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(54) **Title**: METHOD AND APPARATUS FOR FACILITATING EXTENDED TIME-DOMAIN GRANULARITY FOR UPLINK FREQUENCY HOPPING

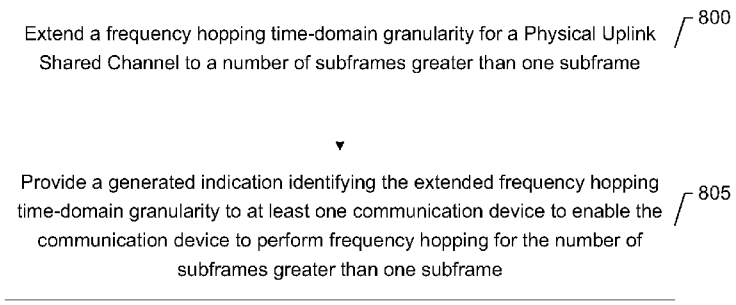


FIG. 8.

(57) **Abstract**: A method, apparatus and computer program product are provided for enhancing frequency hopping with transmission time interval bundling. In this regard, a method is provided that includes extending a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe. The method may further include enabling provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe. Corresponding apparatuses and computer program products are also provided.

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METHOD AND APPARATUS FOR FACILITATING EXTENDED TIME-DOMAIN GRANULARITY FOR UPLINK FREQUENCY HOPPING

TECHNOLOGICAL FIELD

Embodiments of the present invention relate generally to wireless communications technology and, more particularly, to a method and apparatus for an enhancement of frequency hopping with transmission time interval bundling in a communications system.

BACKGROUND

The communications between a mobile terminal and a serving cell, such as the uplink communications from the mobile terminal to the serving cell, may sometimes affect resource utilization, throughput, latency and coverage. To enhance uplink communications improvements, the ongoing evolution of wireless communications systems into wireless standard specifications, such as the third generation partnership project (3GGP) are being enhanced.

For example, currently in 3GPP Radio Access Network (RAN) a low cost traffic model is being considered in which an additional coverage requirement of a 20 decibels (dB) improvement in comparison to category 1 UEs (User Equipment) (e.g., mobile terminals (e.g., mobile phones)) is targeted. The category 1 UEs may be the lowest level UEs in the current LTE standard having minimal capabilities.

The coverage improvement for the Physical Uplink Shared Channel (PUSCH) is the most challenging, as its coverage needs to be improved 20 dB for Frequency Division Duplexing (FDD), while other channels typically have lower improvement requirements. Meanwhile, it is required that traffic package of 100 bytes should be reliably received by the network with latency of less than five seconds.

At present, low-cost MTC devices (e.g., low cost MTC UEs (e.g., metering devices)) may be unable to achieve the required 20 dB coverage improvement or gain by utilizing existing LTE solutions.

In view of the foregoing drawbacks, a more efficient manner of providing coverage improvement may be beneficial.

BRIEF SUMMARY

A method, apparatus and computer program product are therefore provided according to an example embodiment in order to provide an efficient and reliable manner for providing an enhancement of frequency hopping with transmission time interval (TTI) bundling on an uplink channel (e.g., PUSCH), targeting coverage improvement for low-cost machine type communications (MTC) at extremely low signal-to-noise ratio (SNR) in a communications system (e.g., Long-Term Evolution (LTE), LTE-Advanced).

In some example embodiments, the time-domain granularity of PUSCH frequency hopping may be extended, by a network device (e.g., an evolved Node B (eNB)) to more than one subframe, in an instance in which a long transmission time interval (TTI) bundling may be utilized under a very low SNR scenario.

In this manner, some example embodiments may provide the benefits of both cross-subframe channel estimation and frequency hopping for PUSCH transmission for low-cost MTC devices at low SNR.

In one example embodiment, a method is provided that includes extending a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe. The method of this embodiment also includes enabling provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the

communication device to perform frequency hopping for the number of subframes greater than one subframe.

In another example embodiment, an apparatus is provided that includes at least one processor and at least one memory including computer program code with the at least one memory and computer program code being configured to, with the processor, cause the apparatus to at least extend a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe. The at least one memory and the computer program code of this embodiment are also configured to, with the processor, cause the apparatus to enable provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe.

In a further example embodiment, a computer program product is provided that includes at least one computer-readable storage medium having computer-readable program instructions stored therein with the computer-readable program instructions including program instructions configured to extend a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe. The computer-readable program instructions of this embodiment also include program instructions configured to enable provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe.

In yet another example embodiment, an apparatus is provided that includes means for extending a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe. The apparatus of this embodiment also includes means for enabling provision of a generated indication

identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe.

In a further example embodiment, a method is provided that includes receiving, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe. The method of this embodiment also includes performing frequency hopping for the number of subframes greater than one subframe.

In yet another example embodiment, an apparatus is provided that includes at least one processor and at least one memory including computer program code with the at least one memory and the computer program code being configured to, with the processor, cause the apparatus to at least receive, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe. The at least one memory and the computer program code of this embodiment are also configured to, with the processor, cause the apparatus to perform frequency hopping for the number of subframes greater than one subframe.

In a further example embodiment, a computer program product is provided that includes at least one computer-readable storage medium having computer-readable program instructions stored therein with the computer-readable program instructions including program instructions configured to cause receipt, from a network device, of an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe. The computer-readable program instructions of this embodiment also include program instructions configured to perform frequency hopping for the number of subframes greater than one subframe.

In another example embodiment, an apparatus is provided that includes means for receiving, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe. The apparatus of this embodiment also includes performing frequency hopping for the number of subframes greater than one subframe.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a schematic representation of a system that may benefit from an embodiment of the present invention;

FIG. 2 is a schematic block diagram of an apparatus from the perspective of a base station in accordance with an example embodiment of the invention;

FIG. 3 is a block diagram of an apparatus that may be embodied by a mobile terminal in accordance with one embodiment of the present invention;

FIG. 4 is a diagram of a table according to an example embodiment of the invention;

FIG. 5 is a diagram illustrating low cost MTC performance according to an example embodiment of the invention;

FIG. 6 is a diagram of a table according to one example embodiment of the invention;

FIG. 7 is a diagram of another table according to another example embodiment of the invention;

FIG. 8 is a flowchart illustrating operations performed in accordance with one embodiment of the present invention; and

FIG. 9 illustrates the flowchart of operations performed in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the inventions are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

As used in this application, the term 'circuitry' refers to all of the following: (a) hardware-only circuit implementations (such as implementations in only analog and/or digital circuitry) and (b) to combinations of circuits and software (and/or firmware), such as (as applicable): (i) to a combination of processor(s) or (ii) to portions of processor(s)/software (including digital signal processor(s)), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone or server, to perform various functions) and (c) to circuits, such as a microprocessor(s) or a portion of a microprocessor(s), that require software or firmware for operation, even if the software or firmware is not physically present.

This definition of 'circuitry' applies to all uses of this term in this application, including in any claims. As a further example, as used in this application, the term "circuitry" would also cover an implementation of merely a processor (or multiple processors) or portion of a processor and its (or their) accompanying software and/or firmware. The term "circuitry" would also cover, for example and if applicable to the particular claim element, a baseband integrated circuit or application specific integrated

circuit for a mobile phone or a similar integrated circuit in server, a cellular network device, or other network device.

As defined herein a "computer-readable storage medium," which refers to a non-transitory, physical or tangible storage medium (e.g., volatile or non-volatile memory device), may be differentiated from a "computer-readable transmission medium," which refers to an electromagnetic signal.

Additionally, as referred to herein, a transmission time interval (TTI) may, but need not, denote a resource(s) or parameter(s) that provides a duration for transmission of data on a radio link, channel or the like.

Also, as referred to herein, frequency hopping may, but need not, denote a radio communication process that may rapidly switch a carrier among multiple frequency channels to transfer information. In this regard, information may be transmitted over assigned and constantly changing frequency channels.

