiple core processor composed of a variety of materials, such as silicon, polysilicon, high-K dielectric, copper, and so on. CRM 284 may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), hard disk drives, or Flash memory useful to store device data 286 of the core network server 280. The device data 286 includes data to support a core network function or entity, and/or an operating system of the core network server 280, which are executable by processor(s) 282.

[0021] CRM 284 also includes one or more core network applications 288, which, in one implementation, is embodied on CRM 284 (as shown). The one or more core network applications 288 may implement the functionality of a User Plane Function (UPF), a Session Management Function (SMF), or an Access and Mobility Function (AMF). Alternately or additionally, the one or more core network applications 288 may be implemented in whole or part as hardware logic or circuitry integrated with or separate from other components of the core network server 280. The core network server 280 also includes a core network interface 290 for communication of user-plane and control-plane data with the other functions or entities in the core network 150 or base stations 120 using any of the network interfaces described herein.

User Plane and Control Plane Signaling

[0022] FIG. 3 illustrates an example block diagram 300 of a wireless network stack model 300 (stack 300, network stack 300). The network stack 300 characterizes a communication system for the example environment 100, in which various aspects of communication of scheduling assistance information can be implemented. The network stack 300 includes a user plane 302 and a control plane 304. Upper layers of the user plane 302 and the control plane 304 share common lower layers in the network stack 300. Wireless devices, such as the UE 110 or the base station 120, implement each layer as an entity for communication with another device using the protocols

defined for the layer. For example, a UE 110 uses a Packet Data Convergence Protocol (PDCP) entity to communicate to a peer PDCP entity in a base station 120 using the PDCP.

[0023] The shared lower layers include a physical (PHY) layer 306, a Media Access Control (MAC) layer 308, a Radio Link Control (RLC) layer 310, and a PDCP layer 312. The PHY layer 306 provides hardware specifications for devices that communicate with each other. As such, the PHY layer 306 establishes how devices connect to each other, assists in managing how communication resources are shared among devices, and the like.

[0024] The MAC layer 308 specifies how data is transferred between devices. Generally, the MAC layer 308 provides a way in which data packets being transmitted are encoded and decoded into bits as part of a transmission protocol.

[0025] The RLC layer 310 provides data transfer services to higher layers in the network stack 300. Generally, the RLC layer 310 provides error correction, packet segmentation and reassembly, and management of data transfers in various modes, such as acknowledged, unacknowledged, or transparent modes.

[0026] The PDCP layer 312 provides data transfer services to higher layers in the network stack 300. Generally, the PDCP layer 312 provides transfer of user plane 302 and control plane 304 data, header compression, ciphering, and integrity protection.

[0027] Above the PDCP layer 312, the stack splits into the user-plane 302 and the control-plane 304. Layers of the user plane 302 include an optional Service Data Adaptation Protocol (SDAP) layer 314, an Internet Protocol (IP) layer 316, a Transmission Control Protocol/User Datagram Protocol (TCP/UDP) layer 318, and an application layer 320, which transfers data using the wireless link 106. The optional SDAP layer 314 is present in 5G NR networks. The SDAP layer 314 maps a Quality of Service (QoS) flow for each data radio bearer and marks QoS flow identifiers in uplink and downlink data packets for each packet data session. The IP layer 316 specifies how the data from the application layer 320 is transferred to a destination node. The TCP/UDP layer 318 verifies that data packets intended to be transferred to the destination node

reached the destination node, using either TCP or UDP for data transfers by the application layer 320. In some implementations, the user plane 302 may also include a data services layer (not shown) that provides data transport services to transport application data, such as IP packets including web browsing content, video content, image content, audio content, or social media content.

[0028] The control plane 304 includes a Radio Resource Control (RRC) layer 324 and a Non-Access Stratum (NAS) layer 326. The RRC layer 324 establishes and releases connections and radio bearers, broadcasts system information, or performs power control. The RRC layer 324 also controls a resource control state of the UE 110 and causes the UE 110 to perform operations according to the resource control state. Example resource control states include a connected state (e.g., an RRC connected state) or a disconnected state, such as an inactive state (e.g., an RRC inactive state) or an idle state (e.g., an RRC idle state). In general, if the UE 110 is in the connected state, the connection with the base station 120 is active. In the inactive state, the connection with the base station 120 is suspended. If the UE 110 is in the idle state, the connection with the base station 120 is released. Generally, the RRC layer 324 supports 3GPP access but does not support non-3GPP access (e.g., WLAN communications).

[0029] The NAS layer 326 provides support for mobility management (e.g., using a Fifth-Generation Mobility Management (5GMM) layer 328) and packet data bearer contexts (e.g., using a Fifth-Generation Session Management (5GSM) layer 330) between the UE 110 and entities or functions in the core network, such as the Access and Mobility Management Function 152 (AMF 152) of the 5GC 150 or the like. The NAS layer 326 supports both 3GPP access and non-3GPP access.

[0030] In the UE 110, each layer in both the user plane 302 and the control plane 304 of the network stack 300 interacts with a corresponding peer layer or entity in the base station 120, a core network entity or function, and/or a remote service, to support user applications and control operation of the UE 110 in the RAN 140.

Air Interface Resources

[0031] FIG. 4 illustrates an air interface resource that extends between a user equipment and a base station and with which various aspects of communication of scheduling assistance information can be implemented. The air interface resource 402 can be divided into resource units 404, each of which occupies some intersection of frequency spectrum and elapsed time. A portion of the air interface resource 402 is illustrated graphically in a grid or matrix having multiple resource blocks 410, including example resource blocks 411, 412, 413, 414. An example of a resource unit 404 therefore includes at least one resource block 410. As shown, time is depicted along the horizontal dimension as the abscissa axis, and frequency is depicted along the vertical dimension as the ordinate axis. The air interface resource 402, as defined by a given communication protocol or standard, may span any suitable specified frequency range, and/or may be divided into intervals of any specified duration. Increments of time can correspond to, for example, milliseconds (ms). Increments of frequency can correspond to, for example, megahertz (MHz).

[0032] In example operations generally, the base stations 120 allocate portions (*e.g.*, resource units 404) of the air interface resource 402 for uplink and downlink communications. Each resource block 410 of network access resources may be allocated to support respective wireless communication links 130 of multiple user equipment 110. In the lower left corner of the grid, the resource block 411 may span, as defined by a given communication protocol, a specified frequency range 406 and includes multiple subcarriers or frequency sub-bands. The resource block 411 may include any suitable number of subcarriers (*e.g.*, 12) that each correspond to a respective portion (*e.g.*, 15 kHz) of the specified frequency range 406 (*e.g.*, 180 kHz). The resource block 411 may also span, as defined by the given communication protocol, a specified time interval 408 or time slot (*e.g.*, lasting approximately one-half millisecond or 7 orthogonal frequency-division multiplexing (OFDM) symbols). The time interval 408 includes subintervals

that may each correspond to a symbol, such as an OFDM symbol. As shown in FIG. 4, each resource block 410 may include multiple resource elements 420 (REs) that correspond to, or are defined by, a subcarrier of the frequency range 406 and a subinterval (or symbol) of the time interval 408. Alternatively, a given resource element 420 may span more than one frequency subcarrier or symbol. Thus, a resource unit 404 may include at least one resource block 410, at least one resource element 420, and so forth.

