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(54) **SOUNDING REFERENCE SIGNAL (SRS) USAGE**

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CPC ***H04L 5/0053*** (2013.01); ***H04L 5/005*** (2013.01); ***H04L 5/0007*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,274,931	B2	9/2012	Pajukoski et al.	
2012/0120854	A1*	5/2012	Zhang et al.	370/280
2012/0281604	A1*	11/2012	Papasakellariou et al.	370/310
2013/0194908	A1*	8/2013	Gao et al.	370/203
2013/0223394	A1*	8/2013	Nishio et al.	370/329
2013/0279435	A1*	10/2013	Dinan	370/329
2013/0322276	A1*	12/2013	Pelletier et al.	370/252
2014/0198766	A1*	7/2014	Siomina	H04W 72/082 370/330
2014/0219267	A1*	8/2014	Eyuboglu et al.	370/350

FOREIGN PATENT DOCUMENTS

EP	2 536 047	A2	12/2012	
EP	2 538 738	A1	12/2012	
EP	2 660 992	A1	11/2013	
WO	2011/102768	A1	8/2011	
WO	WO 2011/102768	A1 *	8/2011	H04L 5/00
WO	2012/088876	A1	7/2012	
WO	2013/025147	A1	2/2013	

OTHER PUBLICATIONS

International Search Report application No. PCT/EP2014/056241 dated Jun. 23, 2014.
3GPP TSG RAN WG1 Meeting #72, "TR skeleton for small cell enhancements—physical layer aspects", Jan. 28-Feb. 1, 2013, St. Julian's, Malta, R1-130019.

(Continued)

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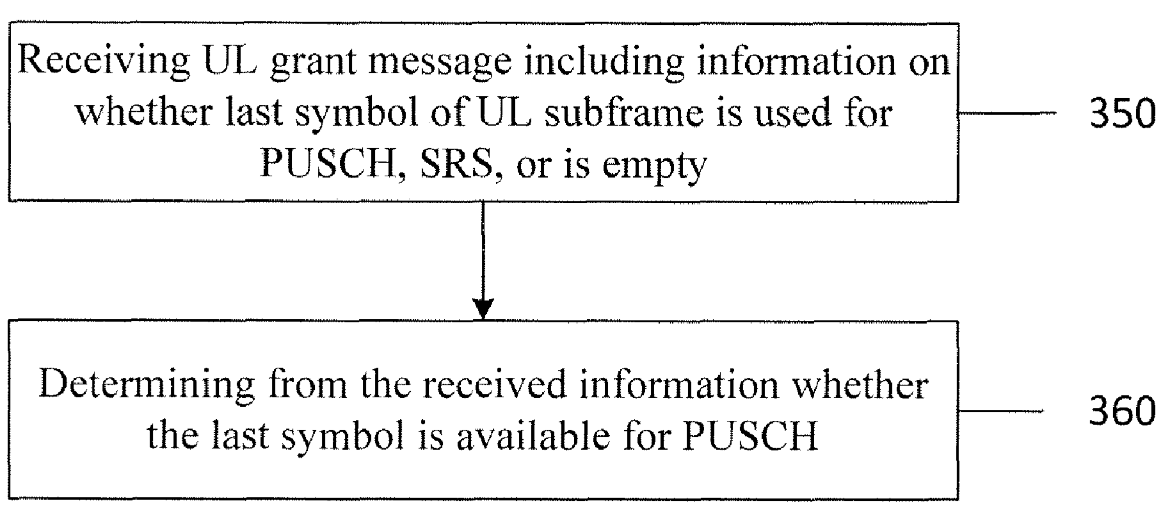
(57) **ABSTRACT**

Systems, methods, apparatuses, and computer program products for controlling sounding reference signal (SRS) transmission are provided. One method includes incorporating into an uplink grant message, by a base station in a communications system, information on whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty. The method may then include transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE).

38 Claims, 3 Drawing Sheets



(56) **References Cited**

OTHER PUBLICATIONS

3GPP TSG-RAN Meeting #58, "New Study Item Proposal for Small Cell Enhancements for E-UTRA and E-UTRAN—Physical-layer Aspects", Dec. 4-7, 2012, Barcelona, Spain, RP-122032.
"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Small Cell Enhancements for E-UTRA and E-UTRAN—Physical Layer Aspects" (Release 12), 3GPP TR 36.8xy, V0.0.1 (Jan. 2013).
"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Small Cell Enhancements for E-UTRA and E-UTRAN—Physical Layer Aspects" (Release 12), 3GPP TR 36.872, V12.1.0 (Dec. 2013).

* cited by examiner

SC-FDMA symbol #	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Contents	PUSCH	PUSCH	PUSCH	DM-RS	PUSCH	PUSCH	PUSCH	PUSCH	PUSCH	PUSCH	DM-RS	PUSCH	PUSCH	PUSCH or SRS

