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(54) **ENERGY-HARVESTING DEVICES IN WIRELESS NETWORKS**

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CPC ***H04W 52/243*** (2013.01); ***H04L 47/12*** (2013.01); ***H04L 47/20*** (2013.01); ***H04W 24/02*** (2013.01); ***H04W 24/10*** (2013.01); ***H04W 28/0247*** (2013.01); ***H04W 28/0252*** (2013.01); ***H04W 28/08*** (2013.01); ***H04W 52/244*** (2013.01); ***H04W 52/283*** (2013.01)

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None
See application file for complete search history.

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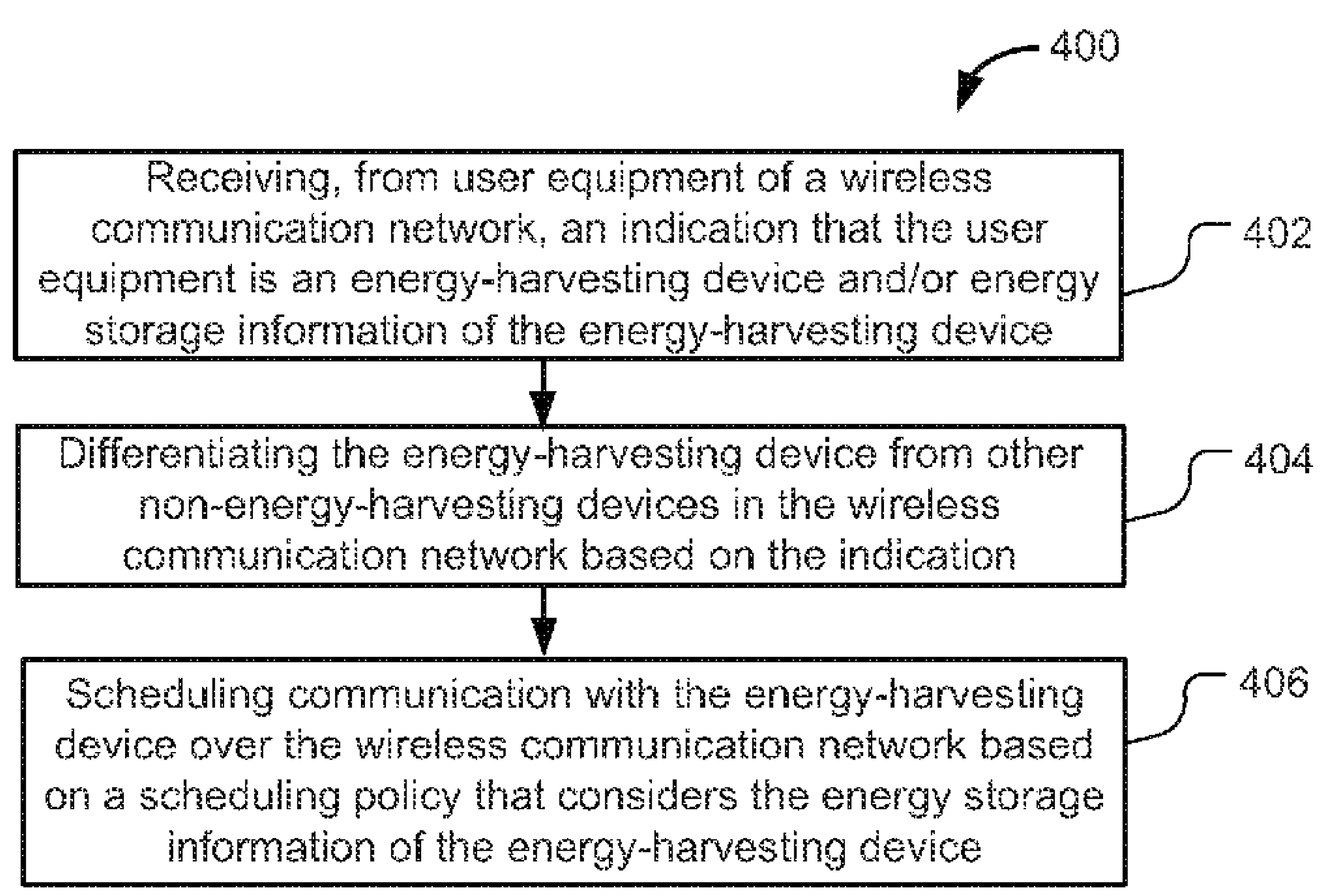
(57) **ABSTRACT**

Embodiments of the present disclosure describe communication techniques and configurations for energy-harvesting devices in a wireless communication network. An apparatus may include circuitry to receive, by a network device of a wireless communication network, a message from user equipment, the message including an indication that the user equipment is an energy-harvesting device and circuitry to differentiate the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication. Other embodiments may be described and/or claimed.

34 Claims, 4 Drawing Sheets



(51) **Int. Cl.**

H04W 24/02	(2009.01)
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H04L 12/813	(2013.01)
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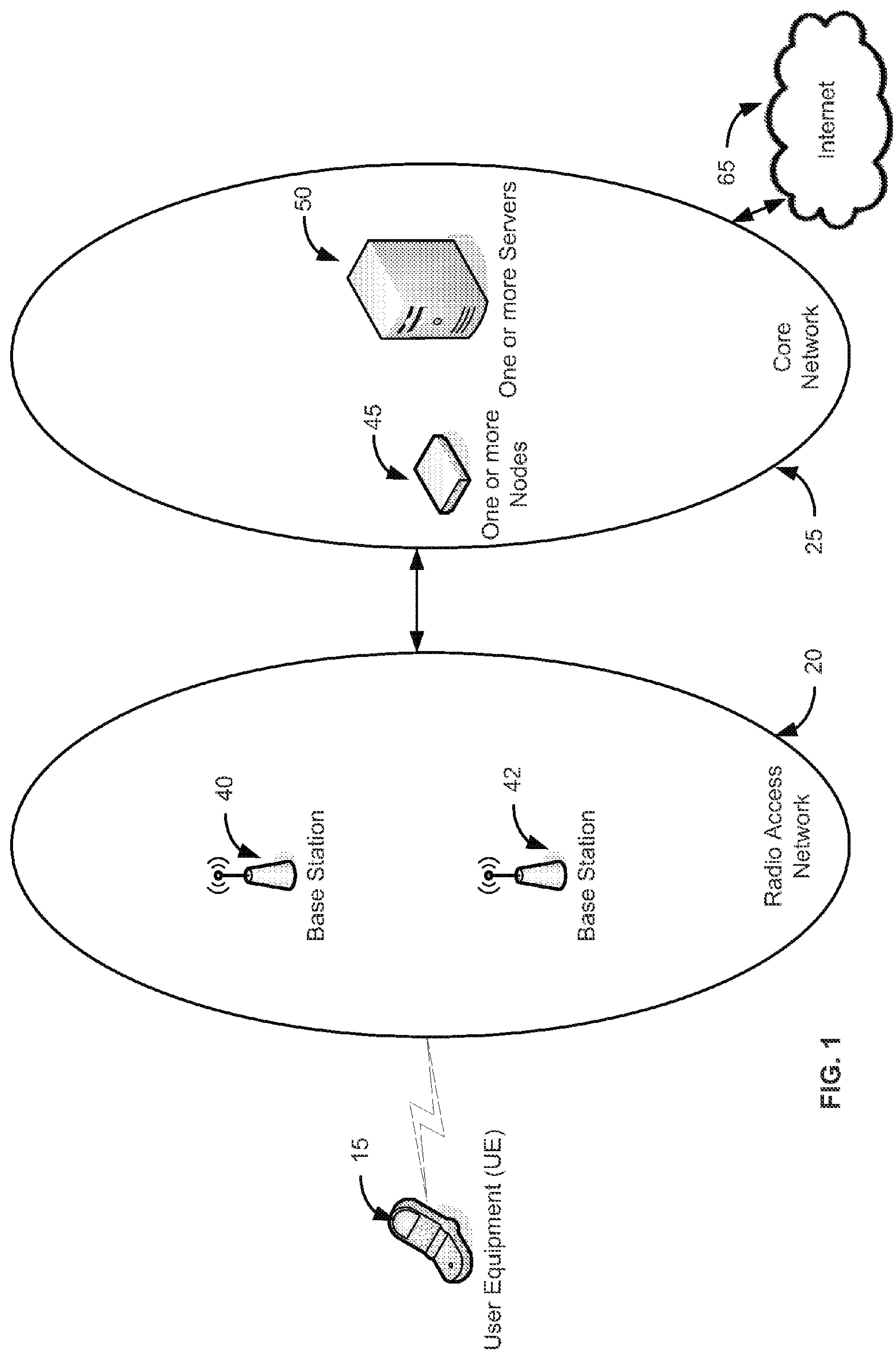
100
User Equipment (UE)
15
Base Station
40
Base Station
42
Radio Access Network
20
One or more Nodes
45
One or more Servers
50
Core Network
25
Internet
65