Referring now to FIG. 1, a system according to an example embodiment is provided. The system of FIG. 1 which includes a first communication device (e.g., mobile terminal 10), a second communication device (e.g., mobile terminal 10') that is capable of communication via a serving cell 12, such as a base station, a Node B, an evolved Node B (eNB), a radio network controller (RNC) or other access point, with a network 14 (e.g., a core network). While the network may be configured in accordance with Long Term Evolution (LTE) or LTE-Advanced (LTE-A), other networks may support the method, apparatus and computer program product of embodiments of the present invention including those configured in accordance with wideband code division multiple access (W-CDMA), CDMA2000, global system for mobile communications (GSM), general packet radio service (GPRS) and/or the like.

The network 14 may include a collection of various different nodes, devices or functions that may be in communication with each other via corresponding wired and/or

wireless interfaces. For example, the network may include one or more cells, including serving cell 12 and one or more neighbor cells 16 (designated neighbor cell 1, neighbor cell 2, ... neighbor cell n in the embodiment of FIG. 1), each of which may serve a respective coverage area. The serving cell and the neighbor cells could be, for example, part of one or more cellular or mobile networks or public land mobile networks (PLMNs). In turn, other devices such as processing devices (e.g., personal computers, server computers or the like) may be coupled to the mobile terminal 10, the mobile terminal 10' and/or other communication devices via the network.

Communication devices, such as the mobile terminal 10 (also referred to herein as user equipment (UE) 10), and/or the mobile terminal 10' (also referred to herein as UE 10') may be in communication with other communication devices or other devices via the serving cell 12 and, in turn, the network 14. In some cases, the communication devices may include an antenna for transmitting signals to and for receiving signals from a serving cell.

In some example embodiments, the mobile terminal 10 (also referred to herein as legacy UE 10, or legacy VoIP UE 10) may be a mobile communication device such as, for example, a mobile telephone, portable digital assistant (PDA), pager, laptop computer, or any of numerous other hand held or portable communication devices, computation devices, content generation devices, content consumption devices, or combinations thereof. In some other example embodiments, the mobile terminal 10' may be a limited-bandwidth device(s) such as, for example, machine-type communications (MTC) device which may communicate through a network 14 without human intervention. In other example embodiments, the mobile terminal 10' may be operated in part with human intervention. The mobile terminal 10' may be a mobile communication device such as, for example, a sensor(s), a metering device(s) (e.g., gas meter, temperature meter, electricity meter, etc.). In some example embodiments, the mobile terminal 10' (also referred to herein as MTC

UE 10' or low cost MTC UE 10') may be a MTC device configured to operate according to a low cost and/or low data rate. The mobile terminal 10, and/or mobile terminal 10' may include one or more processors that may define processing circuitry either alone or in combination with one or more memories. The processing circuitry may utilize instructions stored in the memory to cause the mobile terminal 10 to operate in a particular way or execute specific functionality when the instructions are executed by the one or more processors. The mobile terminal 10 and/or mobile terminal 10' may also include communication circuitry and corresponding hardware/software to enable communication with other devices and/or the network 14.

In one embodiment, for example, a neighbor cell 16 (also referred to herein as target cell 16) and/or the serving cell 12 (also referred to herein as evolved node B (eNB) 12) may be embodied as or otherwise include an apparatus 20 as generically represented by the block diagram of FIG. 2. Additionally, in one example embodiment, the mobile terminal 10 and/or mobile terminal 10' may be embodied as or otherwise include an apparatus 30 as generically represented by the block diagram of FIG. 3. While the apparatus 20 may be employed, for example, by a serving cell 12, or a neighbor cell 16 and the apparatus 30 may be employed, for example, by a mobile terminal 10, it should be noted that the components, devices or elements described below may not be mandatory and thus some may be omitted in certain embodiments. Additionally, some embodiments may include further or different components, devices or elements beyond those shown and described herein.

In one embodiment, for example, a neighbor cell 16 (also referred to herein as target cell 16) and/or the serving cell 12 may be embodied as or otherwise include an apparatus 20 as generically represented by the block diagram of FIG. 2. Additionally, in one example embodiment, the mobile terminal 10, and/or mobile terminal 10' may be embodied as or otherwise include an apparatus 30 as generically represented by the block

diagram of FIG. 3. While the apparatus 20 may be employed, for example, by a serving cell 12, or a neighbor cell 16 and the apparatus 30 may be employed, for example, by a mobile terminal 10, and/or mobile terminal 10' it should be noted that the components, devices or elements described below may not be mandatory and thus some may be omitted in certain embodiments. Additionally, some embodiments may include further or different components, devices or elements beyond those shown and described herein.

As shown in FIG. 2, the apparatus 20 may include or otherwise be in communication with processing circuitry 22 that is configurable to perform actions in accordance with example embodiments described herein. The processing circuitry may be configured to perform data processing, application execution and/or other processing and management services according to an example embodiment of the invention. In some example embodiments, the apparatus or the processing circuitry may be embodied as a chip or chip set. In other words, the apparatus or the processing circuitry may comprise one or more physical packages (e.g., chips) including materials, components and/or wires on a structural assembly (e.g., a baseboard). The structural assembly may provide physical strength, conservation of size, and/or limitation of electrical interaction for component circuitry included thereon. The apparatus or the processing circuitry may therefore, in some cases, be configured to implement an embodiment of the present invention on a single chip or as a single "system on a chip." As such, in some cases, a chip or chipset may constitute means for performing one or more operations for providing the functionalities described herein.

In an example embodiment, the processing circuitry 22 may include a processor 24 and memory 26 that may be in communication with or otherwise control a device interface 28. As such, the processing circuitry may be embodied as a circuit chip (e.g., an integrated circuit chip) configured (e.g., with hardware, software or a combination of

hardware and software) to perform operations described herein in relation to the apparatus 20.

The device interface 28 may include one or more interface mechanisms for enabling communication with other devices, such as one or more mobile terminals 10. In some cases, the device interface may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to receive and/or transmit data from/to a network and/or any other device or module in communication with the processing circuitry 22. In this regard, the device interface may include, for example, an antenna (or multiple antennas) and supporting hardware and/or software for enabling communications with a wireless communication network and/or a communication modem, such as a cellular modem 21 (e.g., a UMTS modem), and/or an optional non-cellular modem 23 (e.g., a WiFi modem, WLAN modem, etc.) for enabling communications with other terminals (e.g., WiFi terminals, WLAN terminals, APs, etc).

In an example embodiment, the memory 26 may include one or more non-transitory memory devices such as, for example, volatile and/or non-volatile memory that may be either fixed or removable. The memory may be configured to store information, data, applications, instructions or the like for enabling the apparatus 20 to carry out various functions in accordance with example embodiments of the present invention. For example, the memory could be configured to buffer input data for processing by the processor 24. Additionally or alternatively, the memory could be configured to store instructions for execution by the processor. As yet another alternative, the memory may include one of a plurality of databases that may store a variety of files, contents or data sets. Among the contents of the memory, applications may be stored for execution by the processor in order to carry out the functionality associated with each respective application. In some cases, the memory may be in communication with the processor via a bus for passing information among components of the apparatus.

The processor 24 may be embodied in a number of different ways. For example, the processor may be embodied as various processing means such as one or more of a microprocessor or other processing element, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), or the like. In an example embodiment, the processor may be configured to execute instructions stored in the memory 26 or otherwise accessible to the processor. As such, whether configured by hardware or by a combination of hardware and software, the processor may represent an entity (e.g., physically embodied in circuitry – in the form of processing circuitry 22) capable of performing operations according to embodiments of the present invention while configured accordingly. Thus, for example, when the processor is embodied as an ASIC, FPGA or the like, the processor may be specifically configured hardware for conducting the operations described herein. Alternatively, as another example, when the processor is embodied as an executor of software instructions, the instructions may specifically configure the processor to perform the operations described herein.

In one embodiment, the mobile terminals 10 may be embodied as or otherwise include an apparatus 30 as generically represented by the block diagram of FIG. 3. In this regard, the apparatus may be configured to provide for communications with the eNB 12 or another terminal(s) via communications system (e.g., a LTE system, a LTE-Advanced system). While the apparatus may be employed, for example, by a mobile terminal, it should be noted that the components, devices or elements described below may not be mandatory and thus some may be omitted in certain embodiments. Additionally, some embodiments may include further or different components, devices or elements beyond those shown and described herein.