Fig. 1

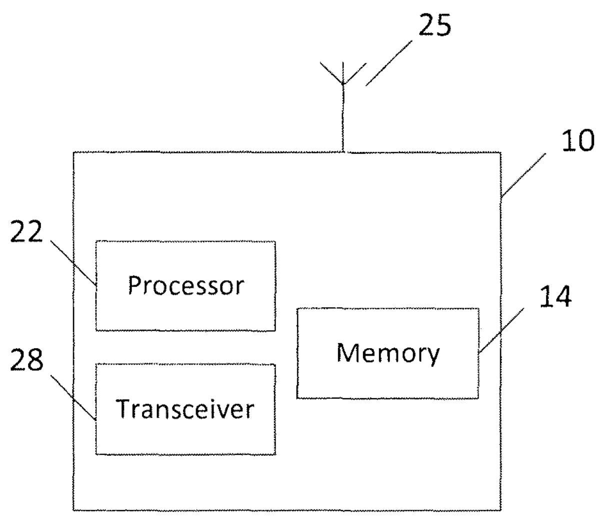

25
10
22
Processor
14
Memory
28
Transceiver

Fig. 2a

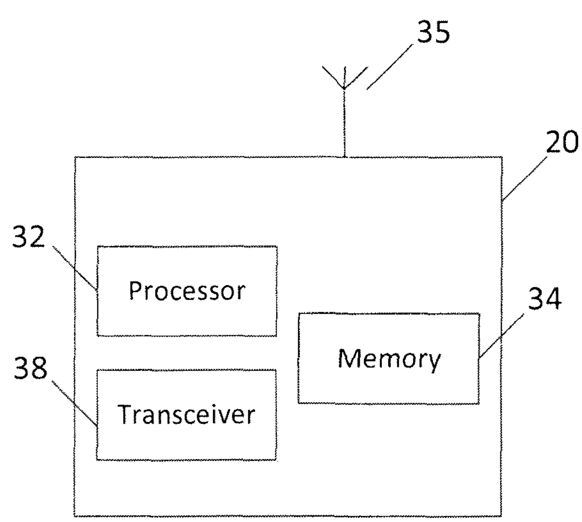

35
20
32
Processor
34
Memory
38
Transceiver

Fig. 2b

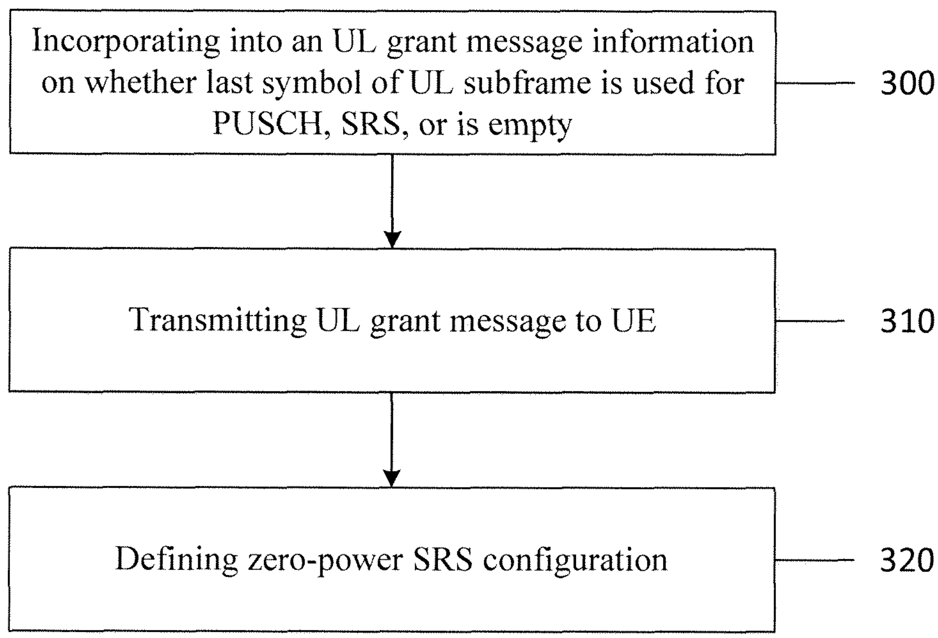

Incorporating into an UL grant message information on whether last symbol of UL subframe is used for PUSCH, SRS, or is empty
300
Transmitting UL grant message to UE
310
Defining zero-power SRS configuration
320

Fig. 3a

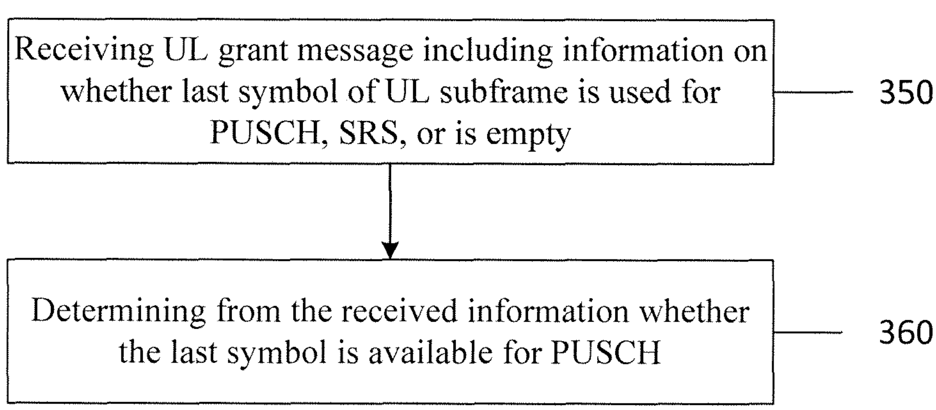

Receiving UL grant message including information on whether last symbol of UL subframe is used for PUSCH, SRS, or is empty
350
Determining from the received information whether the last symbol is available for PUSCH
360

Fig. 3b

SOUNDING REFERENCE SIGNAL (SRS) USAGE

BACKGROUND

1. Field

Embodiments of the invention generally relate to mobile communications networks, such as, but not limited to, the Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (UTRAN), Long Term Evolution (LTE) Evolved UTRAN (E-UTRAN), and/or LTE-A.

2. Description of the Related Art

Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (UTRAN) refers to a communications network including base stations, or Node Bs, and for example radio network controllers (RNC). UTRAN allows for connectivity between the user equipment (UE) and the core network. The RNC provides control functionalities for one or more Node Bs. The RNC and its corresponding Node Bs are called the Radio Network Subsystem (RNS). In case of E-UTRAN (enhanced UTRAN), no RNC exists and most of the RNC functionalities are contained in the enhanced Node B (eNodeB or eNB).

Long Term Evolution (LTE) or E-UTRAN refers to improvements of the UMTS through improved efficiency and services, lower costs, and use of new spectrum opportunities. In particular, LTE is a 3GPP standard that provides for uplink peak rates of at least 50 megabits per second (Mbps) and downlink peak rates of at least 100 Mbps. LTE supports scalable carrier bandwidths from 20 MHz down to 1.4 MHz and supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD).