FIG. 1

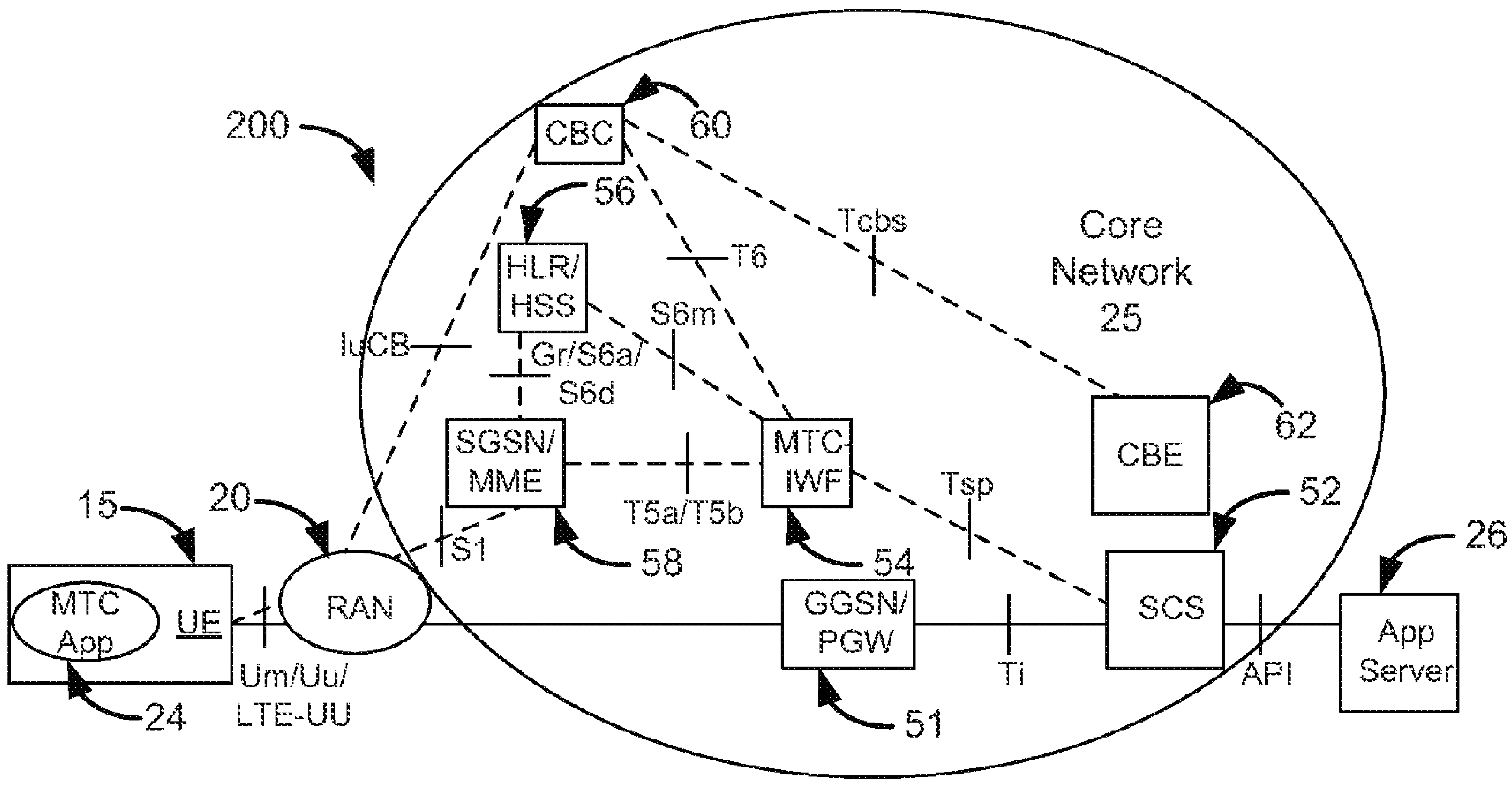
200
CBC
60
56
HLR/
HSS
T6
Tcbs
Core
Network
25
S6m
IuCB
Gr/S6a/
S6d
SGSN/
MME
MTC-
IWF
CBE
62
Tsp
52
T5a/T5b
S1
58
54
15
20
MTC
App
UE
RAN
GGSN/
PGW
Ti
SCS
API
App
Server
26
Um/Uu/
LTE-UU
24
51

FIG. 2

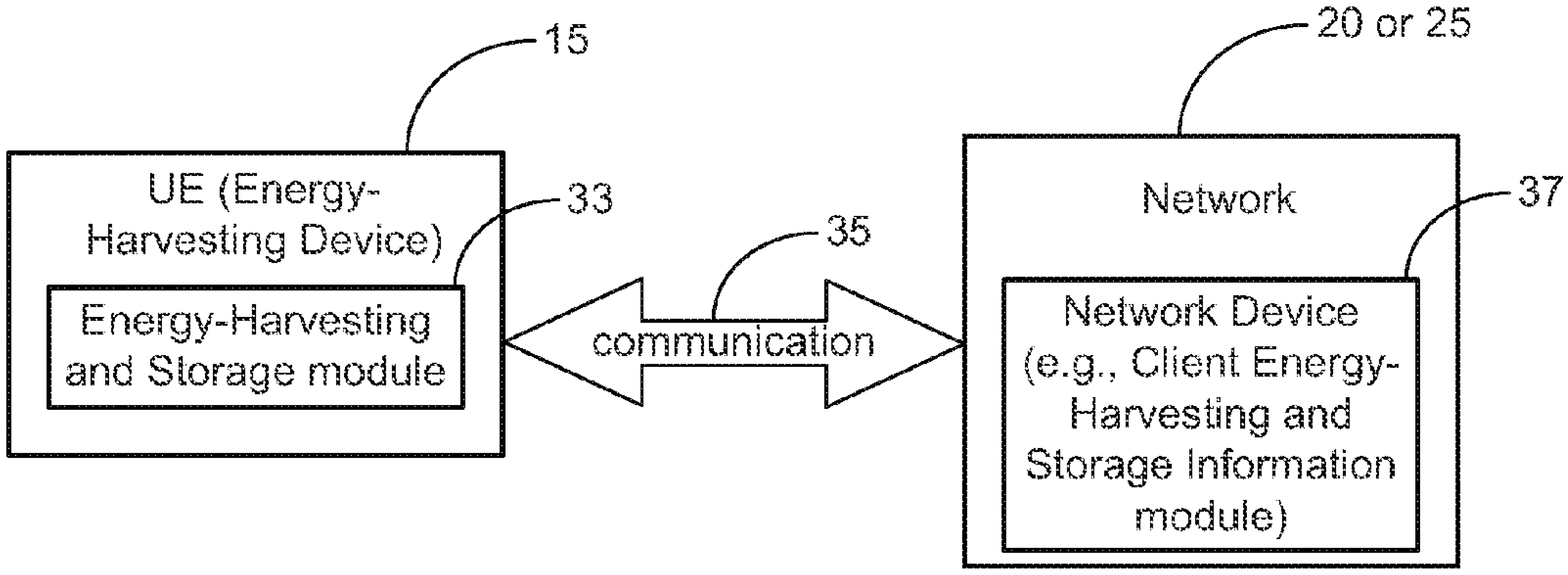
15
20 or 25
UE (Energy-
Harvesting Device)
33
Energy-Harvesting
and Storage module
35
communication
Network
37
Network Device
(e.g., Client Energy-
Harvesting and
Storage Information
module)

FIG. 3

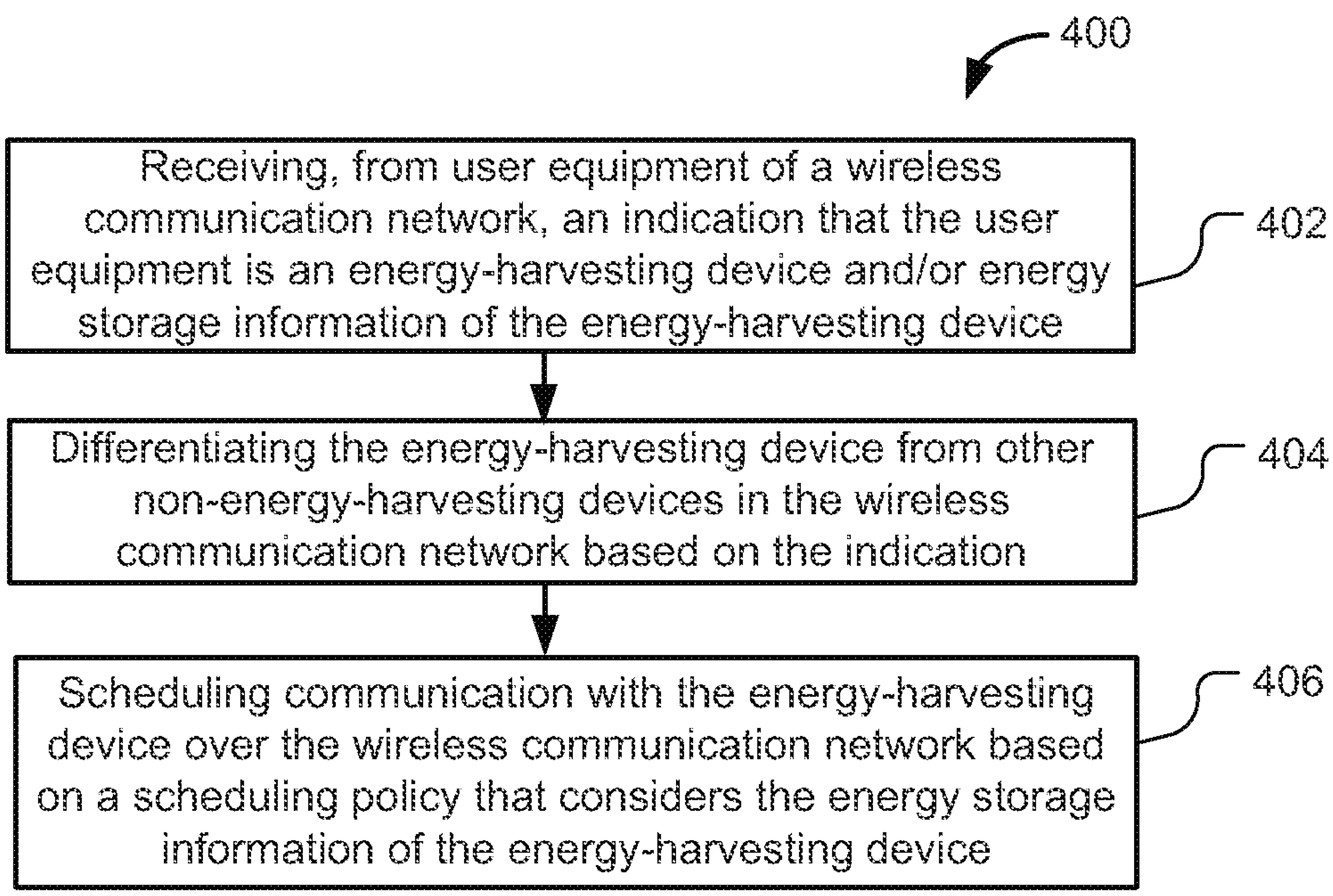
400
Receiving, from user equipment of a wireless communication network, an indication that the user equipment is an energy-harvesting device and/or energy storage information of the energy-harvesting device
402
Differentiating the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication
404
Scheduling communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers the energy storage information of the energy-harvesting device
406