As shown in FIG. 3, the apparatus 30 may include or otherwise be in communication with processing circuitry 32 that is configurable to perform actions in accordance with example embodiments described herein. The processing circuitry may be configured to perform data processing, application execution and/or other processing and management services according to an example embodiment of the present invention. In some embodiments, the apparatus or the processing circuitry may be embodied as a chip or chip set. In other words, the apparatus or the processing circuitry may comprise one or more physical packages (e.g., chips) including materials, components and/or wires on a structural assembly (e.g., a baseboard). The structural assembly may provide physical strength, conservation of size, and/or limitation of electrical interaction for component circuitry included thereon. The apparatus or the processing circuitry may therefore, in some cases, be configured to implement an embodiment of the present invention on a single chip or as a single "system on a chip." As such, in some cases, a chip or chipset may constitute means for performing one or more operations for providing the functionalities described herein.

In an example embodiment, the processing circuitry 32 may include a processor 34 and memory 36 that may be in communication with or otherwise control a device interface 38 and, in some cases, a user interface 44. As such, the processing circuitry may be embodied as a circuit chip (e.g., an integrated circuit chip) configured (e.g., with hardware, software or a combination of hardware and software) to perform operations described herein. However, in some embodiments taken in the context of the mobile terminal, the processing circuitry may be embodied as a portion of a mobile computing device or other mobile terminal.

The optional user interface 44 may be in communication with the processing circuitry 32 to receive an indication of a user input at the user interface and/or to provide an audible, visual, mechanical or other output to the user. As such, the user interface in

the context of a mobile terminal may include, for example, a keyboard, a mouse, a joystick, a display, a touch screen, a microphone, a speaker, and/or other input/output mechanisms.

The device interface 38 may include one or more interface mechanisms for enabling communication with other devices and/or networks. In some cases, the device interface may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to receive and/or transmit data from/to a network and/or any other device or module in communication with the processing circuitry 32. In this regard, the device interface may include, for example, an antenna (or multiple antennas) and supporting hardware and/or software for enabling communications with a wireless communication network and/or a communication modem or other hardware/software for supporting communication via cable, digital subscriber line (DSL), universal serial bus (USB), Ethernet or other methods. In the illustrated embodiment, for example, the device interface includes a cellular modem 40 (e.g., a UMTS modem) for supporting communications with the eNB 12 and an optional non-cellular modem 42 (e.g., a WiFi modem, WLAN modem, Bluetooth (BT) modem, etc.) for supporting communications with other terminals (e.g., a WiFi station(s), a WLAN station(s)), etc.).

In an example embodiment, the memory 36 may include one or more non-transitory memory devices such as, for example, volatile and/or non-volatile memory that may be either fixed or removable. The memory may be configured to store information, data, applications, instructions or the like for enabling the apparatus 30 to carry out various functions in accordance with example embodiments of the present invention. For example, the memory could be configured to buffer input data for processing by the processor 34. Additionally or alternatively, the memory could be configured to store instructions for execution by the processor. As yet another alternative, the memory may include one of a plurality of databases that may store a variety of files, contents or data

sets. Among the contents of the memory, applications may be stored for execution by the processor in order to carry out the functionality associated with each respective application. In some cases, the memory may be in communication with the processor via a bus for passing information among components of the apparatus.

The processor 34 may be embodied in a number of different ways. For example, the processor may be embodied as various processing means such as one or more of a microprocessor or other processing element, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC, an FPGA or the like. In an example embodiment, the processor may be configured to execute instructions stored in the memory 36 or otherwise accessible to the processor. As such, whether configured by hardware or by a combination of hardware and software, the processor may represent an entity (e.g., physically embodied in circuitry – in the form of processing circuitry 32) capable of performing operations according to embodiments of the present invention while configured accordingly. Thus, for example, when the processor is embodied as an ASIC, FPGA or the like, the processor may be specifically configured hardware for conducting the operations described herein. Alternatively, as another example, when the processor is embodied as an executor of software instructions, the instructions may specifically configure the processor to perform the operations described herein.

Considering the significant coverage gap between low-cost MTC UEs (e.g., meter devices) and category 1 UEs (also referred to herein as legacy UEs) (e.g., mobile terminals (e.g., mobile phones)), repetition and retransmission may be useful schemes for coverage improvement of data channels, which may achieve much lower effective coding rate, although power boosting, beamforming, inter-cell coordination and interference cancellation may also be exploited. In LTE Release 8 specifications and beyond, TTI bundling has been introduced to improve uplink coverage at cell edge or in poor radio

conditions supporting Voice over Internet Protocol (VoIP) (utilized by legacy VoIP UEs (e.g., category 1 UEs)) in which different redundancy versions (RVs) of the same set of coded bits may be transmitted in four consecutive TTIs. Comparing with Hybrid Automatic Repeat Request (HARQ), no HARQ acknowledgement/negative-acknowledgement (ACK/NACK), feedback is required within a TTI bundling duration, and therefore control overhead may be reduced as well as latency. In a low-cost MTC scenario (e.g., for low cost MTC UEs), TTI bundling may also be utilized with an even longer bundling duration, for example, 1,000 TTI bundling, in order to achieve the significantly low operation SNR. On the other hand, HARQ may not be desired, as HARQ ACK/NACK may consume a large downlink control resource and may lead to a long delay.

Frequency hopping (FH) may be another beneficial technique utilized in LTE uplink transmission. Utilizing frequency hopping may enable a UE to exploit the frequency diversity of a wideband channel used in LTE while keeping a required contiguous allocation. The LTE standard currently allows two modes for frequency hopping, enabled by higher layer signaling, from one to the other time slot (e.g., intra-subframe) or from one to the other subframe (e.g., inter-subframe). For low-cost MTC coverage, frequency hopping may also be utilized as a starting point.

In order to determine whether very long TTI bundling may be utilized to achieve the required 20 dB gain for PUSCH with the 100 byte package size and 5 second latency defined in the traffic model for LTE, a processor (e.g., processor 24) of a network device (e.g., eNB 12) may perform link-level simulations.

Referring to FIG. 4, a table illustrating the simulation parameters is provided according to an exemplary embodiment. As shown in table 1 of FIG. 4, the TTI bundling selected for legacy VoIP UEs (e.g., UEs 10) is four TTIs as per the LTE Release 8 specifications (also referred to herein as LTE Release 8 standard). Each TTI may be a one

millisecond (ms) timeslot (e.g., resources) and as such four TTIs is 4 ms. In this example embodiment, the TTI bundling for low cost MTC UEs (e.g., UEs 10') is selected as 1,000 TTIs (e.g., 1 second, since each TTI is 1 ms), as shown in table 1. In some example embodiments, a number of TTIs (e.g., 1,000 TTIs) in a bundle that exceeds a number TTIs (e.g., 4 TTIs) of a smaller bundle may, but need not, relate to more reliable transmissions since more resources (e.g., timeslots) may be available to transmit traffic (e.g., data).

Additionally, the frequency hopping selected for the legacy VoIP UEs may be selected as inter-subframe frequency hopping as shown in table 1. In the current LTE standard, inter-subframe frequency hopping may denote frequency hopping every subframe for legacy UEs (e.g., UEs 10 (e.g., legacy VoIP UEs)). As such, a legacy UE may utilize a different frequency channel to transmit/receive data each subframe. The frequency hopping for the low-cost MTC UEs may be selected, for example, as every 1, 40 or 1,000 subframes. For the scenario of low cost MTC UEs, the 100 byte package may be segmented into five 20 byte transport blocks (TBs), and each TB is transmitted in one second.

FIG. 5 shows the residual Block Error Rate (BLER) and throughput (TP) curves of normal LTE UEs (e.g., legacy VoIP UEs (e.g., UEs 10)) and low-cost MTC UEs (e.g., MTC UEs 10'). In the example embodiment of FIG. 5, curve 3 corresponds to frequency hopping every TTI or every subframe according to the current LTE standard for legacy UEs. Curve 5 corresponds to frequency hopping every TTI or subframe for MTC UEs (e.g., MTC UEs 10') and curve 7 corresponds to frequency hopping every 1,000 TTIs or 1,000 subframes for MTC UEs. Additionally, curve 9 corresponds to frequency hopping every 40 TTIs or 40 subframes for MTC UEs.