As mentioned above, LTE may also improve spectral efficiency in networks, allowing carriers to provide more data and voice services over a given bandwidth. Therefore, LTE is designed to fulfill the needs for high-speed data and media transport in addition to high-capacity voice support. Advantages of LTE include, for example, high throughput, low latency, FDD and TDD support in the same platform, an improved end-user experience, and a simple architecture resulting in low operating costs.

Further releases of 3GPP LTE (e.g., LTE Rel-10, LTE Rel-11, LTE Rel-12) are targeted towards future international mobile telecommunications advanced (IMT-A) systems, referred to herein for convenience simply as LTE-Advanced (LTE-A).

LTE-A is directed toward extending and optimizing the 3GPP LTE radio access technologies. A goal of LTE-A is to provide significantly enhanced services by means of higher data rates and lower latency with reduced cost. LTE-A is a more optimized radio system fulfilling the international telecommunication union-radio (ITU-R) requirements for IMT-Advanced while keeping the backward compatibility.

SUMMARY

One embodiment is directed to a method including incorporating into an uplink grant message, by a base station in a communications system, information on whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty. The method includes transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE).

Another embodiment is directed to an apparatus including at least one processor and at least one memory comprising computer program code. The at least one memory and the

computer program code are configured, with the at least one processor, to cause the apparatus at least to incorporate, into an uplink grant message, information on whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty, and to transmit the uplink grant message comprising the information on the last symbol to a user equipment (UE).

Another embodiment is directed to a computer program, embodied on a non-transitory computer readable medium. The computer program is configured to control a processor to perform a process. The process includes incorporating into an uplink grant message information on whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty, and transmitting the uplink grant message comprising the information on the last symbol to a user equipment.

An embodiment is directed to a method including receiving, by a user equipment, an uplink grant message comprising information indicating whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty. The method also includes determining from the received information whether the last symbol is available for physical uplink shared channel (PUSCH), or is used for sounding reference signal (SRS) transmission, or is left empty. The user equipment is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of PUSCH, SRS, or is left empty.

Another embodiment is directed to an apparatus including at least one processor and at least one memory comprising computer program code. The at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to receive an uplink grant message comprising information indicating whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty, and to determine from the received information whether the last symbol is available for physical uplink shared channel (PUSCH), or is used for sounding reference signal transmission, or is left empty. The apparatus is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of PUSCH, SRS, or is left empty.

Another embodiment is directed to a computer program, embodied on a non-transitory computer readable medium. The computer program is configured to control a processor to perform a process. The process includes receiving an uplink grant message comprising information indicating whether a last symbol of an uplink subframe is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty. The process also includes determining from the received information whether the last symbol is available for physical uplink shared channel (PUSCH). The determining comprises ignoring cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of PUSCH, SRS, or is left empty.

BRIEF DESCRIPTION OF THE DRAWINGS

For proper understanding of the invention, reference should be made to the accompanying drawings, wherein:

FIG. **1** illustrates an example of the uplink frame structure, according to an embodiment;

FIG. **2***a* illustrates an example of an apparatus, according to one embodiment;

FIG. **2***b* illustrates an example of an apparatus, according to another embodiment;

FIG. **3***a* illustrates a flow chart of a method, according to one embodiment; and

FIG. **3***b* illustrates a flow chart of a method, according to another embodiment.

DETAILED DESCRIPTION

It will be readily understood that the components of the invention, as generally described and illustrated in the figures herein, may be arranged and designed in a wide variety of different configurations. Thus, the following detailed description of the embodiments of systems, methods, apparatuses, and computer program products for controlling sounding reference signal (SRS) transmission, as represented in the attached figures, is not intended to limit the scope of the invention, but is merely representative of selected embodiments of the invention.

If desired, the different functions discussed below may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the described functions may be optional or may be combined. As such, the following description should be considered as merely illustrative of the principles, teachings and embodiments of this invention, and not in limitation thereof.

The 3GPP RANI study item entitled, "Small Cell Enhancements for E-UTRA and E-UTRAN—Physical-layer Aspects" has an objective of identifying potential enhancements for LTE physical layer operation in a small cell environment. The study item description mentions that spectral efficiency improvements related to overhead reduction of user specific reference signals should be studied. In LTE uplink, two types of reference signals are defined: demodulation reference signals and sounding reference signals (SRS). Embodiments of the present invention provide an enhancement related to sounding reference signals, for example, in a small cell environment.

Currently, in the 3GPP Release 11 specification, if the subframe is configured as a cell specific SRS subframe, when the UE transmits physical uplink shared channel (PUSCH), it must puncture last single carrier frequency division multiple access (SC-FDMA) symbol of the subframe regardless of whether the UE actually transmits SRS or not.

As will be outlined in detail below, certain embodiments provide a more efficient way to control SRS transmission such that more bandwidth may become available for PUSCH transmission. More specifically, an embodiment allows eNB control of SRS transmission on a per UE basis rather than on a per cell basis, and enables resources that are reserved by default for PUSCH transmission to be used for SRS.

An LTE small cell environment can be characterized as having following properties: UE(s) are close to the eNB, for example the distance between the eNB and UE(s) is significantly shorter than in a macro cell environment and, consequently, the uplink (UL) path loss is lower than in the larger cells; UE(s) attached to a small cell can be assumed to be low to moderate speed only (high speed UEs are served by macro cell); number of UE(s) served by the small cell is low; and/or number of active UE(s) may change quickly

Channel conditions can be expected to be more stable and channel coherence bandwidth larger in a small cell when compared to a macro cell. As a result, continuous and frequent sounding of the channel is not needed in a small cell (UL interference characteristics can be measured at the eNB side also without sounding signal).