FIG. 4

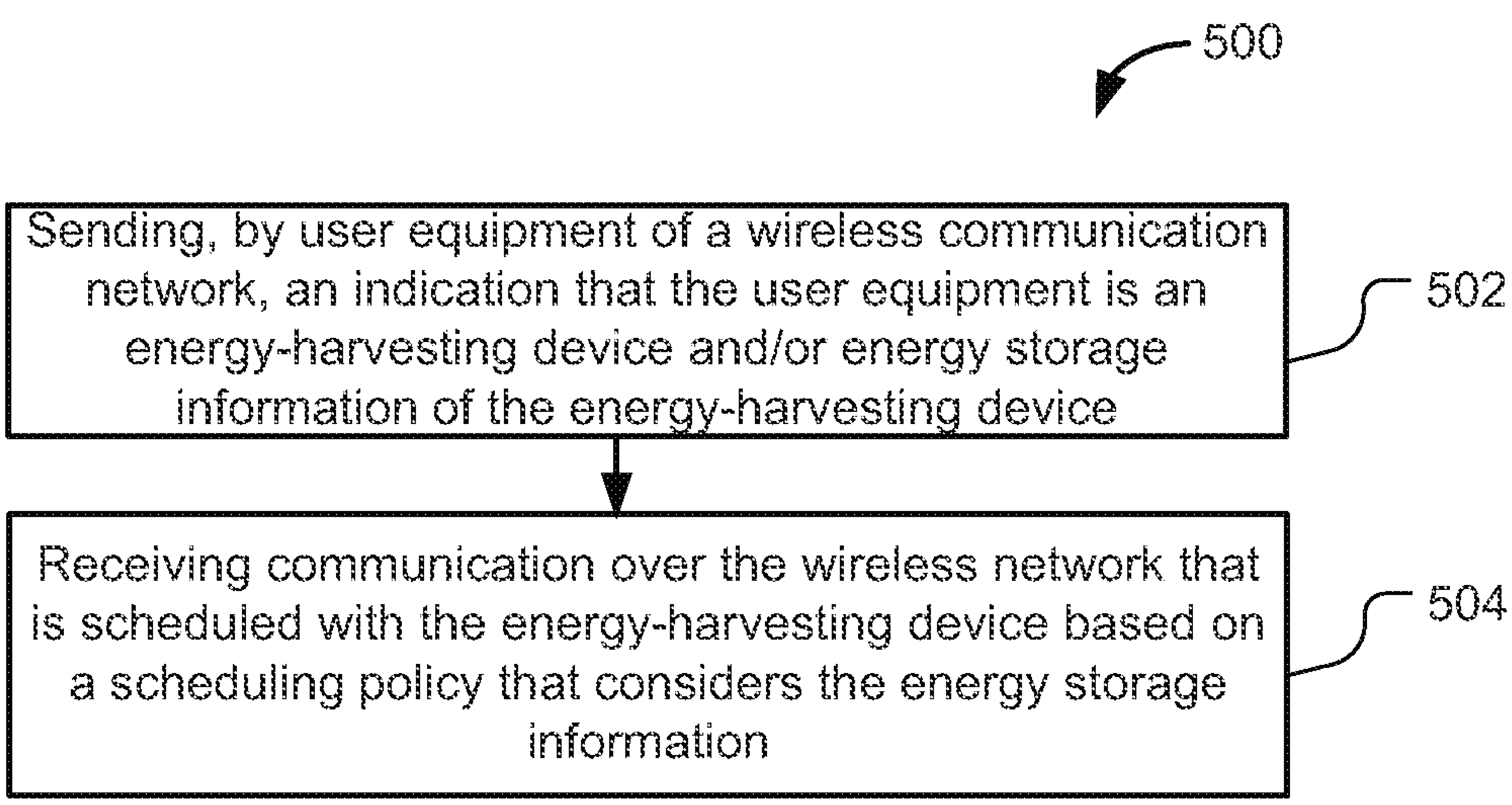
500
Sending, by user equipment of a wireless communication network, an indication that the user equipment is an energy-harvesting device and/or energy storage information of the energy-harvesting device
502
Receiving communication over the wireless network that is scheduled with the energy-harvesting device based on a scheduling policy that considers the energy storage information
504

FIG. 5

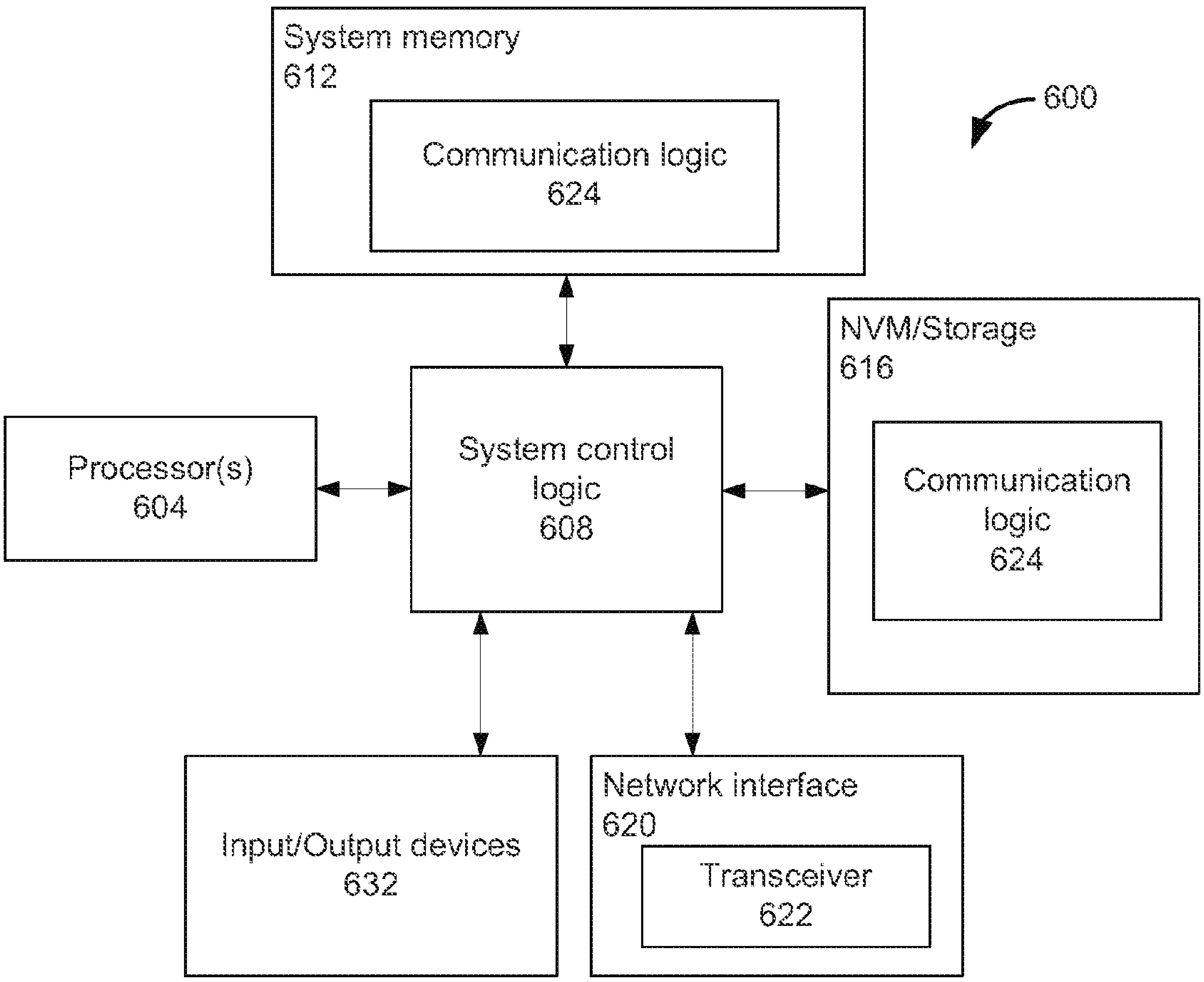
System memory
612
Communication logic
624
600
NVM/Storage
616
Processor(s)
604
System control logic
608
Communication logic
624
Input/Output devices
632
Network interface
620
Transceiver
622

FIG. 6

ENERGY-HARVESTING DEVICES IN WIRELESS NETWORKS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a national phase entry under 35 U.S.C. §371 of International Application No. PCT/US2013/058564, filed Sep. 6, 2013, entitled "ENERGY-HARVESTING DEVICES IN WIRELESS NETWORKS", which designates the United States of America, and which claims priority to U.S. Provisional Patent Application No. 61/752,386, filed Jan. 14, 2013, entitled "Advanced Wireless Communication Systems and Techniques," the entire disclosure of which is hereby incorporated by reference in its entirety.

FIELD

Embodiments of the present disclosure generally relate to the field of wireless communication systems, and more particularly, to energy-harvesting devices in wireless networks.

BACKGROUND

Mobile networks that facilitate transfer of information at broadband rates continue to be developed and deployed. Such networks may be colloquially referred to herein as broadband wireless access (BWA) networks. A variety of different device types may be used in broadband wireless technologies. Such devices may include, for example, personal computers, smartphone, laptops, netbooks, ultrabooks, tablets, handheld devices, and other consumer electronics such as music players, digital cameras, etc., that are configured to communicate over the wireless broadband networks.

Machine-to-Machine (M2M) may refer to technologies that allow wireless and wired systems to communicate with other devices without any human intervention. M2M may use a device such as, for example, a sensor or meter to collect information, which may be relayed through a network (e.g., wireless, wired, or hybrid) to an application that translates the information into meaningful data. The device may be, for example, a machine type communication (MTC) device configured to communicate with an MTC server in a BWA network. The expansion of BWA networks across the world and accompanying increased speed/bandwidth and reduced power of wireless communication has facilitated growth of M2M communication.