In an example embodiment, the BLER and the throughput curves may be generated by the processor (e.g., processor 24) of a network device (e.g., eNB 12). Presuming 2% residual BLER as the performance target, FIG. 5 shows that the operation Signal-to-Noise

Ratio (SNR) for uplink VoIP is about -6.8 dB for curve 3. To achieve a 20 dB gain, the processor (e.g., processor 24) may determine that a low-cost MTC UE should support an operation SNR lower than -6.8 – 20 + 3 = -23.8 dB, where an extra 3 dB is added because one resource block (RB) instead of two RBs are utilized for low-cost MTC PUSCH transmission and the effective noise power is therefore halved.

As shown in FIG. 5, when inter-subframe frequency hopping is on, 1,000 TTI bundling may achieve 2% BLER at -19.3 dB SNR for curve 5, translating into 12.5 dB (e.g. the difference between -19.3 dB and -6.8 dB = 12.5 dB) gain comparing with 4 TTI bundling for curve 3, which is much lower than the theoretical 24 dB gain (e.g., approximately -23.8 dB). In other words, although the gain (e.g., 12.5 dB) improved for curve 5 the gain did not improve by 20 dB with respect to curve 3. One reason for this big loss may be very poor channel estimation performance under such low SNR scenario. One mechanism may be that multiple consecutive subframes using a channel is jointly estimated assuming the same demodulation reference signal sequence, since the channel is extremely slow time-variant for these low-cost MTC UEs (e.g., UE 10'). However, with inter-subframe frequency hopping the benefits of cross-subframe channel estimation cannot be achieved. In order to improve channel estimation, frequency hopping may need to be turned off. In the example embodiment of FIG. 5, curve 7 corresponds to frequency hopping every 1,000 TTIs which equivalently denotes that frequency hopping is turned off, as only one frequency carrier is used in the duration of the transmission for one transport block, for example, 1,000 TTIs. However, in an instance in which the frequency hopping is off, there is no frequency diversity gain and the performance becomes even worse as shown per curve 7.

To solve this problem, the benefits of cross-subframe channel estimation and frequency diversity may need to be kept at the same time. One approach is for the processor (e.g., processor 24) of the network device (e.g., eNB 12) extending the current

frequency hopping time-domain granularity from one time-slot or one subframe to N_{FH} subframes, where $N_{FH} > 1$ in which N denotes number and FH denotes frequency hopping. As such, cross-subframe channel estimation may be applied within these N_{FH} subframes, where the same frequency resource may be utilized by one MTC UE (e.g., UE 10'). Assuming the number (N) of TTIs in one TTI bundling duration is $N_{TTIbundling}$, as long as $N_{TTIbundling} \gg N_{FH}$, frequency diversity gain due to frequency hopping may still be achieved. In this regard, FIG. 5 shows an example with $N_{FH} = 40$ and $N_{TTIbundling} = 1{,}000$ associated with curve 9. As shown in FIG. 5, the operation SNR may reach -25.3 dB for curve 9, which is lower than the targeted -23.8 dB. In other words, the curve 9 exhibits a 20 dB gain (as compared with 4 TTI bundling for curve 3). As such, by utilizing a frequency hopping greater than 1 subframe (e.g., 40 subframes, or subframes between 1 and 1,000 (e.g., 50 subframes)), the processor (e.g., processor 24) of the network device (e.g., eNB 12) may determine that a 20 dB gain may be achieved.

As described in the background section, TTI bundling and frequency hopping are existing techniques used for PUSCH transmission in the current LTE standard. But for the low-cost MTC UE scenario, the existing LTE solution of utilizing one subframe, or a half subframe, is unable (see e.g., curve 5 of FIG. 5) to satisfy channel estimation performance and frequency diversity gain at the same time, and is unable to achieve the required 20 dB gain with simple TTI bundling extension, regardless of whether frequency hopping is turned on or off. As described above, and shown in FIG. 5 with respect to curve 5, a frequency hopping of greater than one subframe is needed to achieve a 20 dB gain.

As such, in some example embodiments, the time-domain granularity of PUSCH frequency hopping may be extended by a processor (e.g., processor 24) of a network device (e.g., eNB 12) to more than one subframe, in an instance in which a long TTI bundling is utilized under a very low SNR scenario. In this manner, a low cost MTC UE (e.g., UE 10') may achieve an additional coverage requirement such as a 20 dB gain.

In this regard, a time-domain granularity of PUSCH hopping may be indicated by the processor (e.g., processor 24) of the network device (e.g., eNB 12) via higher layer signaling, via an uplink grant in a Random Access Response (RAR) or in a certain field in a Downlink Control Information (DCI) format, in which at least one of the indicated values is longer than one subframe.

In one example embodiment, a field of the RAR, a field of the DCI format or a field of an information element of higher layer signaling may indicate the PUSCH frequency hopping time-domain granularity. In another example embodiment, the field of higher layer signaling, the field of the RAR or the field of the DCI format may indicate both TTI bundling size and PUSCH frequency hopping time-domain granularity, which may have an implicit linkage.

In one example embodiment, a field of a PUSCH frequency hopping time-domain granularity may be provided by a network device to a UE (e.g., UE 10') in a UE-specific Radio Resource Control, (RRC) Information Element (IE), such as for example, a PUSCH-ConfigDedicated or Media Access Control (MAC)-MainConfig IE. The RRC IE (e.g., PUSCH-ConfigDedicated, MAC-MainConfig IE) may be signaled by the network device (e.g., eNB 12) to a UE (e.g., UE 10') in a random access procedure. This higher layer signaling could also be other UE specific RRC signaling, cell specific RRC signaling (e.g., a cell specific information element (e.g., PUSCH-ConfigCommon)), content that is part of a Random-Access Channel (RACH) response, RRC signaling that is common to a group of UEs, or any other suitable signaling.

The indication of the field indicating that PUSCH frequency hopping is extended to more than one subframe may be in a form of enumeration. In one example embodiment, table 2 of FIG. 6 illustrates an example of the frequency hopping granularity only indication. In another example embodiment, table 3 of FIG. 7 illustrates the TTI bundling size with frequency hopping granularity joint indication.

Referring now to FIG. 6, an example embodiment of a PUSCH frequency hopping time-domain granularity indication in a table is provided. In the example embodiment of FIG. 6, a processor (e.g., processor 24) of a network device (e.g., eNB 12) may include data in the table 2 indicating a frequency hopping time-domain granularity of 10 subframes associated with index 2 and a frequency hopping time-domain granularity of 40 subframes associated with index 3. In this manner a MTC UE (e.g., UE 10') that receives the PUSCH hopping time-domain granularity indication of table 2, from a network device (e.g., eNB 12), may utilize (e.g., transmit data (e.g., radio signals) by rapidly switching a carrier among various frequency channels) the frequency hopping indication of more than one subframe (e.g., 10 subframes, 40 subframes) to achieve a 20 dB gain. In addition, the processor (e.g., processor 24) of the network device (e.g., eNB 12) may include data indicating a frequency hopping time-domain granularity subframe of 0.5 and a frequency hopping time-domain granularity subframe of 1 to enable MTC UEs (e.g., UE 10') receiving the PUSCH frequency hopping time-domain granularity of table 2 to frequency hop per the existing LTE standard.

Referring now to FIG. 7, an example embodiment of a joint PUSCH TTI bundling size and PUSCH frequency hopping time-domain granularity indication in a table is provided. In the example embodiment of FIG. 7, a processor (e.g., processor 24) of the network device (e.g., eNB 12) may include data indicating TTI bundling sizes associated with frequency hopping time-domain granularity subframes in table 3. For example, the processor (e.g., processor 24) may indicate frequency hopping time-domain granularities in which subframes are greater than one subframe and corresponding to respective TTI bundling sizes. For instance, 2 subframes may correspond to 10 TTIs, 5 subframes may correspond to 40 TTIs, 10 subframes may correspond to 100 TTIs, 20 subframes may correspond to 400 TTIs, and 40 subframes may correspond to 1,000 subframes.