FIG. **1** illustrates an example of UL frame structure in LTE Releases **8** to **11**, according to one example. In the following, this may also be referred to as a subframe. The last SC-FDMA symbol (e.g., symbol #13) can be configured for SRS, in which case PUSCH is punctured. Currently, as illustrated in FIG. **1**, when the UE transmits PUSCH, it must puncture the last SC-FDMA symbol (e.g., symbol #13) of the subframe if the subframe is configured as cell specific SRS subframe regardless of whether the UE actually transmits SRS or not. The cell-specific configuration of SRS transmission opportunities is periodic even with aperiodic SRS transmission, meaning that SC-FDMA symbols are reserved deterministically in every nth subframe, even if the need for transmitting SRS occurs only every now and then.

Furthermore, SRS transmission bandwidth is configurable and UE-specific SRS may occupy almost the whole UL band or just a few physical resource blocks (PRBs). Often, especially if SRS load in the cell is low, PUSCH transmission does not collide with simultaneous narrow band SRS transmission, and then puncturing of PUSCH is unnecessary.

With the Release 11 specification, the allocation of the last subframe symbol to either PUSCH or SRS is part of cell configuration. The SRS resources need to be dimensioned to facilitate the highest expected number of active UEs. In a small cell environment, such burst of UEs occurs only occasionally and SRS load is frequently low. Then, a significant portion of resource elements on the last symbol are not used for PUSCH or SRS. Unnecessary puncturing of the last symbol of the PUSCH results in loss in spectral efficiency as 1/12 of the PUSCH resources are lost. Therefore, an efficient method to allocate last symbol of the subframe for PUSCH or SRS would be beneficial.

When considering SRS transmission configuration for the small cell case, an objective may be that a reduction in SRS transmissions can be translated to more efficient PUSCH transmission. Accordingly, certain embodiments provide that the last symbol of the subframe can be flexibly used for PUSCH or for SRS. In one embodiment, this may be achieved by means of a specific SRS configuration (referred to herein as SRS configuration type B) combined with a specific SRS trigger type (referred to herein as SRS trigger type B).

In an embodiment, a specific operation is defined for terminals configured for SRS configuration type B. According to this embodiment, the UE ignores cell specific SRS subframe configuration when determining if the last symbol of the subframe is available for transmission of PUSCH, or SRS, or is left empty. For example, in this embodiment, the uplink grant may contain the information, for instance in a SRS trigger type B, if the last symbol of the subframe is used for PUSCH, for SRS, or if the symbol is left empty. The possibility of leaving the last symbol empty can prevent collision between PUSCH and SRS transmission from other terminals. In other words, the possibility for dynamic muting of the last symbol facilitates SRS transmission from other terminals on subframes that are not contained in the cell specific SRS subframe configuration. An example way to enable keeping the last PUSCH SC-FDMA empty is to define zero-power SRS configuration, i.e., a transmission similar to SRS in terms of, for example, bandwidth but with zero power. This allows for flexible muting of the last PUSCH symbol, making it easier to align the PUSCH/SRS transmission of different users.

According to an embodiment, SRS configuration type B can be defined by using existing SRS configuration and related parameters. In one embodiment, usage of SRS trigger type B is combined with SRS configuration type B only. The UE can support multiple parallel SRS configuration type B, in addition to existing SRS configurations.

Further, in an embodiment, some of the existing SRS configuration parameters can be optimized to support improved functionality with SRS configuration type B. For example, SRS Periodicity (TSRS) of 1 ms could be supported with SRS configuration type B (due to the fact that SRS configuration type B does not introduce any overhead in the case SRS is not triggered). Cell specific SRS subframe configuration can still be used in the cell by earlier release UEs (e.g., prior to Release 11) and UEs not configured for the new mode provided by embodiments of the invention, such as UEs performing initial access in the small cell. However, the density (or periodicity) of cell specific SRS subframe configuration can be considerably decreased (or periodicity increased) with the use of embodiments of invention.

There can be pre-defined priorities defined between different trigger types (i.e., trigger type **0**/**1** based on existing SRS procedure and SRS trigger type B). According to an embodiment, SRS trigger type B would have the highest priority compared to trigger type **0** or **1**. This would allow, for example, a Release 12 UE to transmit PUSCH via resources configured for cell specific SRS (assuming that those resources are not actually used for transmitting SRS).

According to an embodiment, one additional bit may be included in the uplink grant. The additional bit, e.g., "PUSCH in the last symbol bit", can be used to inform whether the last symbol of the subframe is available for PUSCH. When aperiodic SRS is used, one bit in the UL grant, i.e., a "SRS request bit" informs the UE whether it should send SRS. In one embodiment, the "SRS request bit" and "PUSCH in the last symbol bit" may be interpreted jointly as follows:

A straightforward interpretation of the two bits may include:
- '00' do not transmit SRS, puncture PUSCH;
- '01' do not transmit SRS, transmit PUSCH in the last symbol;
- '10' transmit SRS, puncture PUSCH;
- '11' transmit SRS, transmit PUSCH (transmissions must be in non-overlapping PRBs). Simultaneous SRS and PUSCH in the same cell may not be considered as valid option, so this combination may be replaced by another interpretation, as discussed below.

With two different SRS configurations, an interpretation of the two bits may include:
- '00' do not transmit SRS, puncture PUSCH;
- '01' do not transmit SRS, transmit PUSCH in the last symbol;
- '10' transmit SRS config **1**, puncture PUSCH;
- '11' transmit SRS config **2**, puncture PUSCH.

In an embodiment, there could also be a 2-bit indication for "PUSCH in the last symbol", for example, so that the bits are interpreted in the following way:
- '00' puncture PUSCH in the last symbol;
- '01' transmit part of the allocated PUSCH PRBs;
- '10' transmit another part of the allocated PUSCH PRBs;
- '11' transmit PUSCH.