Communication of Scheduling Assistance Information

[0033] In one aspect, the base station 121 sends an indication of available air interface resources that are available (*e.g.*, unassigned resource blocks 410) over a future period of time (*e.g.*, the upcoming ten seconds, an upcoming number of frames or time slots) to the UE 110. The indication of available air interface resources is dynamically calculated, unlike static predictive estimates provided in carrier aggregation (CA) or dual connectivity (DC).

[0034] The base station scheduler 268 determines when air interface resources (*e.g.*, resource blocks 410 or resource elements 420) are available. These air interface resources can be Physical Downlink Shared Channel (PDSCH) or Physical Uplink Shared Channel (PUSCH) resource blocks or resource elements that are not currently assigned to any particular UE. The base station 121 can communicate the indication of the available DL and UL resources in separate messages or in a single message to the UE 110. Alternatively and optionally, the base station 121 can broadcast the indication of the available DL and UL resources. In a further option or alternative, the base station 121 can prioritize individually communicating the indication of the available DL and UL resources based on the history of individual UEs 110, data quotas or data throttling for a UE 110, a contracted Quality of Service (QoS) level purchased by a user, or the like.

[0035] In one option, the base station scheduler 268 can compute the available future air interface resources amount using averaging (*e.g.*, a moving average) of previously assigned

resources, for example by using a low-pass filter (*e.g.*, the low-pass filter averages the last 100 time slots to calculate a resource block utilization). The base station 121 can provide the low-pass filter coefficients to the UE 110 to aid the UE 110 in interpreting the indication of the available future air interface resources. Alternatively, the UE 110 can request a low-pass filter time constant in the request for the scheduling assistance information, as discussed below.

[0036] In another option, the base station 121 can predict the future resource utilization based on one or more parameters, such as a time of day, traffic patterns of other UEs, or other situational information. For example, the base station 121 can determine the available air interface resource information based on current (instantaneous or non-instantaneous) load (air interface resource utilization) information of the base station 121. The base station 121 can send the predicted load information associated with a predicted time window (*e.g.*, the next 10 seconds) to the UE 110, based on the time of day, traffic patterns of other UEs, historical statistics, and/or other situational information (*e.g.*, out-of-band information such as a current large capacity event (sports, music, conference) in the cell provided by the base station 121).

[0037] To adapt application layer parameters using this information (*e.g.*, resolution, frame rate, buffer size, computation offloading, and so forth), the UE 110 computes the average DL throughput based on a current DL Channel Quality Indicator (CQI) and/or a current Modulation and Coding Scheme (MCS), a currently used number of DL resource blocks 410 (or resource elements 420), and the indication of the available future DL air interface resources received from the base station 121. The UE 110 computes the estimated UL throughput based on a currently used number of UL resource blocks 410 (or resource elements 420), the indication of the available future UL air interface resources received from the base station 121, and the available power headroom.

[0038] In another aspect, the base station 121 sends an UL SINR or UL interference information to the UE 110. The UE 110 can use the UL interference information to compute the expected UL SINR at base station 121. For example, the UE 110 uses a current UL transmit power

of the UE, a path loss estimate, and the UL SINR or UL interference information from the base station 121 to compute an expected UL SINR at the base station 121. The UE 110 uses this UL SINR calculation to estimate the achievable UL data throughput so that the UE 110 can adapt application parameters using this information (*e.g.*, codec resolution, video quality, buffer size, and so forth).

[0039] In a further aspect, a network entity (the base station 121 and/or the core network 150) sends DL queueing delay and/or jitter information to the UE 110. The base station 121 can send the DL queueing delay and/or jitter information to the UE 110 on a per-radio-bearer basis (sending the DL queueing delay and/or jitter information for each radio bearer). The DL queueing delay and/or jitter information can be characterized by the percentile (*e.g.*, such as 50th percentile, 95th percentile, and so forth) of DL queueing delay and/or jitter information or characterized by a 5G Quality of Service (QoS) class (5QI). The UE 110 uses this DL queueing delay and/or jitter information to adapt a buffer size for an application or adjust the computing on the UE 110 (*e.g.*, using a local graphics processing unit to perform rendering as opposed to using a cloud or edge server that might offer better rendering performance).

[0040] The core network 150 can also send the DL queueing delay and/or jitter information to the UE 110. The core network 150 can send the DL queueing delay and/or jitter information on a per-QoS-flow basis (sending the DL queueing delay and/or jitter information for each QoS flow). The DL queueing delay and/or jitter information can be estimated by the User Plane Function (UPF) in the core network 150 and communicated to the UE 110 in NAS layer 326 messages using the Session Management Function (SMF) and/or the Access and Mobility Function (AMF) of the core network 150.

[0041] In an additional aspect, the base station 121 configures the scheduling assistance information for transmission to the UE 110. The UE 110 can request the scheduling assistance information by transmitting an RRC message to the base station 121. After the base station 121 grants the request from the UE 110 for the scheduling assistance information, the base station 121

periodically transmits the scheduling assistance information to the UE 110. Additionally or optionally, the UE 110 can include a desired periodicity in the RRC message requesting the scheduling assistance information. Additionally or optionally, the UE 110 can send threshold information to the base station 121 that directs the base station 121 to only update the scheduling assistance information if the requested data (such as a number of available future resource blocks 410) is above a threshold value or within a range of values.

[0042] In other aspects, the UE 110 can adjust application settings based on the lower layer metrics. For example, the UE 110 can adjust a video-streaming codec resolution or a streaming buffer time based on the DL scheduling assistance information provided by the base station 121. In another example, the UE 110 can adjust video call quality based on UL scheduling assistant information. In a further example, the UE 110 can adjust application settings based on the queueing delay and/or jitter information provided by the core network 150. If the latency is low (below a first threshold set at the application), then the UE 110 application may request to perform graphics processing at a cloud service or an edge computing service. If the latency is high (above a second threshold set at the application), then the UE 110 can opt for more local processing as opposed to offloading the processing to the cloud service or the edge computing service.

[0043] FIG. 5 illustrates example data and control transactions between the UE 110, the base station 120, and the core network 150 in accordance with aspects of communication of scheduling assistance information. Although not illustrated for the sake of illustration clarity, various acknowledgements for messages illustrated in FIG. 5 may be implemented to ensure reliable operations of communication of scheduling assistance information.

[0044] At 505, the UE 110 requests scheduling assistance information from the base station 120. For example, the UE 110 transmits an RRC message requesting scheduling assistance information. The request may include requested parameters for the scheduling assistance information, for example a periodicity for receiving the scheduling assistance information, what

information to include in the scheduling assistance information, a low-pass filter time constant to calculate a moving average of available air interface resources, and so forth.