Additionally, the processor (e.g., processor 24) of the network device (e.g., eNB 12) may include data indicating a frequency hopping time-domain granularity subframe of 0.5 and a frequency hopping time-domain granularity subframe of 1 to enable MTC UEs (e.g., UE 10') receiving the PUSCH hopping time-domain granularity of table 3 to frequency hop per the existing LTE standard. In the example embodiment of FIG. 7, the subframe of 0.5 may be associated with, for example, with 1 TTI, and a subframe of 1 may be associated with 1 TTI. Additionally, another subframe of 1 may be associated with 4 TTIs.

In the example embodiment of FIG. 7 there may be an implicit linkage, by the processor (e.g., processor 24) between the subframes and the TTIs that are utilized. For example, the longer the TTI(s), the longer one or more subframes may be assigned by the processor (e.g., processor 24) of the network device (e.g., eNB 12) to support the frequency hopping time. In response to receiving the joint PUSCH TTI bundling size and frequency hopping time-domain granularity indication of table 3 from a network device (e.g., eNB 12), a low-cost MTC UE (e.g., UE 10') may perform the frequency hopping by utilizing (e.g., transmitting data (e.g., radio signals) by rapidly switching a carrier among many frequency channels) a subframe greater than 1 to achieve a 20 dB gain for the duration of the TTI bundling size. Additionally, the MTC UE may also perform frequency hopping by utilizing a subframe of 1 or 0.5 for the duration of a TTI bundling size (e.g., 1 TTI, 4 TTIs).

As such, some example embodiments may provide benefits of both cross-subframe channel estimation and frequency hopping for PUSCH transmission for low-cost MTC UEs at extremely low SNR, based in part on utilizing changes to signaling (e.g., RRC signaling).

Referring now to FIG. 8, a flowchart of an example method for enhancing frequency hopping with transmission time interval bundling according to an example embodiment is provided. At operation 800, an apparatus (e.g., a network device (e.g.,

eNB 12)) may assign or extend a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes (e.g., 40 subframes) greater than one subframe. At operation 805, an apparatus (e.g., a network device (e.g., eNB 12)) may provide a generated indication (e.g., a RAR, a DCI format, an information element, etc.) identifying the extended frequency hopping time-domain granularity to at least one communication device (e.g., a MTC UE (e.g., UE 10')) to enable the communication device to perform frequency hopping for the number of subframes greater (e.g., 40 subframes) than one subframe. In an example embodiment, the provision of the indication to the communication device may enable the communication device to perform frequency hopping for the number of subframes during a duration of a group or bundle of transmission time intervals in order to achieve a 20 dB gain improvement in coverage.

Referring now to FIG. 9, a flowchart of an example method for enhancing frequency hopping with transmission time interval bundling according to an example embodiment is provided. At operation 900, an apparatus (e.g., a MTC UE (e.g., UE 10')) may receive, from a network device (e.g., eNB 12), an indication (e.g., a RAR, a DCI format, an information element, etc.) of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes (e.g., 40 subframes) greater than one subframe. At operation 905, an apparatus (e.g., a MTC UE (e.g., UE 10')) may perform frequency hopping for the number of subframes greater than one subframe. In an example embodiment, the apparatus (e.g., a MTC UE (e.g., UE 10')) may perform frequency hopping for the number of subframes during a duration of a group or bundle of transmission time intervals. In some example embodiments, by performing frequency hopping for the number of subframes during a duration of a group/bundle of transmission time intervals, the apparatus (e.g., a MTC UE (e.g., UE 10')) may achieve at least a 20 dB gain improvement in coverage.

It should be pointed out that FIGS. 8 and 9 are flowcharts of a system, method and computer program product according to an example embodiment of the invention. It will be understood that each block of the flowcharts, and combinations of blocks in the flowcharts, can be implemented by various means, such as hardware, firmware, and/or a computer program product including one or more computer program instructions. For example, one or more of the procedures described above may be embodied by computer program instructions. In this regard, in an example embodiment, the computer program instructions which embody the procedures described above are stored by a memory device (e.g., memory 26, memory 36) and executed by a processor (e.g., processor 24, processor 34). As will be appreciated, any such computer program instructions may be loaded onto a computer or other programmable apparatus (e.g., hardware) to produce a machine, such that the instructions which execute on the computer or other programmable apparatus cause the functions specified in the flowcharts blocks to be implemented. In one embodiment, the computer program instructions are stored in a computer-readable memory that can direct a computer or other programmable apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instructions which implement the function(s) specified in the flowcharts blocks. The computer program instructions may also be loaded onto a computer or other programmable apparatus to cause a series of operations to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions which execute on the computer or other programmable apparatus implement the functions specified in the flowcharts blocks.

Accordingly, blocks of the flowcharts support combinations of means for performing the specified functions. It will also be understood that one or more blocks of the flowcharts, and combinations of blocks in the flowcharts, can be implemented by

special purpose hardware-based computer systems which perform the specified functions, or combinations of special purpose hardware and computer instructions.

In an example embodiment, an apparatus for performing the methods of FIGS. 8 and 9 above may comprise a processor (e.g., the processor 24, processor 34) configured to perform some or each of the operations (800 – 805, 900 – 905) described above. The processor may, for example, be configured to perform the operations (800 – 805, 900 – 905) by performing hardware implemented logical functions, executing stored instructions, or executing algorithms for performing each of the operations. Alternatively, the apparatus may comprise means for performing each of the operations described above. In this regard, according to an example embodiment, examples of means for performing operations (800 – 805, 900 – 905) may comprise, for example, the processor 24 (e.g., as means for performing any of the operations described above), and/or a device or circuitry for executing instructions or executing an algorithm for processing information as described above.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe example embodiments in the context of certain example combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

WHAT IS CLAIMED IS:

1. A method comprising:

extending a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe; and

enabling provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe.

2. The method of claim 1, wherein enabling provision further comprises enabling provision of the indication to the communication device to enable the communication device to perform frequency hopping for the number of subframes during a duration of a group of transmission time intervals.

3. The method of claims 1 or 2, wherein the generated indication is included in a field of an uplink grant of a Random Access Response.

4. The method of claims 1 or 2 wherein the generated indication is included in a field of a Downlink Control Information format.

5. The method of claims 1 or 2, wherein the indication is included in an information element.

6. The method of claim 5, wherein the information element comprises a Radio Resource Control information element.

7. The method of claim 6, wherein the Radio Resource Control information element comprises at least one of a Physical Uplink Shared Channel-ConfigDedicated information element or a Media Access Control-MainConfig information element.

8. The method of claims 1 or 5, wherein enabling provision comprises signaling the indication to the communication device in a random access procedure.

9. The method of claims 1 or 2, wherein the indication comprises one or more values denoting additional numbers of subframes that are greater than one subframe.

10. The method of claims 1 or 2, wherein enabling provision comprises providing the indication to the communication device via higher layer signaling comprising at least one of cell specific signaling, content that is part of a Random Access Channel response or Radio Resource Control signaling that is designated for a group of communication devices.

11. The method of claim 10, wherein the cell specific Radio Resource Control signaling comprises a cell specific information element.

12. The method of claim 11, wherein the cell specific information element comprises a Physical Uplink Shared Channel-ConfigCommon information element.

13. The method of claims 1 or 2 wherein the generated indication identifying the frequency hopping time-domain granularity comprises indicating the extended frequency hopping time-domain granularity in a field.

14. The method of claim 13, wherein the field comprises data indicating a transmission time interval bundling size linked to the number of subframes that is greater than one subframe.

15. The method of claim 13, wherein the field comprises data indicating a plurality of transmission time interval bundling sizes that are linked to respective numbers of subframes that are greater than one subframe.

16. The method of claim 1, wherein enabling provision further comprises enabling provision of the indication to the communication device to enable the communication device to perform frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve a low signal-to-noise ratio.

17. The method of claim 16, wherein the duration comprises a long bundling duration based in part on a number of the transmission time intervals of the group.

18. The method of claim 17, wherein the number of the transmission time intervals comprises 1,000.

19. The method of claims 1 or 2, wherein the communication device comprises a machine type communications device.

20. An apparatus comprising:

at least one processor; and

at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

extend a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe; and

enable provision of a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe.