Currently, there is growing interest in introducing energy-harvesting devices in wireless networks, especially for M2M communications in applications where the devices need to be small, cheap and are not easily maintained. Current wireless protocols may be designed with an expectation that a client device will have sufficient energy from either battery or connected power supply for communication for communication. However, energy-harvesting devices may store energy harvested by the device and, thus, may not have an amount of energy sufficient to communicate with the wireless network in accordance with current wireless protocols. For example, in present cellular networks, a network scheduler may schedule transmissions based on factors that fail to consider energy storage capability, capacity or level of an energy harvesting device, which may result in inefficient operation of the energy storage device due to wasted energy, lost opportunity to harvest energy, potentially failed transmission/receptions. For example, if the energy storage information of the energy-harvesting device is not known at the network, the scheduler may communicate with the energy-harvesting device at a

time that results in lost opportunity to generate and store energy or at a time when energy harvesting capability or storage level is too low to support reliable communication.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

FIG. **1** schematically illustrates an example broadband wireless access (BWA) network in accordance with some embodiments.

FIG. **2** schematically illustrates an example system architecture for communication with an energy-harvesting device, in accordance with some embodiments.

FIG. **3** schematically illustrates communication between an energy-harvesting device and a network device, in accordance with some embodiments.

FIG. **4** is a flow diagram of a method for communicating with an energy-harvesting device from a network perspective, in accordance with some embodiments.

FIG. **5** is a flow diagram of a method for communicating with a network from user equipment perspective, in accordance with some embodiments.

FIG. **6** schematically illustrates an example system that may be used to practice various embodiments described herein.

DETAILED DESCRIPTION

Embodiments of the present disclosure describe communication techniques and configurations for energy-harvesting devices in a wireless communication network. In the following detailed description, reference is made to the accompanying drawings which form a part hereof, wherein like numerals designate like parts throughout, and in which is shown by way of illustration embodiments in which the subject matter of the present disclosure may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments is defined by the appended claims and their equivalents.

For the purposes of the present disclosure, the phrase "A and/or B" means (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

The description may use the phrases "in an embodiment," or "in embodiments," which may each refer to one or more of the same or different embodiments. Furthermore, the terms "comprising," "including," "having," and the like, as used with respect to embodiments of the present disclosure, are synonymous.

As used herein, the term "circuitry," "module," or "logic" refers to, is part of, or includes hardware components such as an Application Specific Integrated Circuit (ASIC), an electronic circuit, a logic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group) that are configured to provide the described functionality. In some embodiments, the circuitry may execute one or more software or firmware programs to provide at least some of the described functionality.

Example embodiments may be described herein in relation to broadband wireless access (BWA) networks including networks operating in conformance with one or more protocols specified by the 3rd Generation Partnership Project (3GPP) and its derivatives, the WiMAX Forum, the Institute for Electrical and Electronic Engineers (IEEE) 802.16 standards (e.g., IEEE 802.16-2005 Amendment), long-term evolution (LTE) project along with any amendments, updates, and/or revisions (e.g., advanced LTE project, ultra mobile broadband (UMB) project (also referred to as "3GPP2"), etc.). IEEE 802.16 compatible BWA networks are generally referred to as WiMAX networks, an acronym that stands for Worldwide Interoperability for Microwave Access, which is a certification mark for products that pass conformity and interoperability tests for the IEEE 802.16 standards. In other embodiments, communication schemes described herein may be compatible with additional/alternative communication standards, specifications, and/or protocols. For example, embodiments of the present disclosure may be applied to other types of wireless networks where similar advantages may be obtained. Such networks may include, but are not limited to, wireless local area networks (WLANs), wireless personal area networks (WPANs) and/or wireless wide area networks (WWANs) such as cellular networks (e.g., 3G, 4G, 5G and so forth) and the like.

The following embodiments may be used in a variety of applications including transmitters and receivers of a mobile wireless radio system. Radio systems specifically included within the scope of the embodiments include, but are not limited to, network interface cards (NICs), network adaptors, base stations, access points (APs), relay nodes, enhanced node Bs, gateways, bridges, hubs and satellite radiotelephones. Further, the radio systems within the scope of embodiments may include satellite systems, personal communication systems (PCS), two-way radio systems, global positioning systems (GPS), two-way pagers, personal computers (PCs) and related peripherals, personal digital assistants (PDAs), personal computing accessories and all existing and future arising systems which may be related in nature and to which the principles of the embodiments could be suitably applied.

FIG. **1** schematically illustrates an example broadband wireless access (BWA) network **100** in accordance with some embodiments. The BWA network **100** may include one or more radio access networks (hereinafter "RAN **20**") and a core network **25**. The BWA network **100** may be referred to as a "wireless communication network" herein.

User Equipment (UE) **15** may access the core network **25** via a radio link ("link") with a base station (BS) such as, for example, one of base stations **40**, **42**, etc., in the RAN **20**. The UE **15** may, for example, be a client device (e.g., subscriber station) that is configured to communicate with the base stations **40**, **42** in conformance with one or more protocols. In some embodiments, the UE **15** may be or include an energy-harvesting device that is configured to harvest or generate energy for use in connection with communication and/or other operation (e.g., processing) of the UE **15**. The following description is provided for an example BWA network **100** that conforms with 3GPP for ease of discussion; however, subject matter of the present disclosure is not limited in this regard and the described embodiments may apply to other wireless communication networks (e.g., cellular networks) that benefit from the principles described herein. In one embodiment, the BWA network **100** may represent a cellular network configured to operate in conformance with a 3GPP protocol or standard.

In some embodiments, the base stations **40**, **42** may include one or more Node Bs (also commonly denoted as evolved Node Bs, enhanced Node Bs, eNode Bs, or eNBs in 3GPP LTE), hereinafter "eNB station," and a UE **15** that is configured to communicate with the BWA network **100** via the base stations **40**, **42**. In some embodiments, the UE **15** may be configured to communicate using a multiple-input and multiple-output (MIMO) communication scheme. The base stations **40**, **42** may include one or more antennas, one or more radio modules to modulate and/or demodulate signals transmitted or received on an air interface, and one or more digital modules to process signals transmitted and received on the air interface. One or more antennas of the UE **15** may be used to concurrently utilize radio resources of multiple respective component carriers (e.g., which may correspond with antennas of base stations **40**, **42**) of the BWA network **100**. The UE **15** may be configured to communicate using Orthogonal Frequency Division Multiple Access (OFDMA) in, e.g., downlink communications, and/or Single-Carrier Frequency Division Multiple Access (SC-FDMA) in, e.g., uplink communications in some embodiments.

In some embodiments, the UE **15** may be configured to communicate with another machine and be referred to as a machine type communication (MTC) device. The term MTC device refers to a device that is configured to communicate with another machine without the need for human interaction. For example, the MTC device may be configured to communicate with a server of the one or more servers **50**. An MTC device may be as simple as a sensor that is electrically coupled to a wireless transceiver. The wireless transceiver may be configured to communicate with at least one of a WPAN, WLAN, and WWAN. The MTC device can vary from the simple device to a complex device such as a smart phone, a tablet computing device, or a wireless laptop which may be employed for machine to machine communication. The MTC device can include a mobile station, as defined by IEEE 802.16e (2005 or 802.16m (2009) or user equipment, as defined by 3GPP LTE Release 8 (2008), Release 9 (2009), or Release 10 (2011), commonly referred to as Rel. 8/9/10. The term MTC, as used herein, is also considered to be inclusive of the term "machine to machine" (M2M), which is considered to be synonymous with the term "MTC." In some embodiments, the UE **15** may represent a plurality or group of wireless devices (e.g., MTC devices) that are configured to communicate with one or more network devices of the core network **25** via the RAN **20**.

While FIG. **1** generally depicts the UE **15** as a cellular phone, in various embodiments the UE **15** may be a personal computer (PC), a notebook, ultrabook, netbook, smart phone, an ultra mobile PC (UMPC), a handheld mobile device, an universal integrated circuit card (UICC), a sensor, a personal digital assistant (PDA), a Customer Premise Equipment (CPE), a tablet, or other consumer electronics such as MP3 players, digital cameras, and the like.

In some embodiments, communication with the UE **15** via RAN **20** may be facilitated via one or more nodes **45**. The one or more nodes **45** may serve as an interface between the core network **25** and the RAN **20**. According to various embodiments, the one or more nodes **45** may include a Mobile Management Entity (MME) (e.g., SGSN/MME **58** of FIG. **2**) that is configured to manage signaling exchanges (e.g., authentication of the UE **15**) between the base stations **40**, **42** and the core network **25** (e.g., one or more servers **50**), a Packet Data Network Gateway (PGW) (e.g., GGSN/PGW **51** of FIG. **2**) to provide a gateway router to the Internet **65**, and/or a Serving Gateway (SGW) to manage user data tunnels or paths between the base stations **40**, **42** of the RAN **20** and the PGW. Other types of nodes may be used in other embodiments.

The core network **25** may include logic to provide authentication of the UE **15**, device configuration, or other actions associated with establishment of a communication link to provide a connected state of the UE **15** with the BWA network **100**. For example, the core network **25** may include one or more servers **50** that may be communicatively coupled to the base stations **40**, **42**. In an embodiment, the one or more servers **50** may include a Home Subscriber Server (HSS) (e.g., HLR/HSS **56** of FIG. **2**), which may be used to manage user parameters such as a user's International Mobile Subscriber Identity (IMSI), authentication information, and the like. The one or more servers **50** may include logic that is configured to perform actions described in connection with a network device herein. The core network **25** may include other servers, interfaces, and modules some of which are further described in connection with FIG. **2**. The one or more servers **50** may include over-the-air (OTA) servers in some embodiments. In some embodiments, logic associated with different functionalities of the one or more servers **50** may be combined to reduce a number of servers, including, for example, being combined in a single machine or module.

According to various embodiments, the BWA network **100** is an Internet Protocol (IP) based network. For example, the core network **25** may be an IP based network. Interfaces between network nodes (e.g., the one or more nodes **45**) may be based on IP, including a backhaul connection to the base stations **40**, **42**. In some embodiments, the BWA network **100** includes a Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS), High Speed Packet Access (HSPA), Evolved HSPA (E-HSPA), or Long Term Evolution (LTE) network. In some embodiments, the RAN **20** may include GSM EDGE Radio Access Network (GERAN) where EDGE stands for Enhanced Data for GSM Evolution, Universal Terrestrial Radio Access Network (UTRAN), or Evolved UTRAN (E-UTRAN). The BWA network **100** may operate in accordance with other network technologies in other embodiments.