[0045] Optionally at 510, the base station 120 forwards the request for the scheduling assistance information to the core network 150 for scheduling information that is available only from the core network. For example, if the UE 110 only requests available air interface resources, step 510, 515, and 540 are optional. To obtain aspects of the scheduling assistance information, such as DL queueing delay and/or jitter information, the forwarded request directs the UPF to provide scheduling assistance information for the UE 110.

[0046] At 515, the core network 150 provides scheduling assistance information for the UE 110 to the base station 120. At 520, the base station 120 transmits scheduling assistance information to the UE 110. The transmitted scheduling assistance information includes scheduling assistance information generated by the base station 120 and/or scheduling assistance information received from the core network 150.

[0047] At 525, the UE 110 uses the received scheduling assistance information to adjust application settings or application layer parameters to adapt to current network and wireless link conditions. For example, the UE 110 may adjust codec data rates, adjust a buffer size, determine to use local, edge, or cloud-based computing, and so forth.

[0048] At 530, the UE 110 determines whether to continue using the scheduling assistance information. For example, the UE 110 periodically receives scheduling assistance information. At some point, a user stops using an application (*e.g.*, streaming media, video calling, online gaming, etc.) that benefits from the scheduling assistance, and the UE 110 decides to either continue using the periodically received scheduling assistance or terminate reception of the scheduling assistance information.

[0049] At 535, based on the UE 110 deciding to terminate the reception of scheduling assistance information, the UE 110 transmits an RRC message to the base station 120 that directs the base station 120 to terminate providing scheduling assistance information to the UE 110.

Based on receiving the RRC termination message at 535, the base station 120, at 540, forwards the request to terminate the reception of scheduling assistance information to the core network 150, directing the core network 150 to discontinue providing scheduling assistance information to the UE 110.

Example Methods

[0050] Example methods 600 and 700 are described with reference to FIGs. 6 and 7 in accordance with one or more aspects of communication of scheduling assistance information. FIG. 6 illustrates example method(s) 600 of communication of scheduling assistance information as generally related to the user equipment 110.

[0051] At block 602, a user equipment determines to use scheduling assistance information (SAI) to affect application performance. For example, a user equipment (*e.g.*, the UE 110) or an application at an application layer (*e.g.*, the application layer 320) determines that scheduling assistance information can be used to adapt an application layer behavior, such as optimizing a streaming video frame rate or a buffer size based on the scheduling assistance information.

[0052] At block 604, based on the determination to use the scheduling assistance information, the UE transmits a request for the SAI to a network entity. For example, the UE 110 transmits an RRC message requesting scheduling assistance information to a base station (*e.g.*, the base station 120) or via the base station 120 to a core network (*e.g.*, the core network 150) function, such as a User Plane Function, Session Management Function, or an Access and Mobility Function. The request may include requested parameters for the scheduling assistance information: for example, a periodicity for receiving the scheduling assistance information, what information to include in the scheduling assistance information, and so forth.

[0053] At block 606, the UE receives the SAI from the network entity. For example, the UE 110 receives scheduling assistance information generated by the base station 120 and/or

scheduling assistance information generated by the core network 150 and received via the base station 120.

[0054] At block 608, the user equipment adjusts one or more application parameters based on the received SAI. For example, the UE 110 uses the received scheduling assistance information to adjust application or application layer parameters to adapt to current network and wireless link conditions. For example, the UE 110 may adjust codec data rates, adjust a buffer size, determine to use local, edge, or cloud-based computing, or the like.

[0055] FIG. 7 illustrates example method(s) 700 of communication of scheduling assistance information as generally related to a network entity (the base station 120 or a function in the core network 150). At block 702, a network entity receives a request for scheduling assistance information (SAI) from a UE. For example, the network entity (e.g., the base station 120 or a core network 150 function) receives a request for scheduling assistance information from a UE (e.g., the UE 110) in an RRC message.

[0056] At block 704, in response to the received request, the network entity generates the scheduling assistance information. For example, in response to the received request, the base station 120 and/or a core network 150 function generate scheduling information, such as available air interface resources that are available over a future period of time, an uplink SINR, UL interference information, a packet delay, and/or jitter.

[0057] At block 706, the network entity transmits an indication of the generated the SAI to the UE, the transmission assisting the UE to adjust one or more application parameters based on the SAI. For example, the base station 120 (or a core network 150 function via the base station 120) transmits an indication of the SAI to the UE 110. The UE 110 uses the SAI to adjust application or application layer parameters such as codec data rates, a buffer size, the use of local, edge, or cloud-based computing, or the like.

[0058] The order in which the method blocks of methods 600 and 700 are described are not intended to be construed as a limitation, and any number of the described method blocks can

be skipped or combined in any order to implement a method or an alternate method. Generally, any of the components, modules, methods, and operations described herein can be implemented using software, firmware, hardware (*e.g.*, fixed logic circuitry), manual processing, or any combination thereof. Some operations of the example methods may be described in the general context of executable instructions stored on computer-readable storage memory that is local and/or remote to a computer processing system, and implementations can include software applications, programs, functions, and the like. Alternatively or in addition, any of the functionality described herein can be performed, at least in part, by one or more hardware logic components, such as, and without limitation, Field-programmable Gate Arrays (FPGAs), Application-specific Integrated Circuits (ASICs), Application-specific Standard Products (ASSPs), System-on-a-chip systems (SoCs), Complex Programmable Logic Devices (CPLDs), and the like.

[0059] In the following text some examples are described:

Example 1: A method for managing application performance by a user equipment, UE, the method comprising the user equipment:

determining to use scheduling assistance information, SAI, to affect application performance;

based on the determining, transmitting a request for the SAI to a network entity; and
receiving the SAI from the network entity.

Example 2: The method of example 1, wherein the network entity comprises a base station, and wherein the receiving the SAI comprises:

receiving an indication of available air interface resources that are available over a future period of time.

Example 3: The method of example 2, wherein the receiving the indication of the available air interface resources that are available over the future period of time comprises:

receiving an indication of an amount of available Physical Downlink Shared Channel, PDSCH, air interface resources over the future period of time.

Example 4: The method of example 3, the method further comprising the user equipment:

computing an average downlink throughput based on the received indication of the amount of available PDSCH air interface resources and one or more of a current downlink Channel Quality Indicator, CQI, a current Modulation and Coding Scheme, MCS, or a currently used number of downlink resource blocks.

Example 5: The method of any one of examples 2 to 4, wherein the receiving the indication of the available air interface resources that are available over the future period of time comprises:

receiving an indication of an amount of available Physical Uplink Shared Channel, PUSCH, air interface resources that are available over the future period of time.

Example 6: The method of example 5, the method further comprising the user equipment:

computing an average uplink throughput based on the received indication of the amount of available PUSCH air interface resources and one or more of an available power headroom or a currently used number of uplink resource blocks.

Example 7: The method of any one of the preceding examples, wherein the network entity comprises a base station, and wherein the receiving the SAI comprises:

receiving an indication of an uplink Signal to Interference and Noise Ratio, SINR, of the UE from the base station.