21. The apparatus of claim 20, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

enable provision by enabling provision of the indication to the communication device to enable the communication device to perform frequency hopping for the number of subframes during a duration of a group of transmission time intervals.

22. The apparatus of claims 20 or 21, wherein the generated indication is included in a field of an uplink grant of a Random Access Response.

23. The apparatus of claims 20 or 21, wherein the generated indication is included in a field of a Downlink Control Information format.

24. The apparatus of claims 20 or 21, wherein the indication is included in an information element.

25. The apparatus of claim 24, wherein the information element comprises a Radio Resource Control information element.

26. The apparatus of claim 25, wherein the Radio Resource Control information element comprises at least one of a Physical Uplink Shared Channel-ConfigDedicated information element or a Media Access Control-MainConfig information element.

27. The apparatus of claims 20 or 24, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

enable provision by signaling the indication to the communication device in a random access procedure.

28. The apparatus of claims 20 or 21, wherein the indication comprises one or more values denoting additional numbers of subframes that are greater than one subframe.

29. The apparatus of claims 20 or 21, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

enable provision by providing the indication to the communication device via higher layer signaling comprising at least one of cell specific signaling, content that is part of a Random Access Channel response or Radio Resource Control signaling that is designated for a group of communication devices.

30. The apparatus of claim 29, wherein the cell specific Radio Resource Control signaling comprises a cell specific information element.

31. The apparatus of claim 30, wherein the cell-specific information element comprises a Physical Uplink Shared Channel-ConfigCommon information element.

32. The apparatus of claims 20 or 21 wherein the generated indication identifying the frequency hopping time-domain granularity comprises indicating the extended frequency hopping time-domain granularity in a field.

33. The apparatus of claim 32, wherein the field comprises data indicating a transmission time interval bundling size linked to the number of subframes that is greater than one subframe.

34. The apparatus of claim 32, wherein the field comprises data indicating a plurality of transmission time interval bundling sizes that are linked to respective numbers of subframes that are greater than one subframe.

35. The apparatus of anyone of claims 20 to 34, wherein the apparatus comprises a network device.

36. The apparatus of claim 35, wherein the network device comprises a base station.

37. The apparatus of anyone of claims 20 to 34, wherein the communication device comprises a mobile terminal.

38. The apparatus of claim 37, wherein the mobile terminal comprises User Equipment.

39. The apparatus of claim 38, wherein the User Equipment comprises machine type communications User Equipment.

40. The apparatus of anyone of claims 20 to 39, wherein the apparatus is configured for use in a Long Term Evolution system or a Long Term Evolution Advanced system.

41. The apparatus of claim 20, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

enable provision by enabling provision of the indication to the communication device to enable the communication device to perform frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve a low signal-to-noise ratio.

42. The apparatus of claim 41, wherein the duration comprises a long bundling duration based in part on a number of the transmission time intervals of the group.

43. The apparatus of claim 42, wherein the number of the transmission time intervals comprises 1,000.

44. A method comprising:

receiving, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe; and

performing frequency hopping for the number of subframes greater than one subframe.

45. The method of claim 44, wherein performing frequency hopping comprises performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals.

46. The method of claim 44, wherein performing frequency hopping comprises performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve at least a twenty decibel gain improvement in coverage.

47. The method of claims 44 or 45, wherein the indication is included in a detected field of an uplink grant of a Random Access Response.

48. The method of claims 44 or 45 wherein the indication is included in a detected field of a Downlink Control Information format.

49. The method of claim 44, wherein performing frequency hopping comprises performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve at least a twenty decibel gain improvement in coverage at a low signal-to-noise ratio.

50. The method of claim 49, wherein the duration comprises a long bundling duration based in part on a number of the transmission time intervals of the group.

51. The method of claim 50, wherein the number of the transmission time intervals comprises 1,000.

52. An apparatus comprising:

at least one processor; and

at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

receive, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe; and

perform frequency hopping for the number of subframes greater than one subframe.

53. The apparatus of claim 52, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

perform frequency hopping by performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals.

54. The apparatus of claim 52, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

perform frequency hopping by performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve at least a twenty decibel gain improvement in coverage.

55. The apparatus of claims 52 or 53, wherein the indication is included in a detected field of an uplink grant of a Random Access Response.

56. The apparatus of claims 52 or 53, wherein the indication is included in a detected field of a Downlink Control Information format.

57. The apparatus of claims 52 to 56, wherein the apparatus comprises a mobile terminal.

58. The apparatus of anyone of claims 57, wherein the mobile terminal comprises a machine type communications User Equipment.

59. The apparatus of anyone of claims 52 to 58, wherein the apparatus is configured for use in a Long Term Evolution system or a Long Term Evolution Advanced system.

60. The apparatus of claim 52, wherein the at least one memory and the computer program code are further configured to, with the at least one processor, cause the apparatus to:

perform frequency hopping by performing frequency hopping for the number of subframes during a duration of a group of transmission time intervals to achieve at least a twenty decibel gain improvement in coverage at a low signal-to-noise ratio.

61. The apparatus of claim 60, wherein the duration comprises a long bundling duration based in part on a number of the transmission time intervals of the group.

62. The apparatus of claim 61, wherein the number of the transmission time intervals comprises 1,000.

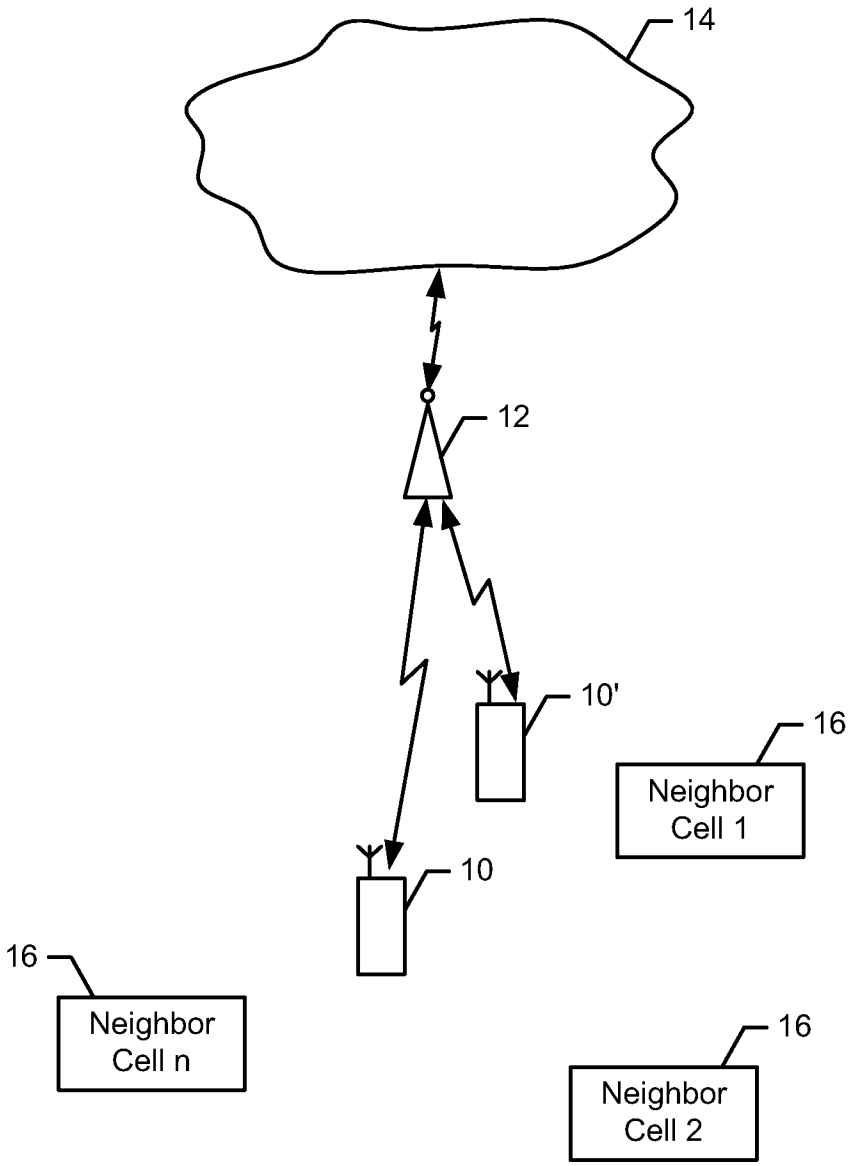

14
12
10'
16
Neighbor
Cell 1
10
16
Neighbor
Cell n
16
Neighbor
Cell 2

FIG. 1.