In an embodiment where the RAN **20** is a UTRAN, the base stations **40**, **42** may represent eNB stations and/or Radio Network Controllers (RNCs), which are configured to communicate with the UE **15**. In an embodiment where the RAN **20** is a GERAN, the base stations **40**, **42** may represent a base station controller (BSC) configured to communicate with the UE **15** (e.g., a mobile station such as an MTC device) via a base transmission station (BTS). A downlink (DL) transmission may be a communication from the base station (e.g., base station **40** or **42**) to the UE **15** (e.g., MTC device), and an uplink (UL) transmission may be a communication from the UE **15** to the base station (e.g., base station **40** or **42**).

FIG. **2** schematically illustrates an example system architecture **200** for communication with an energy-harvesting device, in accordance with some embodiments. The system architecture **200** may be configured to perform actions described in connection with method **400** or **500** in some embodiments. For example, in some embodiments, user equipment (UE) **15** may be an energy-harvesting device. That is, the UE **15** may be configured to independently harvest or generate energy for operation of the UE **15** using any suitable means including, for example, solar, mechanical, radio frequency (RF) or other means. In some embodiments, the UE **15** may be configured to store the harvested energy. In some embodiments, the UE **15** may include or be communicatively coupled with smart meters or sensors to collect small amounts of information for transmission (e.g., health monitoring devices, vending machines, and the like configured to collect information about temperature, inventory, etc.). The UE **15** may represent a plurality of MTC devices, each MTC device being configured to wirelessly communicate with the RAN **20** in some embodiments.

Communication between the UE **15** and the network (e.g., RAN **20** and/or core network **25**) may be performed according to a variety of suitable techniques. In some embodiments, an Application server **26** may be configured to trigger the UE **15** to establish communication with a server of the core network **25**. For example, the UE **15** may be triggered to send a data payload (e.g., MTC data payload including MTC information such as sensor or meter measurement, inventory level, etc.) to a Services Capability Server (SCS) **52**. The data payload may be smaller than a preconfigured threshold to define a small data payload in some embodiments. The preconfigured threshold may be set by subscription or network operator policy in some embodiments.

According to various embodiments, the small data payload may be sent by the UE **15** to the SCS **52** or Application server **26** via RAN **20** and core network **25** or the small data payload may be sent by the Application server **26** or SCS **52** to the UE **15** via the core network **25** and the RAN **20**. For example, the Application server **26** may be configured (e.g., by an MTC user) to send and/or trigger sending of a small data payload to user equipment (UE) **15**. The Application server **26** may be communicatively coupled with the core network **25** using, for example, an Internet connection (e.g., Internet **65** of FIG. **1**). In another example, an MTC application **24** that is communicatively or operatively coupled with the UE **15** may be configured to send or trigger the sending of a small data payload from the UE **15** to the SCS **52** and/or Application server **26**. In some embodiments, the UE **15** is an MTC device configured to send or receive small data payloads and/or otherwise communicate with the MTC application **24**. In some embodiments, the UE **15** may include the MTC application **24**.

The system architecture **200** may include an SCS **52**, which is configured to connect to the core network **25** to communicate with UEs (e.g., UE **15**) that are configured for small data (e.g., MTC) communication. The SCS **52** may be further configured to communicate with an Interworking Function (IWF) such as MTC-IWF **54** to trigger communication between the UE **15** and the core network **25** such as, for example, transmission of a small data payload. In some embodiments, the SCS **52** may be an MTC server or include an MTC server and an application server.

The MTC-IWF **54** may terminate a Tsp reference point or interface (hereinafter "reference point") between the SCS **52** and the MTC-IWF **54**. The MTC-IWF **54** may be configured to hide internal public land mobile network (PLMN) topology and relay or translate signaling protocols used over the Tsp reference point to invoke specific functionality in the PLMN. In some embodiments, the MTC-IWF **54** may authenticate the SCS **52** before communication is established with the core network **25** and/or control plane requests from the SCS **52** are authorized. According to various embodiments, the dashed lines between modules (e.g., **54**, **58**) represent a control plane and the solid lines between modules represent a user plane. While a particular plane may be shown between modules, other embodiments may include additional or alternative planes.

In an embodiment, the MTC-IWF **54** may terminate a T5*a*/T5*b* reference point between a module including a

Mobility Management Entity (MME) and/or a Serving GPRS (General Packet Radio Service) Support Node (SGSN) such as, for example, SGSN/MME **58**. In some embodiments, the T**5** a reference point may terminate on the SGSN of the SGSN/MME **58** and the T**5***b* reference point may terminate on the MME of the SGSN/MME **58**. In another embodiment, the MTC-IWF **54** may terminate an S6m reference point between a module including a Home Location Register (HLR) and/or Home Subscriber Server (HSS) such as, for example, HLR/HSS **56**.

According to various embodiments, the T**5***a*/T**5***b* reference point may be used to send control packet information to a network (e.g., a 3GPP PLMN) based on an indication from the SCS **52**. The S6m reference point may be used to derive routing information for a downlink communication by obtaining an identifier (e.g., 3GPP internal device identifier such as IMSI or Mobile Station International Subscriber Directory Number (MSISDN)) from an MTC device identifier or MTC application identifier. In some embodiments, the MTC-IWF **54** may be configured to trigger communication with one or more MTC devices (e.g., UE **15**) by sending a paging message with a triggering indication to the one or more MTC devices over the T**5***a*/T**5***b* reference point.

In an embodiment, the MTC-IWF **54** may terminate a T**6** reference point between a Cell Broadcast Center (CBC) **60** and the MTC-IWF **54**. The MTC-IWF **54** may be configured to trigger communication with one or more MTC devices by sending a broadcast message to the one or more MTC devices over the T**6** reference point and an IuCB reference point between the CBC **60** and the RAN **20**. The MTC-IWF **54** may perform functionality of a Cell Broadcast Entity (CBE) in some embodiments. In some embodiments, the MTC-IWF **54** may be used to format a Cell Broadcasting Service (CBS) message including, for example, splitting of a CBS message into a number of pages for broadcast transmission. Thus, a number of CBS messages may be broadcast in some embodiments. The MTC-IWF **54** may be configured to broadcast the CBS message through the CBC **60**. For example, the MTC-IWF **54** may be configured send a broadcast message to MTC devices of an MTC group to trigger MTC devices of the MTC group to wake up, if in idle mode, and establish communication with the SCS **52** for small data transmission purposes.

In some embodiments, the CBC **60** may terminate a Tcbs reference point between a cell broadcast entity (CBE) **62** and the CBC **60**. In some embodiments, a triggering message may be sent by the CBE **62** to the CBC **60** over the Tcbs reference point. For example, the CBE **62** may be collocated or implemented as part of the SCS **52** in some embodiments. In this regard, the CBC **60** may terminate a reference point between the SCS **52** (e.g., including the CBE **62**) and the CBC **60**.

The system architecture **200** may further include Gr/S**6***a*/S**6***d* reference points between the HLR/HSS **56** and the SGSN/MME **58**, reference point Ti between the SCS **52** and the GGSN/PGW **51**, reference point Application Programming Interface (API) between the Application server **26** and the SCS **52**, reference point S**1** between the SGSN/MME **58** and the RAN **20**, and reference points Um/Uu/LTE-UU between the RAN **20** and the UE **15**. The reference points are not limited to the example names provided and may be referred to by other names in other embodiments. The system architecture **200** may include other reference points in other embodiments. Communications described herein may take place over any suitable combination of interfaces/reference points of the system architecture **200**.

The system architecture **200** may support efficient scheduling of communication with energy-harvesting devices to reduce network impact associated with failed communication (e.g., owing to potential lack of operating power of the UE **15**), signaling overhead, or allocation of network resources. In some embodiments, one or more MTC devices of a plurality of MTC devices (e.g., UE **15**) may be attached (e.g., by an established Radio Resource Control (RRC) connection) or detached from the RAN **20** when a trigger for communication is sent by the MTC-IWF **54** to the plurality of MTC devices. Further, one or more MTC devices of the plurality of MTC devices (e.g., UE **15**) may be in connected mode or idle mode when the triggering indication is sent by the MTC-IWF **54** to the plurality of MTC devices in some embodiments.

FIG. **3** schematically illustrates communication **35** between an energy-harvesting device (e.g., UE **15**) and a network device **37** (e.g., a client energy-harvesting and storage information module in the RAN **20** or core network **25**), in accordance with some embodiments. The UE **15** may be an energy-harvesting device including an energy-harvesting module and/or an energy storage module (e.g., energy-harvesting and storage module **33**). The energy-harvesting and storage module **33** may be configured to harvest and store energy for operation of the energy-harvesting device. In some embodiments, the energy-harvesting device may be configured to generate energy over time dependent on an energy source and/or lose energy over time due to energy leakage.

The network device **37** may include one or more modules configured to perform network actions described herein. For example, the network device **37** may include a client energy-harvesting and storage information module configured to receive energy storage information from the energy-harvesting device and to perform actions in response to the information. The network device **37** may represent multiple modules/circuitry and may be disposed in any suitable module in system architecture **200** including any of the one or more servers **50** of FIG. **1**. In on embodiment, the network device **37** is coupled with or part of the HLR/HSS **56** of FIG. **2**. The network device **37** may be coupled with or may be part of other suitable network components in other embodiments.

In some embodiments, the UE **15** may indicate to the network device **37** that the UE **15** is an energy-harvesting device. For example, in some embodiments, the UE **15** may be configured to send a message including energy storage information of an energy-harvesting device to indicate that that the UE **15** is an energy-harvesting device. In some embodiments, the message may identify one or more of a type of energy source, an expected energy-harvesting pattern, energy storage capability, energy storage capacity and/or energy storage level. For example, Table 1 describes example message content according to some embodiments.

TABLE 1

Example Message Content

Message Field	#of bits	Meaning/Examples
Energy Source	4	0001 - Solar 0010 - Mechanical 0011 - RF 0100-1111 Reserved
Energy-Harvesting Pattern	n	This field may be an index pointing to one of a variety of known energy-harvesting models with appropriate parameters or a variable-sized field illustrating an energy-harvesting model.
Energy Storage Capability	1	0 - no 1 - yes
Energy Storage Capacity	m	This field may exist only if "yes" in the Energy Storage Capability field and may represent the amount of storage capacity in terms of energy units or time units.