One of the issues to solve with SRS trigger type B is the procedure to be used with hybrid automatic repeat request (HARQ) re-transmissions (where the trigger bits are not available). According to an embodiment, one approach may be to have the HARQ re-transmissions follow a pre-defined codepoint of SRS trigger type B, e.g., '**01**' do not transmit SRS and transmit PUSCH in the last symbol. Alternatively, another embodiment may follow puncturing rules defined for overlapping cell-specific SRS (if configured). In situations where the eNB wants to change the SRS strategy for the retransmissions, it can use scheduled adaptive re-transmission.

FIG. **2***a* illustrates an example of an apparatus **10** according to an embodiment. In one embodiment, apparatus **10** may be a base station, such as a node B or eNB. It should be noted that one of ordinary skill in the art would understand that apparatus **10** may include components or features not shown in FIG. **2***a*. Only those components or feature necessary for illustration of the invention are depicted in FIG. **2***a*.

As illustrated in FIG. **2***a*, apparatus **10** includes a processor **22** for processing information and executing instructions or operations. Processor **22** may be any type of general or specific purpose processor. While a single processor **22** is shown in FIG. **2***a*, multiple processors may be utilized according to other embodiments. In fact, processor **22** may include one or more of general-purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and processors based on a multi-core processor architecture, as examples.

Apparatus **10** further includes a memory **14**, which may be coupled to processor **22**, for storing information and instructions that may be executed by processor **22**. Memory **14** may be one or more memories and of any type suitable to the local application environment, and may be implemented using any suitable volatile or nonvolatile data storage technology such as a semiconductor-based memory device, a magnetic memory device and system, an optical memory device and system, fixed memory, and removable memory. For example, memory **14** can be comprised of any combination of random access memory (RAM), read only memory (ROM), static storage such as a magnetic or optical disk, or any other type of non-transitory machine or computer readable media. The instructions stored in memory **14** may include program instructions or computer program code that, when executed by processor **22**, enable the apparatus **10** to perform tasks as described herein.

Apparatus **10** may also include one or more antennas **25** for transmitting and receiving signals and/or data to and from apparatus **10**. Apparatus **10** may further include a transceiver **28** configured to transmit and receive information. For instance, transceiver **28** may be configured to modulate information on to a carrier waveform for transmission by the antenna(s) **25** and demodulates information received via the antenna(s) **25** for further processing by other elements of apparatus **10**. In other embodiments, transceiver **28** may be capable of transmitting and receiving signals or data directly.

Processor **22** may perform functions associated with the operation of apparatus **10** including, without limitation, precoding of antenna gain/phase parameters, encoding and decoding of individual bits forming a communication message, formatting of information, and overall control of the apparatus **10**, including processes related to management of communication resources.

In an embodiment, memory **14** stores software modules that provide functionality when executed by processor **22**. The modules may include, for example, an operating system that provides operating system functionality for apparatus **10**. The memory may also store one or more functional modules, such as an application or program, to provide additional functionality for apparatus **10**. The components of apparatus **10** may be implemented in hardware, or as any suitable combination of hardware and software.

As mentioned above, according to one embodiment, apparatus **10** may be a base station, such as a node B or eNB, for example. In an embodiment, apparatus **10** may be controlled by memory **14** and processor **22** to incorporate, into an uplink grant message, information on whether a last symbol of the uplink frame structure is used for PUSCH, is used for sounding reference signal (SRS), or is left empty. Apparatus **10** may be controlled by memory **14** and processor **22** to transmit the uplink grant message comprising the information on the last symbol to a UE. In one embodiment, the information is a new SRS trigger type (e.g., SRS trigger type B). In one embodiment, the new SRS trigger type (e.g., SRS trigger type B) has a higher priority than existing SRS trigger types (e.g., trigger type **0** or **1**).

According to an embodiment, apparatus **10** may be controlled by memory **14** and processor **22** to incorporate a single bit in the uplink grant message to indicate whether the last symbol is available for PUSCH, and another bit in the uplink grant message to indicate whether the UE should send SRS. The one bit indicating whether the last symbol is available for PUSCH and the one bit indicating whether the UE should send sounding reference signal (SRS) may be interpreted jointly, for example, according to the following:

'00' indicates to not transmit SRS, and puncture PUSCH;
'01' indicates to not transmit SRS, and transmit PUSCH in the last symbol;
'10' indicates to transmit SRS, and puncture PUSCH;
'11' indicates to transmit SRS, and transmit PUSCH.

In one embodiment, a first and a second SRS configuration are provided, in which case the one bit indicating whether the last symbol is available for PUSCH and the one bit indicating whether the UE should send sounding reference signal (SRS) may be interpreted jointly, for example, according to the following:

'00' indicates to not transmit SRS, and puncture PUSCH;
'01' indicates to not transmit SRS, and transmit PUSCH in the last symbol;
'10' indicates to transmit first SRS configuration, and puncture PUSCH;
'11' indicates to transmit second SRS configuration, and puncture PUSCH.

In another embodiment, apparatus **10** may be controlled by memory **14** and processor **22** to incorporate two bits in the uplink grant message to indicate whether the last symbol is available for physical uplink shared channel (PUSCH). According to this embodiment, the two bits in the uplink grant message indicating whether the last symbol is available for physical uplink shared channel (PUSCH) may be interpreted according to the following:

'00' indicates to puncture PUSCH in the last symbol;
'01' indicates to transmit part of the allocated PUSCH physical resource blocks (PRBs);
'10' indicates to transmit another part of the allocated PUSCH PRBs;
'11' indicates to transmit PUSCH.

According to an embodiment, apparatus **10** may be controlled by memory **14** and processor **22** to define a zero-power sounding reference signal (SRS) configuration to allow for flexible muting of the last symbol. Further, in one embodiment, if the new sounding reference signal (SRS) trigger type is used with hybrid automatic repeat request (HARQ) re-transmissions, the hybrid automatic repeat request (HARQ) re-transmissions can follow a pre-defined codepoint of the new sounding reference signal (SRS) trigger type or can follow puncturing rules defined for overlapping cell-specific sounding reference signal (SRS) resources.