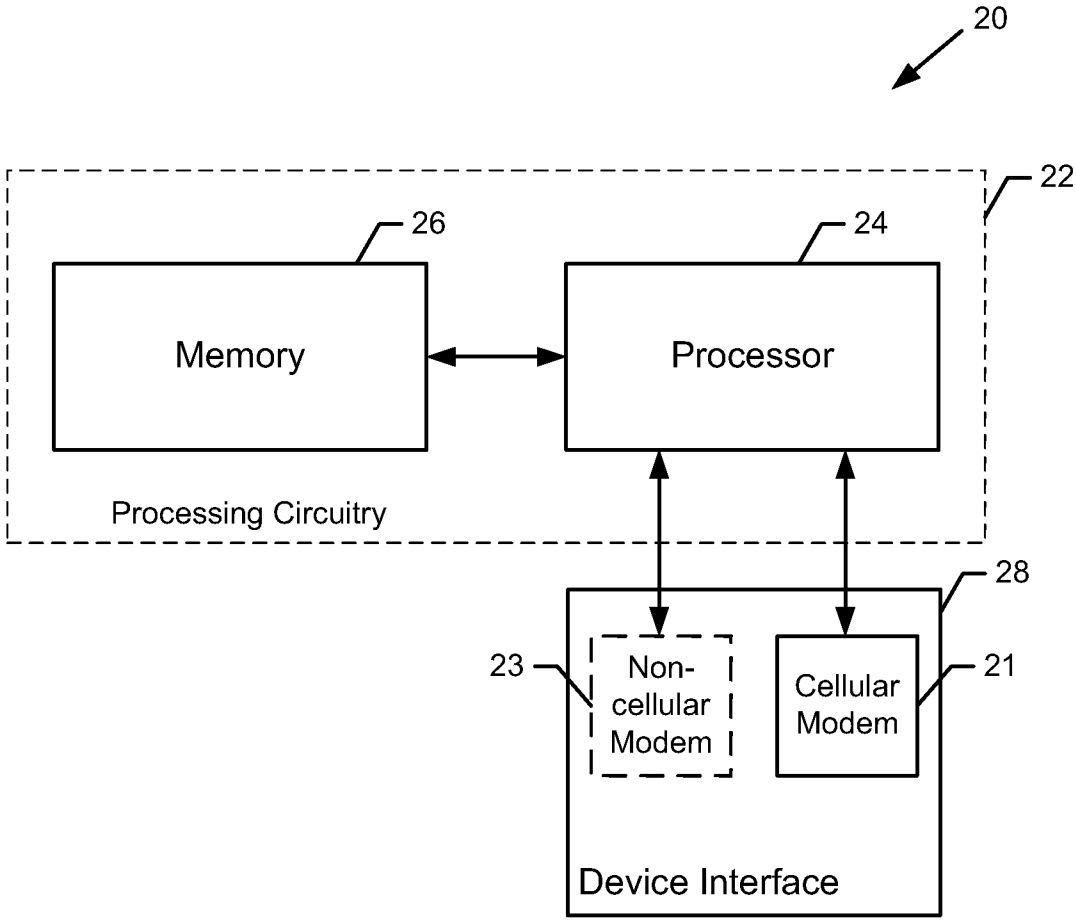

20
22
26
24
Memory
Processor
Processing Circuitry
28
23
Non-
cellular
Modem
Cellular
Modem
21
Device Interface

FIG. 2

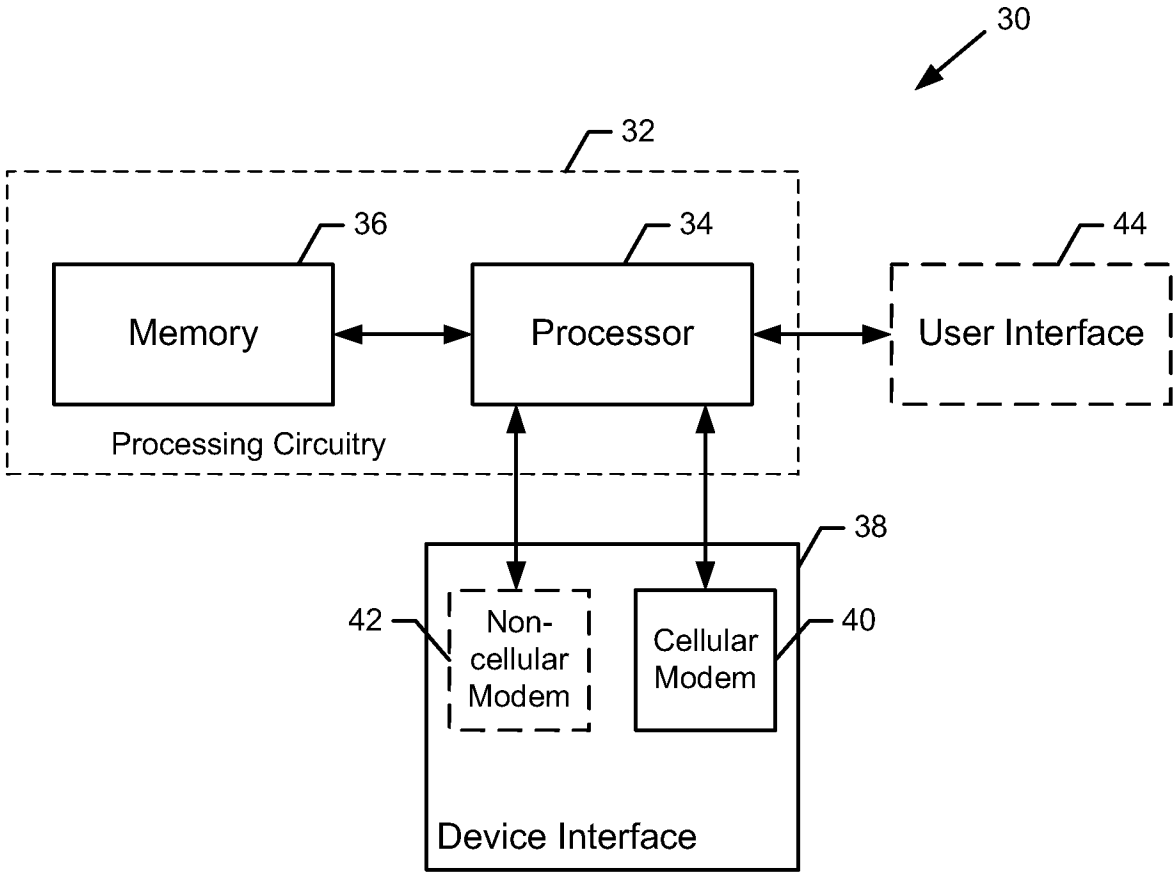
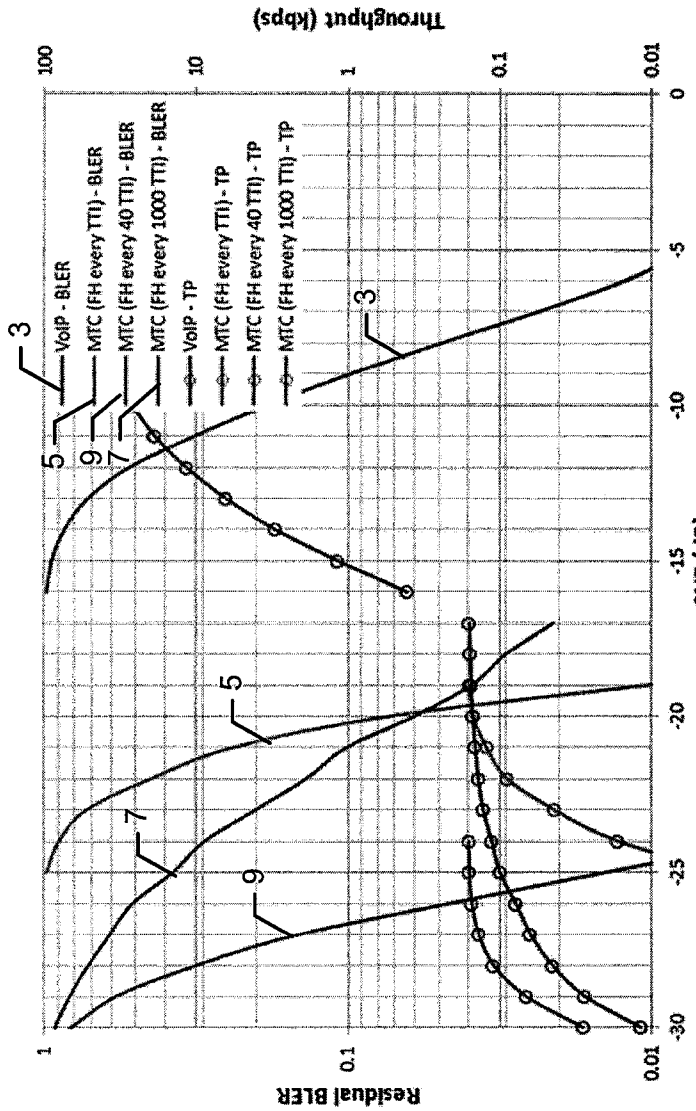

