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

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
5 October 2017 (05.10.2017)

WIPO | PCT

(10) **International Publication Number**
WO 2017/168036 A1

(51) **International Patent Classification**:
H04W 72/04 (2009.01) *H04W 28/06* (2009.01)

(21) **International Application Number**:
PCT/FI2016/050199

(22) **International Filing Date**:
31 March 2016 (31.03.2016)

(25) **Filing Language**: English

(26) **Publication Language**: English

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

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

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

(54) **Title**: TRANSMISSION TIME INTERVALS OF DIFFERENT LENGTHS

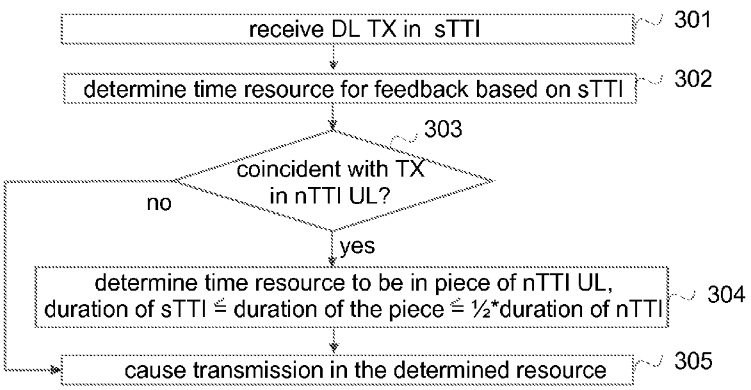

FIG.3

(57) **Abstract**: Determining, for one or more downlink transmissions using at least one shortened length transmission time interval sTTI, based on the at least one sTTI, at least one time resource from an uplink channel for feedback information. If the at least one time resource is coincident with an uplink channel transmission configured to at least one transmission time interval nTTI having a longer length than the length of the at least one sTTI, determining the at least one time resource to be on the uplink channel in at least one piece of at least one nTTI, a duration of the at least one piece being at least the duration of the at least one sTTI and at most half of the duration of the at least one nTTI; and causing the transmission of the feedback information in the at least one time resource.

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TRANSMISSION TIME INTERVALS OF DIFFERENT LENGTHS

TECHNICAL FIELD

The invention relates to wireless communications in a cellular communication system.

BACKGROUND

In recent years the phenomenal growth of mobile services and proliferation of smart phones and tablets have increased a demand for higher network capacity. Network throughput may be increased by using a short transmission time interval to decrease latency. However, a longer transmission time interval provides better coverage for uplink transmissions.

BRIEF DESCRIPTION

According to an aspect, there is provided the subject matter of the independent claims. Some embodiments are defined in the dependent claims.

One or more examples of implementations are set forth in more detail in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

In the following embodiments will be described in greater detail with reference to the attached drawings, in which

Figure 1 illustrates an exemplified wireless communication system;

Figures 2 to 6 illustrate exemplified processes;

Figures 7 to 17 illustrate different resource reservation examples;

Figure 18 illustrates exemplified information exchange; and

Figure 19 is a schematic block diagram.

DETAILED DESCRIPTION OF SOME EMBODIMENTS

The following embodiments are exemplifying. Although the specification may refer to "an", "one", or "some" embodiment(s) and/or example(s) in several locations of the text, this does not necessarily mean that each reference is made to the same embodiment(s) or example(s), or that a particular feature only applies to a single embodiment and/or example. Single features of different embodiments and/or examples may also be combined to provide other embodiments and/or examples.

Embodiments and examples described herein may be implemented in a wireless system, such as in at least one of the following: Universal Mobile Telecommunication System (UMTS, 3G) based on basic wideband-code division multiple access (W-CDMA), high-speed packet access (HSPA), Long Term Evolution (LTE), LTE-Advanced, LTE-Advanced Pro, 5G system, beyond 5G, and/or wireless local area networks (WLAN), such as Wi-Fi. The embodiments are not, however, restricted to the system given as an example but a person skilled in the art may apply the solution to other communication systems provided with necessary properties. One example of a suitable communications system is the 5G system, as listed above.

5G is likely to use multiple-input-multiple-output (MIMO) multi-antenna transmission techniques, many more base stations or access nodes than the current network deployments of LTE (a so-called small cell concept), including macro sites operating in co-operation with smaller local area access nodes, such as local ultra-dense deployment of small cells, and perhaps also employing a variety of radio technologies for better coverage and enhanced data rates. 5G will likely be comprised of more than one radio access technology (RAT), each optimized for certain use cases and/or spectrum. 5G mobile communications will have a wider range of use cases and related applications including video streaming, augmented reality, different ways of data sharing and various forms of machine type applications, including vehicular safety, different sensors and real-time control. 5G is expected to have multiple radio interfaces, namely interfaces for frequency ranges below 6GHz, cmWave frequency ranges ranging from 3GHz to 30GHz, mmWave frequency ranges ranging from 30GHz to 100GHz, and/or for even higher frequencies, and also being integrated and/or interoperate with existing legacy radio access technologies, such as the LTE. Integration with the LTE may be implemented, at least in the early phase, as a system, where macro coverage is provided by the LTE and 5G radio interface access comes from small cells by aggregation to the LTE. In other words, 5G is planned to support both inter-RAT operability (such as LTE-5G) and inter-RI operability (inter-radio interface operability, such as below 6GHz – cmWave, below 6GHz – cmWave – mmWave). One of the concepts considered to be used in 5G networks is network slicing in which multiple independent and dedicated virtual sub-networks (network instances) may be created within the same infrastructure to run services that have different requirements on latency, reliability, throughput and mobility.