FIG. **2***b* illustrates an example of an apparatus **20** according to another embodiment. In an embodiment, apparatus **20** may be a UE. It should be noted that one of ordinary skill in the art would understand that apparatus **20** may include components or features not shown in FIG. **2***b*. Only those components or feature necessary for illustration of the invention are depicted in FIG. **2***b*.

As illustrated in FIG. **2***b*, apparatus **20** includes a processor **32** for processing information and executing instructions or operations. Processor **32** may be any type of general or specific purpose processor. While a single processor **32** is shown in FIG. **2***b*, multiple processors may be utilized according to other embodiments. In fact, processor **32** may include one or more of general-purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and processors based on a multi-core processor architecture, as examples.

Apparatus **20** further includes a memory **34**, which may be coupled to processor **32**, for storing information and instructions that may be executed by processor **32**. Memory **34** may be one or more memories and of any type suitable to the local application environment, and may be implemented using any suitable volatile or nonvolatile data storage technology such as a semiconductor-based memory device, a magnetic memory device and system, an optical memory device and system, fixed memory, and removable memory. For example, memory **34** can be comprised of any combination of random access memory (RAM), read only memory (ROM), static storage such as a magnetic or optical disk, or any other type of non-transitory machine or computer readable media. The instructions stored in memory **34** may include program instructions or computer program code that, when executed by processor **32**, enable the apparatus **20** to perform tasks as described herein.

Apparatus **20** may also include one or more antennas **35** for transmitting and receiving signals and/or data to and from apparatus **20**. Apparatus **20** may further include a transceiver **38** configured to transmit and receive information. For instance, transceiver **38** may be configured to modulate information on to a carrier waveform for transmission by the antenna(s) **35** and demodulates information received via the antenna(s) **35** for further processing by other elements of apparatus **20**. In other embodiments, transceiver **38** may be capable of transmitting and receiving signals or data directly.

Processor **32** may perform functions associated with the operation of apparatus **20** including, without limitation, precoding of antenna gain/phase parameters, encoding and decoding of individual bits forming a communication message, formatting of information, and overall control of the apparatus **20**, including processes related to management of communication resources.

In an embodiment, memory **34** stores software modules that provide functionality when executed by processor **32**. The modules may include, for example, an operating system that provides operating system functionality for apparatus **20**. The memory may also store one or more functional modules, such as an application or program, to provide additional functionality for apparatus **20**. The components of apparatus **20** may be implemented in hardware, or as any suitable combination of hardware and software.

As mentioned above, according to one embodiment, apparatus **20** may be a UE. In this embodiment, apparatus **20** may be controlled by memory **34** and processor **32** to receive an uplink grant message comprising information indicating whether a last symbol of an uplink frame structure is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is empty. Apparatus **20** may then be controlled by memory **34** and processor **32** to determine from the received new sounding reference signal (SRS) trigger whether the last symbol is available for physical uplink shared channel (PUSCH), or for sounding reference signal (SRS), or is to be left empty.

As discussed above, the information included in the uplink grant message may be a new SRS trigger type (e.g., SRS trigger type B) that may have a higher priority than existing SRS trigger types (e.g., trigger type **0** or **1**). In addition, apparatus **20** may be controlled to determine whether or not to transmit SRS or PUSCH in the last symbol and/or whether to puncture PUSCH according to the interpretation of bits in the uplink grant message discussed above in connection with FIG. **2***a*.

FIG. **3***a* illustrates an example of a flow chart of a method for controlling SRS transmission, according to one embodiment. In one example, the method of FIG. **3***a* may be performed by a base station, such as a node B or eNB. As illustrated in the example of FIG. **3***a*, the method may include, at **300**, incorporating, into an uplink grant message, information on whether a last symbol of an uplink frame structure is used for PUSCH, for SRS, or is empty. The method may also include, at **310**, transmitting the uplink grant message comprising the information on the last symbol to a UE. In one embodiment, the method may also include, at **320**, defining a zero-power SRS configuration.

FIG. **3***b* illustrates an example of a flow chart of a method for controlling SRS transmission, according to another embodiment. In one example, the method of FIG. **3***b* may be performed by a UE. As illustrated in the example of FIG. **3***b*, the method may include, at **350**, receiving an uplink grant message comprising information indicating whether a last symbol of an uplink frame structure is used for physical uplink shared channel (PUSCH), for sounding reference signal (SRS), or is left empty. The method may then include, at **360**, determining from the received information whether the last symbol is available for physical uplink shared channel (PUSCH), or for sounding reference signal (SRS), or is to be left empty.

In some embodiments, the functionality of any of the methods described herein, such as those of FIGS. **3***a* and **3***b*, may be implemented by software stored in memory or other computer readable or tangible media, and executed by a processor. In other embodiments, the functionality may be performed by hardware, for example through the use of an application specific integrated circuit (ASIC), a programmable gate array (PGA), a field programmable gate array (FPGA), or any other combination of hardware and software.

The computer readable media mentioned above may be at least partially embodied by a transmission line, a compact disk, digital-video disk, a magnetic disk, holographic disk or tape, flash memory, magnetoresistive memory, integrated circuits, or any other digital processing apparatus memory device.

Embodiments of the invention can provide several advantages. For example, certain embodiments allow for faster triggering and improved latency for aperiodic SRS without any increase in the SRS overhead, as aperiodic SRS transmission does not need to "wait" for cell-specific SRS resources. In addition, the overhead due to resources reserved for SRS but not used can be avoided. The implementation complexity according to certain embodiments is very minor. Also, embodiments are fully backwards compatible in the sense that legacy UE(s) supporting the feature do not suffer from it at all.

The described features, advantages, and characteristics of the invention may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize that the invention may be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the invention.