Example 8: The method of example 7, the method further comprising the user equipment:

computing an average uplink throughput based on the received indication of the uplink SINR and one or more of: a current uplink transmit power of the UE; or a path loss estimate.

Example 9: The method of any one of the preceding examples, wherein the receiving the SAI comprises:

receiving an indication of a delay parameter for downlink data.

Example 10: The method of example 9, wherein the delay parameter is a queueing delay or a jitter.

Example 11: The method of example 9 or example 10, wherein the receiving the SAI comprises:

receiving the SAI on a per-radio-bearer basis; or

receiving the SAI on a per-QoS-flow basis.

Example 12: The method of any one of examples 9 to 11, wherein the network entity is:

a base station;

a User Plane Function, UPF, of a core network;

a Session Management Function, SMF, of the core network; or

an Access and Mobility Function, AMF, of the core network.

Example 13: The method of any one of the preceding examples, the method further comprising the user equipment:

adjusting one or more application parameters based on the received SAI.

Example 14: The method of example 13, wherein adjusting application parameters based on the received SAI, comprises the UE:

adjusting one or more settings of a codec;

adjusting a buffer size; or

adjusting application processing offloading.

Example 15: The method of example 14, wherein the adjusting one or more settings of the codec comprises one or more of:

- adjusting a codec resolution;
- adjusting a codec frame rate; or
- adjusting a codec bit rate.

Example 16: The method of example 14, wherein the adjusting the location for application processing comprises one or more of:

- adjusting an amount of processing performed at the UE;
- adjusting an amount of processing performed at an edge computing service; or
- adjusting an amount of processing performed at a cloud-based computing service.

Example 17: The method of any one of the preceding examples, wherein the receiving the SAI from the network entity comprises:

- receiving the SAI in a Radio Resource Control, RRC, message or a Non-Access Stratum, NAS, message.

Example 18: A user equipment comprising:

- a wireless transceiver;
- a processor; and
- instructions for an application manager that are executable by the processor to configure the user equipment to perform any one of methods 1 to 17.

Example 19: A method for providing scheduling assistance information, SAI, to a user equipment, UE, by a network entity, the method comprising the network entity:

receiving a request for the SAI from the UE;
in response to the received request, generating the SAI; and
transmitting an indication of the generated SAI to the UE, the transmitting assisting the UE to adjust one or more application parameters based on the SAI.

Example 20: The method of example 19, wherein the network entity is a base station, and wherein the generating the SAI comprises:

determining available air interface resources that are available over a future period of time.

Example 21: The method of example 20, wherein the determining the available air interface resources that are available over the future period of time comprises one or more of:

determining available Physical Downlink Shared Channel, PDSCH, air interface resources that are available over the future period of time; or

determining available Physical Uplink Shared Channel, PUSCH, air interface resources that are available over the future period of time.

Example 22: The method of example 20 or example 21, wherein the determining the available air interface resources that are available over the future period of time comprises:

determining an average of available resources over a time period.

Example 23: The method of example 22, wherein the determining the average of available resources over the time period comprises:

determining a moving average.

Example 24: The method of example 23, wherein the determining the moving average comprises:

determining a moving average with a low-pass filter.

Example 25: The method of example 24, further comprising the base station:

receiving, from the UE, a request for a low-pass-filter time constant for the low-pass filter;

or

transmitting low-pass filter coefficients to the UE.

Example 26: The method of any one of examples 20 to 25, wherein the determining the available air interface resources that are available over the future period of time comprises:

determining the available air interface resources based on one or more of:

a time of day;

traffic patterns of other UEs in a cell provided by the base station;

historical statistics; or

a current air interface resource utilization in the cell provided by the base station.

Example 27: The method of any one of examples 19 to 26, wherein the network entity is a base station;

wherein the generating the SAI comprises:

measuring an uplink Signal to Interference and Noise Ratio, SINR, of the UE or

determining uplink interference information; and

wherein the transmitting the generated indication of the SAI to the UE comprises:

transmitting the measured uplink SINR or the determined uplink interference information to the UE.

Example 28: The method of any one of examples 19 to 27, wherein the generating the SAI comprises:

generating an indication of a delay parameter for downlink data.

Example 29: The method of example 28, wherein the delay parameter comprises a queueing delay or a jitter.

Example 30: The method of example 28 or example 29, wherein the generating the SAI comprises:

generating the SAI on a per-radio-bearer basis; or

generating the SAI on a per-QoS-flow basis.

Example 31: The method of any one of examples 28 to 30, wherein the network entity is:

a base station;

a User Plane Function, UPF, of a core network;

a Session Management Function, SMF, of the core network; or

an Access and Mobility Function, AMF, of the core network.

Example 32: The method of any one of examples 19 to 31, wherein the transmitting the generated indication of the SAI to the UE comprises:

transmitting the generated indication of the SAI in a Radio Resource Control, RRC, message or a Non-Access Stratum, NAS, message.

Example 33: A network entity comprising:

a core network interface;

a processor; and

instructions for a scheduling manager that are executable by the processor to configure the network entity to perform any one of methods 19 to 32.

Example 34: A computer-readable medium comprising instructions that, when executed by a processor, cause an apparatus comprising the processor to perform any of the methods of examples 1 to 17 or 19 to 32.

[0060] Although aspects of communication of scheduling assistance information have been described in language specific to features and/or methods, the subject of the appended claims is not necessarily limited to the specific features or methods described. Rather, the specific features and methods are disclosed as example implementations of communication of scheduling assistance information, and other equivalent features and methods are intended to be within the scope of the appended claims. Further, various different aspects are described, and it is to be appreciated that each described aspect can be implemented independently or in connection with one or more other described aspects.

CLAIMS

1. A method for managing application performance by a user equipment, UE, the method comprising the user equipment:

transmitting a request for scheduling assistance information, SAI, to a network entity;

receiving the SAI from the network entity; and

adjusting one or more application parameters based on the received SAI.

2. The method of claim 1, wherein the network entity comprises a base station, and wherein the receiving the SAI comprises:

receiving an indication of available air interface resources that are available over a future period of time, wherein the indication of the available air interface resources that are available over a future period of time includes one or more of:

an indication of an amount of available Physical Downlink Shared Channel, PDSCH, air interface resources over the future period of time; or

an indication of an amount of available Physical Uplink Shared Channel, PUSCH, air interface resources that are available over the future period of time.

3. The method of claim 1 or claim 2, wherein the network entity comprises a base station, and wherein the receiving the SAI comprises:

receiving an indication of an uplink Signal to Interference and Noise Ratio, SINR, of the UE from the base station; and

computing an average uplink throughput based on the received indication of the uplink SINR and one or more of: a current uplink transmit power of the UE; or a path loss estimate.

4. The method of any one of the preceding claims, wherein the receiving the SAI comprises:

receiving an indication of a delay parameter for downlink data, wherein the delay parameter comprises a queueing delay or a jitter.

5. The method of claim 4, wherein the receiving the SAI comprises:

receiving the SAI on a per-radio-bearer basis; or

receiving the SAI on a per-QoS-flow basis.