In some embodiments, the energy-harvesting device may have more than one energy source identified in the Energy Source field and any such combination may be indexed with a corresponding bit value to identify the combination. An energy-harvesting pattern may differ depending on the energy source. In some embodiments, the Energy-Harvesting Pattern field may include an index that corresponds with a particular type of energy-harvesting pattern or combination of energy-harvesting patterns. The Energy-Harvesting Pattern field may be indexed to information of energy-harvesting models including, for example, arrival time and amount of energy, a constant rate (e.g., joules/second for a period of time), Poisson process, stationary ergodic process, or Markov chain model. In some embodiments, to improve scalability, information about the energy-harvesting pattern may be included as part of device capability negotiation between the UE **15** and the network. The message content may include other suitable bit values to provide the information of the message field in other embodiments.

According to various embodiments, the energy-harvesting device (e.g., UE **15**) may identify itself as an energy-harvesting device and also convey energy storage information using a unique message developed for such purpose (e.g., a new RRC message called "UE Energy Source Information Message" or the like), or appending the energy storage information into an existing message (e.g., an RRC config or reconfig message), or through device capability negotiation, which may occur between the UE **15** and the SGSN/MME **58** of the system architecture **200** described in FIG. **2**. In some embodiments, the indication that the UE **15** is an energy-harvesting device may be sent in a first message and the energy harvesting and storage information may be sent in a second message that is different than the first message. For example, in some embodiments, suitable combinations of the techniques described above (e.g., RRC message, device capability negotiation) may be used to separately send the indication and the energy harvesting and storage information. In some embodiments, suitable combinations of the techniques described above may be used to separately send discrete aspects of the energy harvesting and storage information (e.g., corresponding with the different fields of Table 1). Other suitable messaging mechanisms may be used by the UE **15** to send the indication and/or energy harvesting and storage information.

Communications **35** including, for example, triggering messages to trigger communication between the UE **15** and the core network **25**, messages sent by the UE to indicate that the UE is an energy-harvesting device and/or to include energy storage information of the energy-harvesting device, and/or communications scheduled based on the energy storage information may occur over any suitable combination of modules and/or interfaces in the system architecture **200** of FIG. **2**.

Subsequent to receiving the indication that the UE **15** is an energy-harvesting device, a network device **37** may differentiate the energy-harvesting device from other devices that do not harvest energy in the wireless communication network based on the indication. For example, the network device **37** may differentiate the energy-harvesting device by assigning a value of one or more bits to identify the energy-harvesting device. If, for example, a Device ID of the UE **15** is represented by 32 bits, one or more bits (e.g., most significant 2 bits) may index identifiers (e.g., the last 4^{th}) corresponding to energy harvesting devices. In other embodiments, a network device **37** may differentiate the energy-harvesting device by using a Device Type to identify the energy-harvesting device. For example, the energy-harvesting device may be separately categorized by one or more bits so that they can, for example, be de-prioritized for access or other network policy. Setting the Device Type may occur for example, by a network device **37** from information obtained from the energy-harvesting device at connection set up, capability negotiation or other network communication. In other embodiments, a network device **37** may differentiate the energy-harvesting device by allocating a portion of a Radio Network Temporary Identifier (RNTI) to identify the energy-harvesting device. For example, allocated portions of a C-RNTI of UE identity in a cell for an RRC connection, RA-RNTI for random access, P-RNTI for paging and/or SI-RNTI for system information may be used to identify the energy-harvesting device in the network.

In some embodiments, the network device **37** may differentiate the energy-harvesting device by modifying a schedule for communication with the energy-harvesting device (e.g., based on the indication that the UE **15** is an energy-harvesting device). For example, the network device **37** may modify a priority or technique (e.g., signaling scheme) for communication with the energy-harvesting device over the wireless communication network or may otherwise schedule communication with the energy-harvesting device over the wireless communication network according to energy storage information received from the energy-harvesting device. The network device **37** may be configured to schedule communication with the energy-harvesting device in a manner that reduces a likelihood of the energy-harvesting device losing energy due to leakage or in a manner that reduces interference with energy harvesting opportunities of the energy-harvesting device

In some embodiments, the network device **37** may be configured to schedule communication with the energy-harvesting device using a scheduling policy that takes into account the energy storage energy information received from the energy-harvesting device. In some embodiments, the network device **37** may use an energy harvesting related policy to schedule communication. The energy harvesting related policy may consider energy storage information such as, for example, energy storage capacity and/or energy storage level of the energy-harvesting device in some embodiments.

The energy harvesting related policy may be combined with other scheduling policies including, for example, round-robin (RR), opportunistic (OP) and/or proportional fair (PF) policies, which may be used by the network for non-real-time traffic. Other scheduling policies that include quality of service (QoS) requirement may be used in some embodiments. PF may strike a balance between RR and OP policies and provide benefits of both. For example, RR may present a fair policy, but may not consider throughput maximization. OP may maximize throughput, but may not take into account fairness. In some embodiments, a scheduler operating according to PF policy may rank and select devices for transmission and reception based on throughput maximization and fairness as represented by the Equation [1] where J is a selected device for transmission/reception, $D_i(t)$ is an instantaneous data rate of device i at time t, and $R_i(t-1)$ is an average data rate of the device i until time t−1:

$$J=\arg\max_i[D_i(t)/R_i(t-1)] \quad [1]$$

Such PF policy may be combined with an energy harvesting related policy to provide a joint policy that may be used by a scheduler (e.g., network device **37**) to take energy harvesting related information into account in ranking and selecting a UE for transmission/reception. For example, in one embodiment, a joint policy may be represented by Equation [2] where E_i represents energy storage capacity of the energy-harvesting device, e_i represent energy storage level and w_1

and w_2 represent weight factors for the energy harvest related component and the PF component, respectively:

$$J=argmax_i\{w_1[(E_i-e_i)/E_i]+w_2[D_i(t)/R_i(t-1)]\} \quad [2]$$

The energy harvesting related component $[(E_i-e_i)/E_i]$ of the Equation [2] may have a value between 0 and 1 for energy-harvesting devices and may have a value of 0 for other devices in the wireless communication network that do not harvest energy. The Equation [2] may consider more or fewer factors than depicted. For example, in some embodiments, the PF component $[D_i(t)/R_i(t-1)]$ of Equation [2] may not be used at all (e.g., w_2 may be set equal to 0). The weight factors w_1 and w_2 may be determined and/or set by the network using any suitable technique to increase efficiency of communication including, for example, empirical work. In some embodiments, the weight factors w_1 and w_2 may have a value from 0 to 1. In some embodiments, setting of the weight factors w_1 and w_2 may be based on assistance from the UE **15** (e.g., via air-interface messaging between the UE **15** and the network **20** or **25**). The weight factors w_1 and w_2 may, for example, have a particular value for each UE **15** based on energy-harvesting information of the UE **15**.

The energy storage capacity E_i may not change with time, in some embodiments, and may be transmitted one time from the UE **15** to the network **20** or **25** (e.g., to the network device **37** during device capability negotiation). The energy storage level e_i may vary with time, in some embodiments, based on, for example, any energy harvesting opportunity the UE **15** had in the recent past, energy loss due to any transmission, reception or processing, energy leakage over the lapsed time, etc. In some embodiments, the energy storage level e_i may be sent by the UE **15** to the network **20** or **25** (e.g., to network device **37**) periodically or based on an occurrence of an event. For example, the periodic basis or event basis may comport with a period and/or events used in connection with transmission of a channel quality index (CQI). In some embodiments, the energy storage level e_i may be represented by one or more bits and may be signaled to the network **20** or **25** in scheduled slots (e.g., similar to CQI) or in an RRC message.

The energy storage information may comprise one or more bits that correspond with a nominal value of an energy storage level of the energy-harvesting device. For example, as shown in Table 2, the energy storage level e_i may have an index represented by three bits that correspond with a percentage of the energy storage level. The energy storage information may include more or fewer bits than depicted in Table 2 and/or different types of nominal values may be represented in other embodiments. In some embodiments, the energy storage level e_i (e.g., as indexed in Table 2) may be part (e.g., another field) of the message content in Table 1.

TABLE 2

Energy Storage Level Index and Value
Energy Storage Level (e_i)

Index	Percentage
000	10%
001	20%
...	...
111	100%

FIG. **4** is a flow diagram of a method **400** for communicating with an energy-harvesting device from a network perspective, in accordance with some embodiments. Actions of the method **400** may be performed by any suitable network module or circuitry (e.g., network device **37** of FIG. **3**) and may comport with embodiments described in connection with FIGS. **1-3** and vice versa.

At **402**, the method **400** may include receiving, from user equipment of a wireless communication network, an indication that the user equipment is an energy-harvesting device and/or energy storage information of the energy-harvesting device. The indication and/or energy storage information may be received, for example, by receiving signaling sent by the energy-harvesting device. In some embodiments, the indication and/or energy storage information may be received in an RRC message, or in a message received during device capability negotiation between the energy-harvesting device and the wireless communication network, or combinations thereof. In some embodiments, the energy storage information may be received periodically in scheduled slots. In other embodiments, the energy storage information may be received in an RRC message based on occurrence of an event (e.g., a triggering message, energy storage level, etc.).

According to various embodiments, the energy storage information may include one or more of an energy source, energy-harvesting pattern, energy storage capability and an energy storage capacity of the energy-harvesting device. In some embodiments, the indication that the user equipment is an energy-harvesting device may be in the form of a message that identifies energy storage information (e.g., energy source, energy-harvesting pattern, energy storage capability and/or energy storage capacity) of the energy-harvesting device. The energy storage information itself may serve as the indication that the user equipment is an energy-harvesting device. In some embodiments, the energy storage information may include one or more bits that correspond with a nominal value of one or more of an energy storage capacity or energy storage level of the energy-harvesting device

Multiple messages may be received to provide the indication and/or the energy storage information. For example, in one embodiment, the network may initially receive an energy storage capacity (E_i) during device capability negotiation with the user equipment and subsequently the network may receive an energy storage level (e_i) of the energy-harvesting device in a subsequent message (e.g., RRC message) sent by the user equipment.