One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

We claim:

1. A method, comprising:

incorporating into an uplink grant message for a physical uplink shared channel (PUSCH), by a base station in a communications system, information on whether a last symbol of an uplink subframe that is reserved by the base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE), wherein the user equipment is configured to ignore cell-specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH.

2. The method according to claim **1**, wherein the information comprises a new SRS trigger type.

3. The method according to claim **1**, wherein the incorporating further comprises:

incorporating one bit in the uplink grant message to indicate whether the last symbol is available for the PUSCH, and incorporating one bit in the uplink grant message to indicate whether the UE should send an SRS.

4. A method, comprising:

incorporating into an uplink grant message by a base station in a communications system, information on whether a last symbol of an uplink subframe for sounding reference signal (SRS) transmissions, is available for a physical uplink shared channel (PUSCH);

transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE); and

incorporating one bit in the uplink grant message to indicate whether the last symbol is available for the PUSCH, and incorporating one bit in the uplink grant message to indicate whether the UE should send an SRS,

wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating whether the UE should send an SRS are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit an SRS, and puncture the PUSCH;

'11' indicates to transmit an SRS, and transmit the PUSCH.

5. A method, comprising:

incorporating into an uplink grant message by a base station in a communications system, information on whether a last symbol of an uplink subframe for sounding reference signal (SRS) transmissions, is available for a physical uplink shared channel (PUSCH);

transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE); and

incorporating one bit in the uplink grant message to indicate whether the last symbol is available for the PUSCH, and incorporating one bit in the uplink grant message to indicate whether the UE should send an SRS,

wherein a first and a second SRS configuration are provided, and wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the UE should send an SRS are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit a first SRS configuration, and puncture the PUSCH;

'11' indicates to transmit a second SRS configuration, and puncture the PUSCH.

6. The method according to claim 1, wherein the incorporating further comprises:

incorporating two bits in the uplink grant message to indicate whether the last symbol is available for the PUSCH.

7. A method, comprising:

incorporating into an uplink grant message by a base station in a communications system, information on whether a last symbol of an uplink subframe for sounding reference signal (SRS) transmissions, is available for a physical uplink shared channel (PUSCH);

transmitting the uplink grant message comprising the information on the last symbol to a user equipment (UE); and

incorporating two bits in the uplink grant message to indicate whether the last symbol is available for the PUSCH;

wherein the two bits in the uplink grant message indicating whether the last symbol is available for the PUSCH are interpreted according to:

'00' indicates to puncture the PUSCH in the last symbol;

'01' indicates to transmit part of allocated PUSCH physical resource blocks (PRBs);

'10' indicates to transmit another part of allocated PUSCH PRBs;

'11' indicates to transmit the PUSCH.

8. The method according to claim 2, wherein a new SRS trigger type has a higher priority than existing SRS trigger types.

9. The method according to claim 1, further comprising defining a zero-power SRS configuration to allow for flexible muting of the last symbol.

10. The method according to claim 2, wherein, when use of a new SRS trigger type is configured, hybrid automatic repeat request (HARQ) re-transmissions follow a pre-defined codepoint of the new SRS trigger type or follow puncturing rules defined for an overlapping cell-specific SRS.

11. An apparatus, comprising:

at least one processor; and

at least one memory comprising computer program code,

the at least one memory and the computer program code, with the at least one processor, causing the apparatus at least to

incorporate into an uplink grant message for a physical uplink shared channel (PUSCH), information on whether a last symbol of an uplink subframe that is reserved by a base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

transmit the uplink grant message comprising the information on the last symbol to a user equipment (UE), wherein the user equipment is configured to ignore cell-specific SRS subframe configuration when determining whether the last symbol of the uplink subframe available for transmission of the PUSCH.

12. The apparatus according to claim 11, wherein the information comprises a new SRS trigger type.

13. The apparatus according to claim 11, wherein the at least one memory and the computer program code are further configured, with the at least one processor, to cause the apparatus at least to:

incorporate one bit in the uplink grant message to indicate whether the last symbol is available for the PUSCH, and incorporating one bit in the uplink grant message to indicate whether the UE should send an SRS.

14. The apparatus according to claim 13, wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating whether the UE should send an SRS are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit an SRS, and puncture the PUSCH;

'11' indicates to transmit an SRS, and transmit the PUSCH.

15. The apparatus according to claim 13, wherein a first and a second SRS configuration are provided, and wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the UE should send an SRS are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit a first SRS configuration, and puncture the PUSCH;

'11' indicates to transmit a second SRS configuration, and puncture the PUSCH.

16. The apparatus according to claim 11, wherein the at least one memory and the computer program code are further configured, with the at least one processor, to cause the apparatus at least to:

incorporate two bits in the uplink grant message to indicate whether the last symbol is available for the PUSCH.

17. The apparatus according to claim 16, wherein the two bits in the uplink grant message indicating whether the last symbol is available for the PUSCH are interpreted according to:

'00' indicates to puncture the PUSCH in the last symbol;

'01' indicates to transmit part of allocated PUSCH physical resource blocks (PRBs);

'10' indicates to transmit another part of allocated PUSCH PRBs;

'11' indicates to transmit the PUSCH.

18. The apparatus according to claim 12, wherein a new SRS trigger type has a higher priority than existing SRS trigger types.

19. The apparatus according to claim 11, wherein the at least one memory and the computer program code are further configured, with the at least one processor, to cause the apparatus at least to:

define a zero-power SRS configuration to allow for flexible muting of the last symbol.

20. The apparatus according to claim 12, wherein, when use of a new SRS trigger type is configured, hybrid automatic repeat request (HARQ) re-transmissions follow a pre-defined codepoint of the new SRS trigger type or follow puncturing rules defined for an overlapping cell-specific SRS.