6. The method of claim 4 or claim 5, wherein the network entity is:

a base station;

a User Plane Function, UPF, of a core network;

a Session Management Function, SMF, of the core network; or

an Access and Mobility Function, AMF, of the core network.

7. The method of any one or the preceding claims, wherein adjusting application parameters based on the received SAI, comprises the UE:

adjusting one or more settings of a codec;

adjusting a buffer size; or

adjusting application processing offloading.

8. The method of claim 7, wherein the adjusting one or more settings of the codec comprises one or more of:

adjusting a codec resolution;

adjusting a codec frame rate; or

adjusting a codec bit rate.

9. The method of claim 7, wherein the adjusting the application processing offloading comprises one or more of:

adjusting an amount of processing performed at the UE;

adjusting an amount of processing performed by an edge computing service; or

adjusting an amount of processing performed by a cloud-based computing service.

10. A user equipment comprising:

a wireless transceiver;

a processor; and

instructions for an application manager that are executable by the processor to configure the user equipment to perform any one of methods 1 to 9.

11. A method for providing scheduling assistance information, SAI, to a user equipment, UE, by a network entity, the method comprising the network entity:

receiving a request for the SAI from the UE;

in response to the received request, generating the SAI; and

transmitting an indication of the generated SAI to the UE, the transmitting assisting the UE to adjust one or more application parameters based on the SAI.

12. The method of claim 11, wherein the network entity is a base station, and wherein the generating the SAI comprises:

determining available air interface resources that are available over a future period of time, wherein the available air interface resources that are available over the future period of time comprises one or more of:

available Physical Downlink Shared Channel, PDSCH, air interface resources that are available over the future period of time; or

available Physical Uplink Shared Channel, PUSCH, air interface resources that are available over the future period of time.

13. The method of claim 12, wherein the determining the available air interface resources that are available over the future period of time comprises:

determining an average of available resources over a time period by using a low pass filter to determine a moving average;

the method further comprising the base station:

receiving, from the UE, a request for a low-pass filter time constant for the low-pass filter; or

transmitting low-pass filter coefficients to the UE.

14. The method of any one of claims 11 to 13, wherein the network entity is a base station;

wherein the generating the SAI comprises:

measuring an uplink Signal to Interference and Noise Ratio, SINR, of the UE or determining uplink interference information; and

wherein the transmitting the generated indication of the SAI to the UE comprises:

transmitting the measured uplink SINR or the determined uplink interference information to the UE.

15. The method of any one of claims 11 to 14, wherein the generating the SAI comprises:

generating an indication of a delay parameter for downlink data, wherein the delay parameter comprises a queueing delay or a jitter.

16. The method of claim 15, wherein the generating the SAI comprises:

generating the SAI on a per-radio-bearer basis; or

generating the SAI on a per-QoS-flow basis.

17. The method of claim 15 or claim 16, wherein the network entity is:

a base station;

a User Plane Function, UPF, of a core network;

a Session Management Function, SMF, of the core network; or

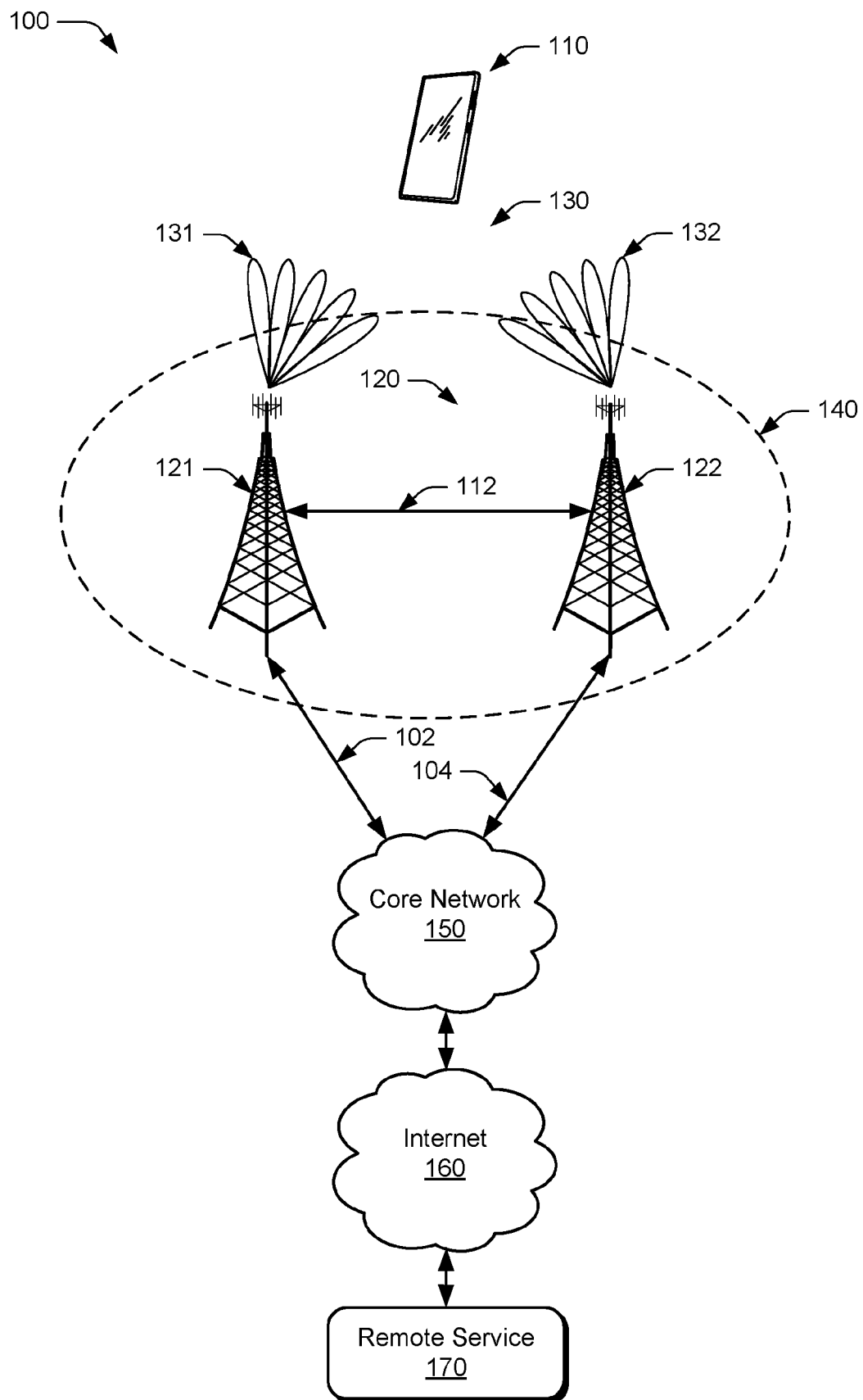
an Access and Mobility Function, AMF, of the core network.

18. A network entity comprising:

a core network interface;

a processor; and

instructions for a scheduling manager that are executable by the processor to configure the network entity to perform any one of methods 11 to 17.