30
32
36
34
44
Memory
Processor
User Interface
Processing Circuitry
38
42
Non-
cellular
Modem
Cellular
Modem
40
Device Interface

FIG. 3

	Legacy VoIP	Low-cost MTC
Carrier frequency	2.0 GHz	2.0 GHz
Antenna configuration	1x2, low correlation	1x2, low correlation
Channel model	EPA	EPA
Doppler shift	5 Hz	1 Hz
System bandwidth	10 MHz	10 MHz
MCS	10	10
Number of UL RBs	2	1
Transmission mode	TM1	TM1
TTI bundling	4 TTI	1000 TTI
Max number of (re)-transmissions	4	1
Frequency hopping	Inter-subframe	Every 1, 40 or 1000 subframes
Performance target	2% residual BLER	2% BLER
Channel estimation	Realistic, intra-subframe	Realistic, within FH duration
Effective code rate	1.53E-01	6.39E-04

TABLE 1

FIG. 4.



LOW-COST MTC PERFORMANCE

FIG. 5.

Index	FH time-domain granularity (subframe)
0	0.5
1	1
2	10
3	40

TABLE 2

FIG. 6.

Index	TTI bundling size (subframe)	FH time-domain granularity (subframe)
0	1	0.5
1	1	1
2	4	1
3	10	2
4	40	5
5	100	10
6	400	20
7	1000	40

TABLE 3

FIG. 7.

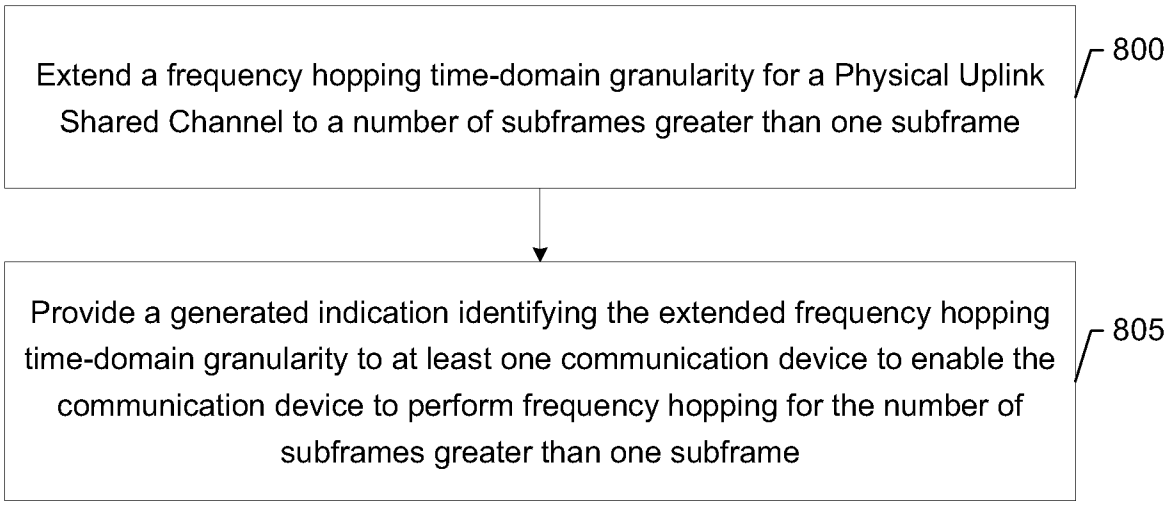

Extend a frequency hopping time-domain granularity for a Physical Uplink Shared Channel to a number of subframes greater than one subframe
800
Provide a generated indication identifying the extended frequency hopping time-domain granularity to at least one communication device to enable the communication device to perform frequency hopping for the number of subframes greater than one subframe
805

FIG. 8.

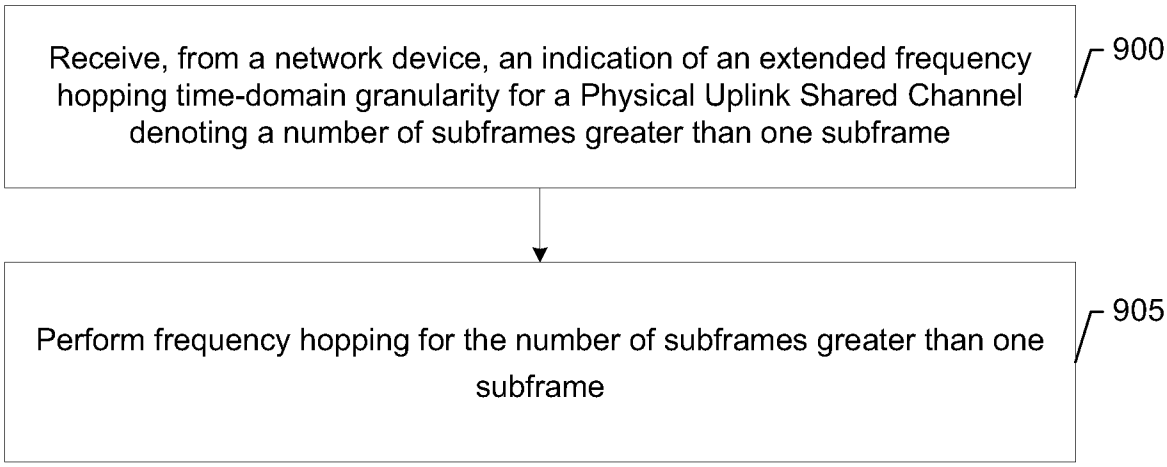

Receive, from a network device, an indication of an extended frequency hopping time-domain granularity for a Physical Uplink Shared Channel denoting a number of subframes greater than one subframe
900
Perform frequency hopping for the number of subframes greater than one subframe
905

FIG. 9.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2013/070602

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/04 (2009.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H04W, H04Q, H04L, H04B

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)

CNKI, CPRSABS, CNTXT, VEN: frequency, hopping, time domain, granularity, PUSCH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102387589 A (CHINA ACADEMY OF TELECOMM TECH) 21 March 2012 (21.03.2012) description, paragraphs [0025]-[0072], figures 2-4	1-62
A	CN 101034912 A (ZTE CORP) 12 September 2007 (12.09.2007) the whole document	1-62

☐ 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	Date of mailing of the international search report
14 October 2013 (14.10.2013)	**31 Oct. 2013 (31.10.2013)**
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer XU, Qian Telephone No. (86-10)62411433

Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2013/070602

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN 102387589 A	21.03.2012	WO 2012028065 A1	08.03.2012
CN 101034912 A	12.09.2007	CN 101034912 B	26.05.2010