At **404**, the method **400** may include differentiating the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication. In some embodiments, the one or more bits may be modified or allocated to indicate that the user equipment is an energy-harvesting device. For example, in some embodiments differentiating may include modifying a schedule for communication with the energy-harvesting device (and potentially other non-energy-harvesting devices). In some embodiments, differentiating may include using a Device Type to identify the energy-harvesting device. In some embodiments, differentiating may include allocating a portion of an RNTI to identify the energy-harvesting device. Other suitable techniques and/or configurations to differentiate the energy-harvesting device may be used in other embodiments.

At **406**, the method **400** may include scheduling communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers the energy storage information of the energy-harvesting device. In some embodiments, the scheduling policy may be configured to consider energy storage capacity and/or energy storage level of the energy-harvesting device. In some embodiments, the scheduling policy may be further configured to consider instantaneous data rate and/or an average data rate of the harvesting device (e.g., in accordance with PF policy of Equation [1]).

FIG. **5** is a flow diagram of a method **500** for communicating with a network from an energy-harvesting device perspective, in accordance with some embodiments. Actions of the method **500** may be performed by any suitable module or circuitry of user equipment (e.g., UE **15** of FIGS. **1-3**) and may comport with embodiments described in connection with FIGS. **1-4** and vice versa.

At **502**, the method **500** may include sending, by user equipment of a wireless communication network, an indication that the user equipment is an energy-harvesting device and/or energy storage information of the energy-harvesting device. In some embodiments, the energy storage information includes an indication that the user equipment is an energy-harvesting device.

According to various embodiments, sending at **502** may performed in accordance with one or more of the techniques described in connection with receiving at **402** of method **400**. For example, indication and/or energy storage information may be sent, for example, by signaling from the energy-harvesting device. In some embodiments, the indication and/or energy storage information may be sent in an RRC message, or in a message sent during device capability negotiation between the energy-harvesting device and the wireless communication network, or combinations thereof. In some embodiments, the energy storage information may be sent periodically in scheduled slots. In other embodiments, the energy storage information may be sent in an RRC message based on occurrence of an event (e.g., a triggering message, energy storage level, etc.).

According to various embodiments, the energy storage information may include one or more of an energy source, energy-harvesting pattern, energy storage capability and an energy storage capacity of the energy-harvesting device. In some embodiments, the indication that the user equipment is an energy-harvesting device may be in the form of a message that identifies energy storage information (e.g., energy source, energy-harvesting pattern, energy storage capability and/or energy storage capacity) of the energy-harvesting device. The energy storage information itself may serve as the indication that the user equipment is an energy-harvesting device. In some embodiments, the energy storage information may include one or more bits that correspond with a nominal value of one or more of an energy storage capacity or energy storage level of the energy-harvesting device.

Multiple messages may be sent to provide the indication and/or the energy storage information. For example, in one embodiment, the user equipment may initially send an energy storage capacity (E_i) during device capability negotiation with the network and subsequently the user equipment may send an energy storage level (e_i) of the energy-harvesting device in a subsequent message (e.g., RRC message).

At **504**, the method **500** may include receiving communication over the wireless network that is scheduled with the energy-harvesting device based on a scheduling policy that considers the energy storage information. For example, the communication may be received in accordance with a scheduling policy as described in connection with scheduling at **406** of method **400**. The scheduling policy may consider one or more other aspects of the energy storage information (e.g., energy source, energy-harvesting pattern, energy storage capability, etc.) in other embodiments.

Various operations are described as multiple discrete operations in turn, in a manner that is most helpful in understanding the claimed subject matter. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations may not be performed in the order of presentation. Operations described may be performed in a different order than the described embodiment. Various additional operations may be performed and/or described operations may be omitted in additional embodiments.

The techniques and configurations described herein may be implemented into a system using any suitable hardware and/or software to configure as desired. FIG. **6** schematically illustrates an example system **600** (e.g., computing device) that may be used to practice various embodiments described herein. The example system **600** may represent, for example, user equipment (e.g., UE **15** of FIG. **3**) or a network device (e.g., network device **37** of FIG. **3**). FIG. **6** illustrates, for one embodiment, an example system **600** comprising one or more processor(s) **604**, system control logic **608** coupled with at least one of the processor(s) **604**, system memory **612** coupled with system control logic **608**, non-volatile memory (NVM)/storage **616** coupled with system control logic **608**, a network interface **620** coupled with system control logic **608**, and input/output (I/O) devices **632** coupled with system control logic **608**. The processor(s) **604** may include one or more single-core or multi-core processors. The processor(s) **604** may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, baseband processors, etc.).

System control logic **608** for one embodiment may include any suitable interface controllers to provide for any suitable interface to at least one of the processor(s) **604** and/or to any suitable device or component in communication with system control logic **608**.

System control logic **608** for one embodiment may include one or more memory controller(s) to provide an interface to system memory **612**. System memory **612** may be used to load and store data and/or instructions, e.g., communication logic **624**. System memory **612** for one embodiment may include any suitable volatile memory, such as suitable dynamic random access memory (DRAM), for example.

NVM/storage **616** may include one or more tangible, non-transitory computer-readable or machine-readable storage or media used to store data and/or instructions, e.g., communication logic **624**. NVM/storage **616** may include any suitable non-volatile memory, such as flash memory, for example, and/or may include any suitable non-volatile storage device(s), such as one or more hard disk drive(s) (HDD(s)), one or more compact disk (CD) drive(s), and/or one or more digital versatile disk (DVD) drive(s), for example.

The NVM/storage **616** may include a storage resource physically part of a device on which the system **600** is installed or it may be accessible by, but not necessarily a part of, the device. For example, the NVM/storage **616** may be accessed over a network via the network interface **620** and/or over Input/Output (I/O) devices **632**.

The communication logic **624** may include instructions that, when executed by one or more of the processors **604**, cause the system **1000** to perform operations associated with methods **400** or **500** as described with respect to the above embodiments. In various embodiments, the communication logic **624** may include hardware, software, and/or firmware components that may or may not be explicitly shown in system **600**.

Network interface **620** may have a transceiver **622** to provide a radio interface for system **600** to communicate over one or more network(s) and/or with any other suitable device. In various embodiments, the transceiver **622** may be integrated with other components of system **600**. For example, the transceiver **622** may include a processor of the processor(s) **604**, memory of the system memory **612**, and NVM/Storage of NVM/Storage **616**. Network interface **620** may include any suitable hardware and/or firmware. Network interface **620** may include a plurality of antennas to provide a multiple input, multiple output radio interface. Network interface **620** for one embodiment may include, for example, a wired network adapter, a wireless network adapter, a telephone modem, and/or a wireless modem.

For one embodiment, at least one of the processor(s) **604** may be packaged together with logic for one or more controller(s) of system control logic **608**. For one embodiment, at least one of the processor(s) **604** may be packaged together with logic for one or more controllers of system control logic **608** to form a System in Package (SiP). For one embodiment, at least one of the processor(s) **604** may be integrated on the same die with logic for one or more controller(s) of system control logic **608**. For one embodiment, at least one of the processor(s) **604** may be integrated on the same die with logic for one or more controller(s) of system control logic **608** to form a System on Chip (SoC).

In various embodiments, the I/O devices **632** may include user interfaces designed to enable user interaction with the system **600**, peripheral component interfaces designed to enable peripheral component interaction with the system **600**, and/or sensors designed to determine environmental conditions and/or location information related to the system **600**.

In various embodiments, the user interfaces could include, but are not limited to, a display (e.g., a liquid crystal display, a touch screen display, etc.), speakers, a microphone, one or more cameras (e.g., a still camera and/or a video camera), a flashlight (e.g., a light emitting diode flash), and a keyboard.

In various embodiments, the peripheral component interfaces may include, but are not limited to, a non-volatile memory port, a universal serial bus (USB) port, an audio jack, and a power supply interface.

In various embodiments, the sensors may include, but are not limited to, a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may also be part of, or interact with, the network interface **620** to communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

In various embodiments, the system **600** may be a mobile computing device such as, but not limited to, a laptop computing device, a tablet computing device, a netbook, a smartphone, etc. In various embodiments, system **600** may have more or less components, and/or different architectures.

EXAMPLES

According to various embodiments, the present disclosure describes communication techniques and configurations for energy-harvesting devices in a wireless communication network. In some embodiments, the present disclosure describes an apparatus (e.g., a network device). Example 1 of the apparatus includes circuitry to receive, by a network device of a wireless communication network, a message from user equipment, the message including an indication that the user equipment is an energy-harvesting device and circuitry to differentiate the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication. Example 2 includes the apparatus of Example 1, wherein the message identifies an energy source of the energy-harvesting device. Example 3 includes the apparatus of Example 1, wherein the message identifies an energy-harvesting pattern of the energy-harvesting device. Example 4 includes the apparatus of Example 1, wherein the message identifies an energy storage capability of the energy-harvesting device. Example 5 includes the apparatus of Example 1, wherein the message identifies an energy storage capacity of the energy-harvesting device. Example 6 includes the apparatus of any of Examples 1-5, wherein the message is a Radio Resource Control (RRC) message. Example 7 includes the apparatus of any of Examples 1-5, wherein the circuitry to receive is to receive the message during device capability negotiation between the energy-harvesting device and the wireless communication network. Example 8 includes the apparatus of any of Examples 1-5, wherein the circuitry to differentiate is to differentiate the energy-harvesting device by modifying a schedule for communication with the energy-harvesting device based on the indication. Example 9 includes the apparatus of any of Examples 1-5, wherein the circuitry to differentiate is to differentiate the energy-harvesting device by using a Device Type to identify the energy-harvesting device. Example 10 includes the apparatus of any of Examples 1-5, wherein the circuitry to differentiate is to differentiate the energy-harvesting device by allocating a portion of a Radio Network Temporary Identifier (RNTI) to identify the energy-harvesting device. Example 11 includes the apparatus of any of Examples 1-5, further comprising circuitry to schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers energy storage capacity or energy storage level of the energy-harvesting device. Example 12 includes the apparatus of Example 11, wherein the scheduling policy considers energy storage capacity and energy storage level of the energy-harvesting device and further considers instantaneous data rate of the energy-harvesting device and an average data rate of the energy-harvesting device.