21. The apparatus according to claim 11, wherein the apparatus comprises an evolved node B (eNB).

22. A computer program, embodied on a non-transitory computer readable medium, the computer program when executed by a processor, causes the processor to:

incorporate into an uplink grant message for a physical uplink shared channel (PUSCH) information on whether a last symbol of an uplink subframe that is reserved by a base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

transmit the uplink grant message comprising the information on the last symbol to a user equipment, wherein the user equipment is configured to ignore cell-specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH.

23. A method, comprising:

receiving, by a user equipment, an uplink grant message for a physical uplink shared channel (PUSCH) comprising information indicating whether a last symbol of an uplink subframe that is reserved by a base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

determining from the received information whether the last symbol is available for the PUSCH;

wherein the user equipment is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH.

24. The method according to claim 23, wherein one bit in the uplink grant message indicates whether the last symbol is available for the PUSCH, and another bit in the uplink grant message indicates whether the user equipment should send an SRS.

25. A method, comprising:

receiving, by a user equipment, an uplink grant message comprising information indicating whether a last symbol of an uplink subframe for sounding reference signal (SRS) transmissions, is available for a physical uplink shared channel (PUSCH); and

determining from the received information whether the last symbol is available for the PUSCH,

wherein the user equipment is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH,

wherein one bit in the uplink grant message indicates whether the last symbol is available for the PUSCH, and another bit in the uplink grant message indicates whether the user equipment should send an SRS,

wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the user equipment should send an SRS are interpreted jointly according to:

'00' indicates to the user equipment to not transmit an SRS, and to puncture the PUSCH;

'01' indicates to the user equipment to not transmit an SRS, and to transmit the PUSCH in the last symbol;

'10' indicates to the user equipment to transmit an SRS, and to puncture the PUSCH;

'11' indicates to the user equipment to transmit an SRS, and to transmit t PUSCH.

26. A method, comprising:

receiving, by a user equipment, an uplink grant message comprising information indicating whether a last symbol of an uplink subframe for sounding reference signal (SRS) transmissions, is available for a physical uplink shared channel (PUSCH); and

determining from the received information whether the last symbol is available for the PUSCH,

wherein the user equipment is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH,

wherein one bit in the uplink grant message indicates whether the last symbol is available for the PUSCH, and another bit in the uplink grant message indicates whether the user equipment should send an SRS,

wherein a first and a second SRS configuration are provided, and wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the UE should send an SRS are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit a first SRS configuration, and puncture the PUSCH;

'11' indicates to transmit a second SRS configuration, and puncture the PUSCH.

27. The method according to claim 23, wherein the receiving further comprises:

receiving the information comprising two bits in the uplink grant message to indicate whether the last symbol is available for the PUSCH.

28. The method according to claim 23, wherein, when use of a new SRS trigger type is configured, hybrid automatic repeat request (HARQ) re-transmissions follow a pre-defined codepoint of the new SRS trigger type or follow puncturing rules defined for an overlapping cell-specific SRS.

29. The method according to claim 23, wherein the information comprises a new SRS trigger type, and wherein the new SRS trigger type has a higher priority than existing SRS trigger types.

30. An apparatus, comprising:

at least one processor; and

at least one memory comprising computer program code,

the at least one memory and the computer program code, with the at least one processor, causing the apparatus at least to

receive an uplink grant message for a physical uplink shared channel (PUSCH) comprising information indicating whether a last symbol of an uplink subframe that is reserved by a base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

determine from the received information whether the last symbol is available for the PUSCH,

wherein the apparatus is configured to ignore cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH.

31. The apparatus according to claim **30**, wherein one bit in the uplink grant message indicates whether the last symbol is available for the PUSCH, and another bit in the uplink grant message indicates whether the apparatus should send an SRS.

32. The apparatus according to claim **31**, wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the apparatus should send an SRS are interpreted jointly according to:

'00' indicates to the apparatus to not transmit an SRS, and to puncture the PUSCH;

'01' indicates to the apparatus to not transmit an SRS, and to transmit the PUSCH in the last symbol;

'10' indicates to the apparatus to transmit an SRS, and to puncture the PUSCH;

'11' indicates to the apparatus to transmit an SRS, and to transmit the PUSCH.

33. The apparatus according to claim **31**, wherein a first and a second SRS configuration are provided, and wherein said one bit indicating whether the last symbol is available for the PUSCH and said one bit indicating indicate whether the UE should send sounding reference signal (SRS) are interpreted jointly according to:

'00' indicates to not transmit an SRS, and puncture the PUSCH;

'01' indicates to not transmit an SRS, and transmit the PUSCH in the last symbol;

'10' indicates to transmit a first SRS configuration, and puncture the PUSCH;

'11' indicates to transmit a second SRS configuration, and puncture the PUSCH.

34. The apparatus according to claim **30**, wherein the at least one memory and the computer program code are further configured, with the at least one processor, to cause the apparatus at least to:

receive the information comprising two bits in the uplink grant message to indicate whether the last symbol is available for the PUSCH.

35. The apparatus according to claim **30**, wherein, when use of a new SRS trigger type is configured, hybrid automatic repeat request (HARQ) re-transmissions follow a pre-defined codepoint of the new SRS trigger type or follow puncturing rules defined for an overlapping cell-specific SRS.

36. The apparatus according to claim **30**, wherein the information comprises a new SRS trigger type, and wherein the new SRS trigger type has a higher priority than existing SRS trigger types.

37. The apparatus according to claim **30**, wherein the apparatus comprises a user equipment.

38. A computer program, embodied on a non-transitory computer readable medium, the computer program, when executed by a processor, causes the processor to:

receive an uplink grant message for a physical uplink shared channel (PUSCH) comprising information indicating whether a last symbol of an uplink subframe that is reserved by a base station in every n^{th} subframe for sounding reference signal (SRS) transmissions, is available for the PUSCH; and

determine from the received information whether the last symbol is available for the PUSCH,

wherein the determining comprises ignoring cell specific SRS subframe configuration when determining whether the last symbol of the uplink subframe is available for transmission of the PUSCH.

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