**Fig. 1**

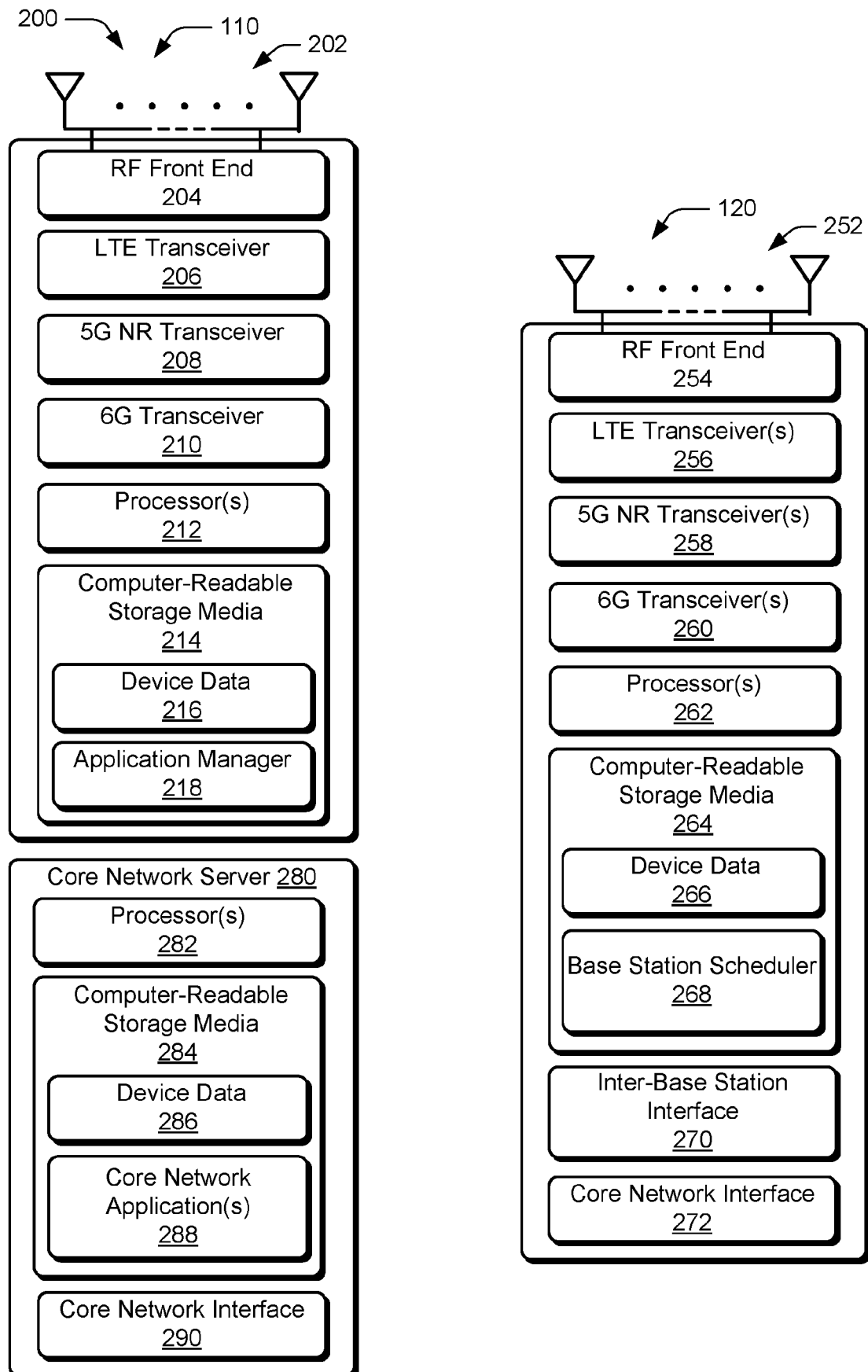


Fig. 2

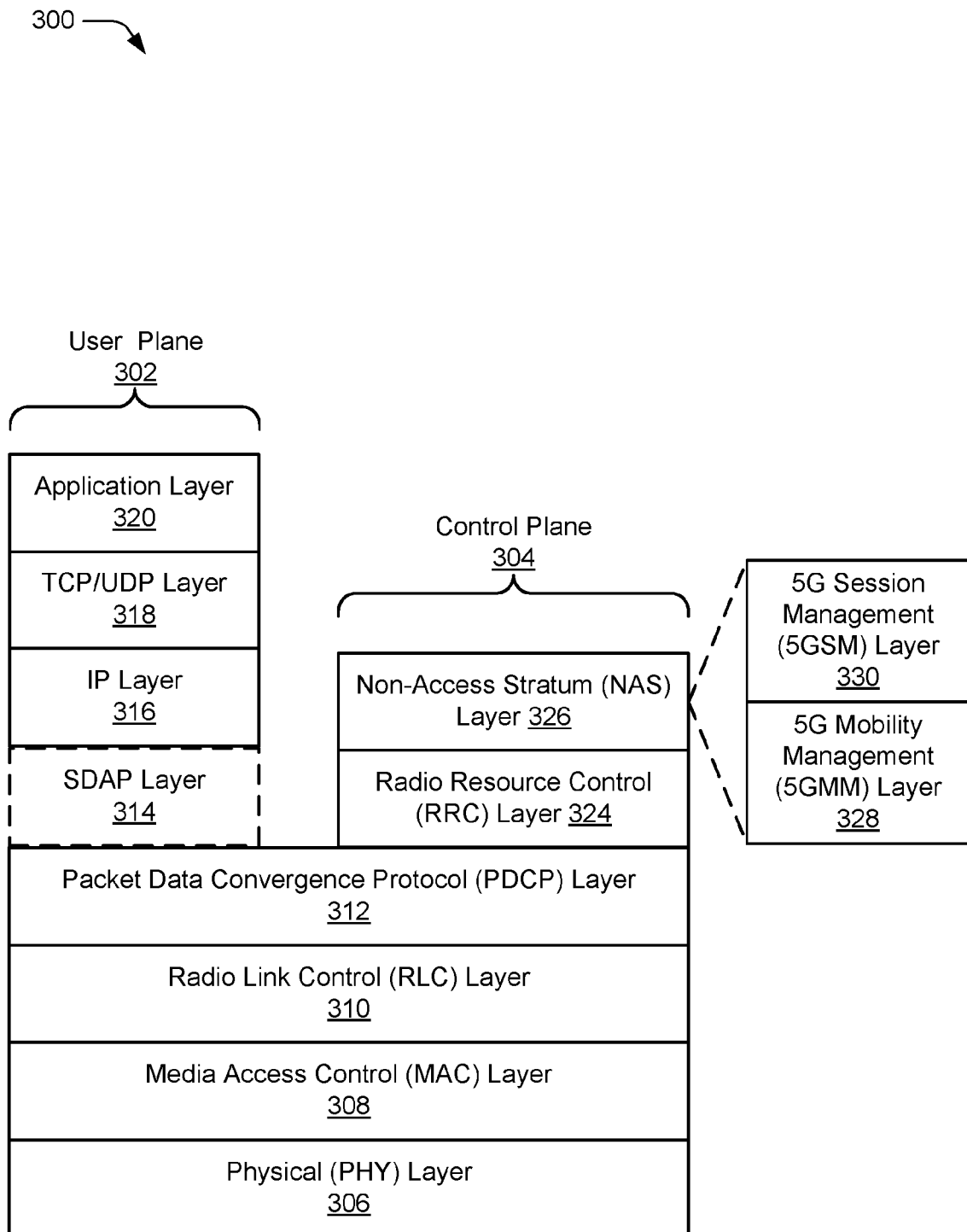


Fig. 3

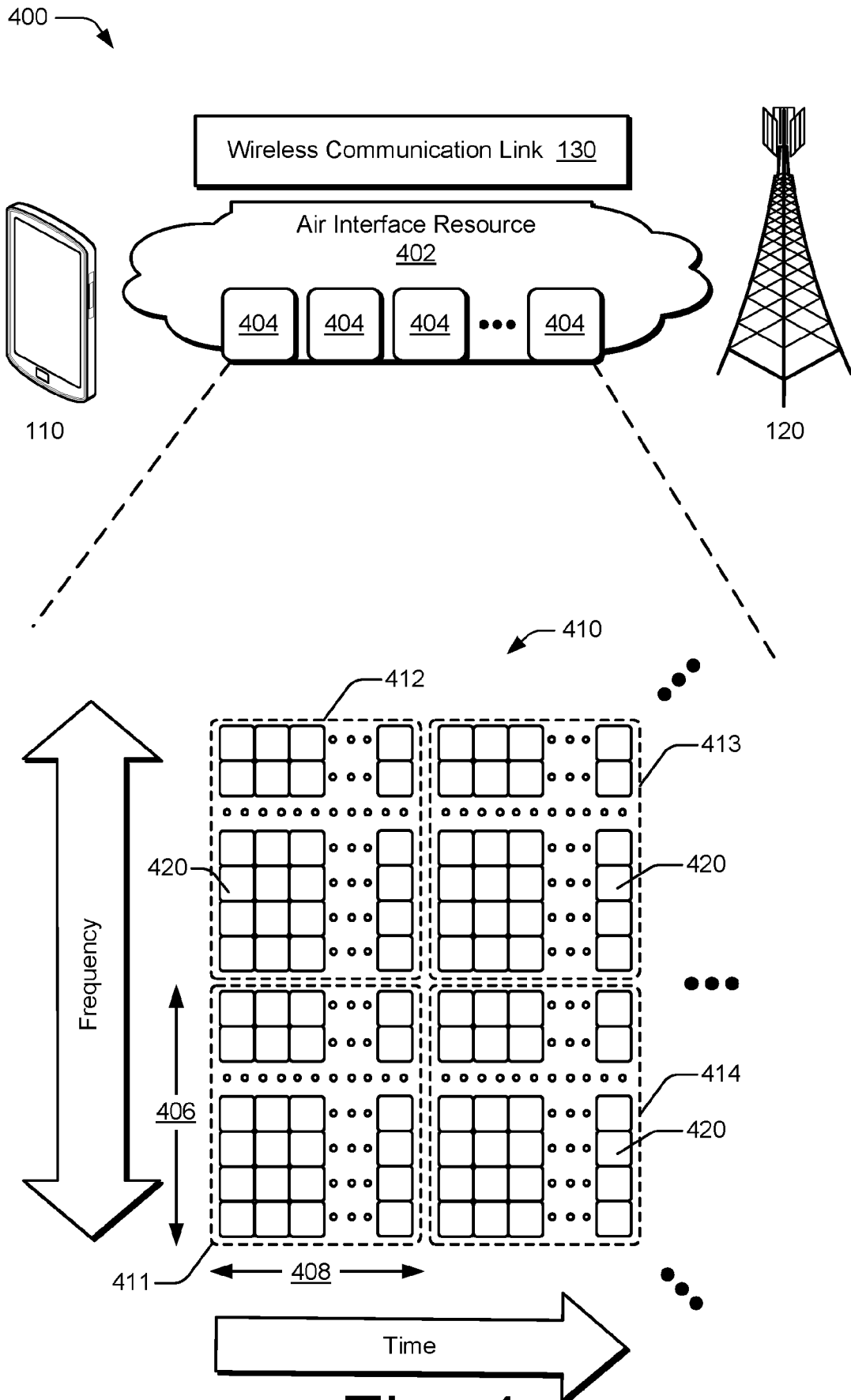


Fig. 4

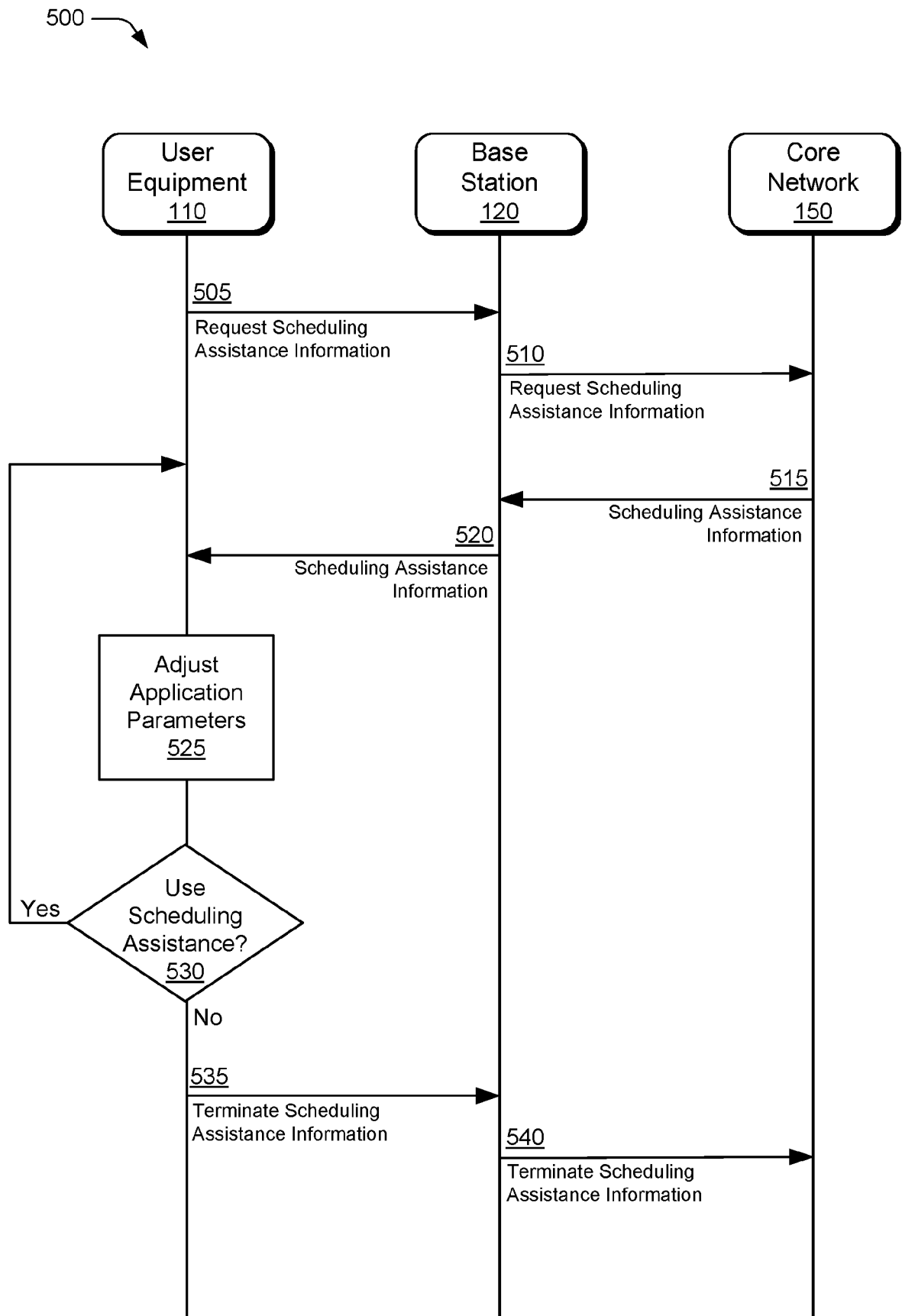


Fig. 5

600 →

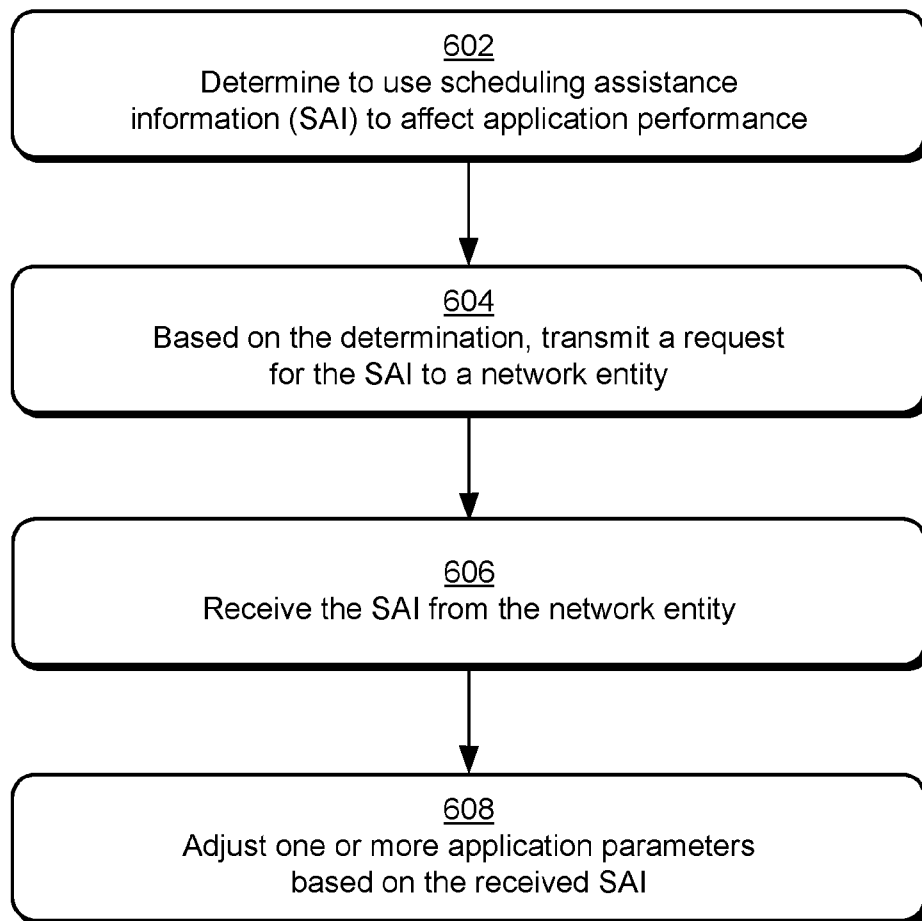


Fig. 6

700 →

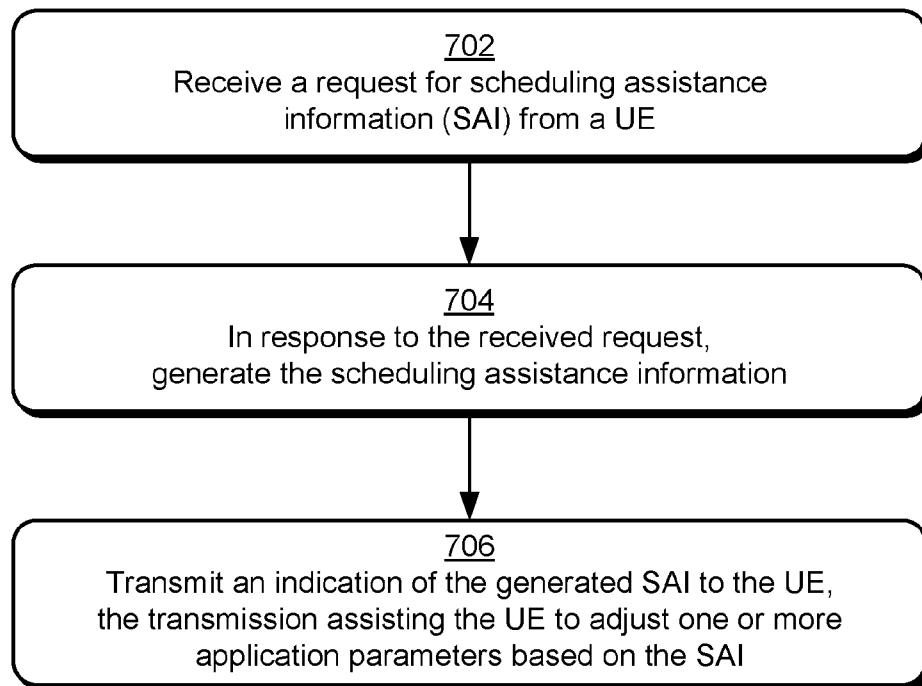


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/056447

A. CLASSIFICATION OF SUBJECT MATTER INV. H04W28/24 ADD. H04W4/18 H04W4/50 H04M1/72403		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H04W H04M		
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.
X	WO 2018/144928 A1 (KYOCERA CORP [JP]; CHANG HENRY [US]; FUJISHIRO MASATO [JP]) 9 August 2018 (2018-08-09) abstract figures 1,2B,3,4 claim 1 paragraphs [0004], [0005], [0027] - [0032], [0039], [0043] -----	1-18
A	US 2020/204291 A1 (AWONIYI-OTERI OLUFUNMILOLA OMOLADE [US] ET AL) 25 June 2020 (2020-06-25) the whole document -----	1-18
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 8 February 2022		Date of mailing of the international search report 23/02/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Manuel, Grégory

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2021/056447

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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