In some embodiments, the present disclosure describes another apparatus (e.g., a network device). Example 13 of such apparatus includes circuitry to receive, by a network device of a wireless communication network, energy storage information of an energy-harvesting device and circuitry to schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers the energy storage information. Example 14 includes the apparatus of Example 13, wherein the circuitry to receive is to receive the energy storage information by receiving signaling sent by the energy-harvesting device, the energy storage information includes energy storage capacity and energy storage level of the energy-harvesting device and the scheduling policy considers the energy storage capacity and the energy storage level of the energy-harvesting device. Example 14 includes the apparatus of Example 13 or 14, wherein the circuitry to receive is to receive the energy storage information by receiving the energy storage information periodically in scheduled slots. Example 16 includes the apparatus of Example 13 or 14, wherein the circuitry to receive is to receive the energy storage information by receiving a Radio Resource Control (RRC) message including the energy storage information based on occurrence of an event. Example 17 includes the apparatus of Example 13 or 14, wherein the energy storage information comprises one or more bits that correspond with a nominal value of an energy storage level of the energy-harvesting device.

In some embodiments, the present disclosure describes another apparatus (e.g. component of user equipment). Example 18 of such apparatus includes circuitry to send energy storage information of user equipment to a network device of a wireless communication network, wherein the energy storage information includes an indication that the user equipment is an energy-harvesting device and circuitry to receive communication over the wireless network, wherein the communication is scheduled with the energy-harvesting device based on a scheduling policy that considers the energy storage information. Example 19 includes the apparatus of Example 18, wherein the energy storage information identifies an energy source of the energy-harvesting device, an energy-harvesting pattern of the energy-harvesting device, an energy storage capability of the energy-harvesting device or an energy storage capacity of the energy-harvesting device. Example 20 includes the apparatus of Example 18 or 19, wherein the circuitry to send is to send the energy storage information during device capability negotiation between the energy-harvesting device and the wireless communication network. Example 21 includes the apparatus of Example 18 or 19, wherein the circuitry to send is to send the energy storage information in a Radio Resource Control (RRC) message. Example 22 includes the apparatus of Example 18 or 19, wherein the energy storage information includes energy storage capacity and energy storage level of the energy-harvesting device and the scheduling policy considers energy storage capacity and energy storage level of the energy-harvesting device. Example 23 includes the apparatus of Example 22, wherein the scheduling policy further considers instantaneous data rate of the energy-harvesting device or an average data rate of the energy-harvesting device, the scheduling policy applies a first weight factor for considering the energy storage capacity and energy storage level of the energy-harvesting device, and the scheduling policy applies a second weight factor for considering the instantaneous date rate or the average data rate of the energy-harvesting device. Example 24 includes the apparatus of Example 18 or 19, wherein the wireless communication network comprises a cellular network configured to operate in accordance with a 3rd Generation Partnership Project (3GPP) protocol.

Various embodiments may include any suitable combination of the above-described embodiments including alternative (or) embodiments of embodiments that are described in conjunctive form (and) above (e.g., the "and" may be "and/or"). Furthermore, some embodiments may include one or more methods or articles of manufacture (e.g., non-transitory computer-readable media) having instructions, stored thereon, that when executed result in actions of any of the above-described embodiments. Moreover, some embodiments may include apparatuses or systems having any suitable means for carrying out the various actions of the above-described embodiments.

Although certain embodiments have been illustrated and described herein for purposes of description, a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments described herein be limited only by the claims and the equivalents thereof.

What is claimed is:

1. An apparatus comprising:

circuitry to receive, by a network device of a wireless communication network, a message from user equipment, the message including an indication that the user equipment is an energy-harvesting device; and

circuitry to differentiate the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication,

wherein the message identifies an energy-harvesting pattern of the energy-harvesting device.

2. The apparatus of claim **1**, wherein the message identifies an energy source of the energy-harvesting device.

3. The apparatus of claim **1**, wherein the message identifies an energy storage capability of the energy-harvesting device.

4. The apparatus of claim **3**, wherein the message identifies an energy storage capacity of the energy-harvesting device.

5. The apparatus of claim **1**, wherein the message is a Radio Resource Control (RRC) message.

6. The apparatus of claim **1**, wherein the circuitry to receive is to receive the message during device capability negotiation between the energy-harvesting device and the wireless communication network.

7. The apparatus of claim **1**, wherein the circuitry to differentiate is to differentiate the energy-harvesting device by modifying a schedule for communication with the energy-harvesting device based on the indication.

8. The apparatus of claim **1**, wherein the circuitry to differentiate is to differentiate the energy-harvesting device by using a Device Type to identify the energy-harvesting device.

9. The apparatus of claim **1**,

wherein the circuitry to differentiate is to differentiate the energy-harvesting device by allocating a portion of a Radio Network Temporary Identifier (RNTI) to identify the energy-harvesting device.

10. An apparatus comprising:

circuitry to receive, by a network device of a wireless communication network, a message from user equipment, the message including an indication that the user equipment is an energy-harvesting device;

circuitry to differentiate the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication; and

circuitry to schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers energy storage capacity or energy storage level of the energy-harvesting device.

11. The apparatus of claim **10**, wherein the scheduling policy considers energy storage capacity and energy storage level of the energy-harvesting device and further considers instantaneous data rate of the energy-harvesting device and an average data rate of the energy-harvesting device.

12. An apparatus comprising:

circuitry to receive, by a network device of a wireless communication network, energy storage information of an energy-harvesting device; and

circuitry to schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers the energy storage information.

13. The apparatus of claim **12**, wherein:

the circuitry to receive is to receive the energy storage information by receiving signaling sent by the energy-harvesting device;

the energy storage information includes energy storage capacity and energy storage level of the energy-harvesting device; and

the scheduling policy considers the energy storage capacity and the energy storage level of the energy-harvesting device.

14. The apparatus of claim **12**, wherein the circuitry to receive is to receive the energy storage information by receiving the energy storage information periodically in scheduled slots.

15. The apparatus of claim 12, wherein the circuitry to receive is to receive the energy storage information by receiving a Radio Resource Control (RRC) message including the energy storage information based on occurrence of an event.

16. The apparatus of claim 12, wherein the energy storage information comprises one or more bits that correspond with a nominal value of an energy storage level of the energy-harvesting device.

17. An apparatus comprising:

circuitry to send energy storage information of user equipment to a network device of a wireless communication network, wherein the energy storage information includes an indication that the user equipment is an energy-harvesting device; and

circuitry to receive communication over the wireless network, wherein the communication is scheduled with the energy-harvesting device based on a scheduling policy that considers the energy storage information.

18. The apparatus of claim 17, wherein the energy storage information identifies an energy source of the energy-harvesting device, an energy-harvesting pattern of the energy-harvesting device, an energy storage capability of the energy-harvesting device or an energy storage capacity of the energy-harvesting device.

19. The apparatus of claim 17, wherein the circuitry to send is to send the energy storage information during device capability negotiation between the energy-harvesting device and the wireless communication network.

20. The apparatus of claim 17, wherein the circuitry to send is to send the energy storage information in a Radio Resource Control (RRC) message.

21. The apparatus of claim 17, wherein:

the energy storage information includes energy storage capacity and energy storage level of the energy-harvesting device; and

the scheduling policy considers energy storage capacity and energy storage level of the energy-harvesting device.

22. The apparatus of claim 21, wherein:

the scheduling policy further considers instantaneous data rate of the energy-harvesting device or an average data rate of the energy-harvesting device;

the scheduling policy applies a first weight factor for considering the energy storage capacity and energy storage level of the energy-harvesting device; and

the scheduling policy applies a second weight factor for considering the instantaneous date rate or the average data rate of the energy-harvesting device.

23. The apparatus of claim 17, wherein the wireless communication network comprises a cellular network configured to operate in accordance with a 3rd Generation Partnership Project (3GPP) protocol.

24. One or more non-transitory, computer-readable media having instructions that, when executed, cause a network device of a wireless communication network to:

receive a message from user equipment, the message including an indication that the user equipment is an energy-harvesting device; and

differentiate the energy-harvesting device from other non-energy-harvesting devices in the wireless communication network based on the indication,

wherein the message identifies an energy-harvesting pattern of the energy-harvesting device.

25. The one or more non-transitory, computer-readable medium of claim 24, wherein the message identifies an energy source of the energy-harvesting device.

26. The one or more non-transitory, computer-readable medium of claim 24, wherein the message identifies an energy storage capability or capacity of the energy-harvesting device.

27. The one or more non-transitory, computer-readable medium of claim 24, wherein the message is a Radio Resource Control (RRC) message.

28. The one or more non-transitory, computer-readable media of claim 24, wherein the instructions, when executed, further cause the device to:

differentiate the energy-harvesting device by:

modifying a schedule for communication with the energy-harvesting device based on the indication;

using a Device Type to identify the energy-harvesting device; or

allocating a portion of a Radio Network Temporary Identifier (RNTI) to identify the energy-harvesting device.

29. The one or more non-transitory, computer-readable media of claim 24, wherein the instructions, when executed, further cause the device to:

schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers energy storage capacity or energy storage level of the energy-harvesting device.

30. The one or more non-transitory, computer-readable media of claim 29, wherein the scheduling policy considers energy storage capacity and energy storage level of the energy-harvesting device and further considers instantaneous data rate of the energy-harvesting device and an average data rate of the energy-harvesting device.

31. One or more non-transitory, computer-readable media having instructions that, when executed, cause a network device of a wireless communication network to:

receive energy storage information of an energy-harvesting device; and

schedule communication with the energy-harvesting device over the wireless communication network based on a scheduling policy that considers the energy storage information.

32. The one or more non-transitory, computer-readable media of claim 31, wherein the energy storage information includes energy storage capacity and energy storage level of the energy-harvesting device; and

the scheduling policy considers the energy storage capacity and the energy storage level of the energy-harvesting device.

33. The one or more non-transitory, computer-readable media of claim 31, wherein the instructions, when executed, further cause the apparatus to receive the energy storage information by receiving the energy storage information periodically in scheduled slots.

34. The one or more non-transitory, computer-readable media of claim 31, wherein the energy storage information comprises one or more bits that correspond with a nominal value of an energy storage level of the energy-harvesting device.

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