It should be appreciated that future networks will most probably utilize network functions virtualization (NFV) which is a network architecture concept that proposes virtualizing network node functions into “building blocks” or entities that may be operationally connected or linked together to provide services. A virtualized network function (VNF) may comprise one or more virtual machines running computer program codes using standard or general type servers instead of customized hardware. Cloud computing or cloud data storage may also be utilized. In radio communications this may mean node operations to be carried out, at least partly, in a server, host or node operationally coupled to a remote radio head. It is also possible that node operations will be distributed among a plurality of servers, nodes or hosts. It should also be understood that the distribution of labor between core network operations and base station operations, and terminal device operations may differ from that of the LTE or even be non-existent. Some other technology advancements probably to be used are Software-Defined Networking (SDN), Big Data, and all-IP, which may change the way networks are being constructed and managed. For example, one or more of the below described network node functionalities may be migrated to any corresponding abstraction or apparatus or device. Therefore, all words and expressions should be interpreted broadly and they are intended to illustrate, not to restrict, the embodiment.

An extremely general architecture of an exemplifying system 100 to which embodiments of the invention may be applied is illustrated in Figure 1. Figure 1 is a simplified system architecture only showing some elements and functional entities, all being logical units whose implementation may differ from what is shown. It is apparent to a person skilled in the art that the system may comprise any number of the illustrated elements and functional entities.

Referring to Figure 1, a cellular communication system 100, formed by one or more cellular radio communication networks, such as the Long Term Evolution (LTE), the LTE-Advanced (LTE-A) of the 3rd Generation Partnership Project (3GPP), or the predicted future 5G solutions, are typically composed of one or more network nodes that may be of different type. An example of such network nodes is a base station 110, such as an evolved NodeB (eNB), providing a wide area, medium range or local area coverage 101 for terminal devices 120, for example for the terminal devices to obtain wireless access to other networks 130 such as the Internet, either directly or via a core network (not illustrated in Figure 1).

In general a base station 110 may be any network node (device, apparatus) capable of providing coverage and controlling radio communication within its own cell, including configuring a terminal device 120 with one or more transmission time intervals (TTI). The TTI configuration, such as one or more values for downlink TTI and/or for uplink TTI, may be a semi-static configuration which is valid at least for a longer period of time, or a transmission-specific configuration, i.e. carried out for each transmission.

The terminal device (TD) 120 refers to a portable computing device (equipment, apparatus), and it may also be referred to as a user device, a user terminal or a mobile terminal or a machine-type-communication (MTC) device, also called Machine-to-Machine device and peer-to-peer device. Such computing devices (apparatuses) include wireless mobile communication devices operating with or without a subscriber identification module (SIM) in hardware or in soft-ware, including, but not limited to, the following types of devices: mobile phone, smart-phone, personal digital assistant (PDA), handset, laptop and/or touch screen computer, e-reading device, tablet, game console, notebook, multimedia device, sensor, actuator, video camera, car, refrigerator, other domestic appliances, telemetry appliances, and telemonitoring appliances. In the illustrated example the terminal device 120 is configured to apply a virtual TTI concept to feedback information, such as channel state information and/or hybrid automatic repeat request (HARQ) acknowledgements and negative acknowledgements. For that purpose the terminal device 120 comprises a feedback transmitting unit (f-t-u) 121 configured to use TTI configuration information (TTI config.) 122 stored at least temporarily to the terminal device. Examples of different functionalities of the feedback transmitting unit will be described in more detail below as part of the terminal device functionality. The TTI configuration may comprise zero or more first TTI lengths for downlink and one or more second TTI lengths usable for uplink and downlink. The TTI configuration may be channel-specific, channel type –specific or general. When one or more first TTI lengths and one or more second TTI lengths are configured to be used on a same channel, the first TTI lengths are shorter in time than the second TTI lengths. A first TTI length may be called a short TTI, a shortened length TTI, shortened TTI, or sTTI. The second TTI length may be called a normal TTI, normal length TTI, nTTI, longer TTI, long TTI, or TTI. The second TTI may be a legacy TTI, and/or a default TTI. The legacy TTI means a long TTI value used in LTE releases 13 or older. For example, the long TTI length is 1 ms in LTE releases 8-13. The default TTI means a TTI value used in case of no other TTI value is configured. The first TTI values may be 0.1 ms, 0.2 ms, or 0.5 ms, for example. The TTI value may be also expressed by number of symbols it comprises. For example, the normal TTI (the second TTI) may comprise 14 symbols and the short TTI (the first TTI) may comprise 1 symbol, 2 symbols or 7 symbols or the short TTI may be an alternating TTI, for example alternating with 3 and 4 symbols. When channel-specific, or channel type –specific TTI configuration is used, the value of the first TTI in one channel may be the value of the second TTI in another channel. For example, physical shared channels may be configured with a first TTI with 7 symbols and a second TTI with 14 symbols, and physical control channels may be configured with a second TTI with 7 symbols. Although not explicitly mentioned herein, is should be appreciated that an actual TTI length contains also a cyclic prefix duration of a symbol.

Below different examples are described assuming that two different transmission time interval lengths, a short TTI (sTTI) and a normal length TTI (nTTI) are implemented, without restricting the embodiments thereto. It is a straightforward process for one skilled in the art to apply the teachings to implementations supporting three or more different transmission time interval lengths.

Figure 2 is a flow chart illustrating an exemplified basic functionality of a terminal device. The functionality may be performed by the feedback transmitting unit in the terminal device, or the terminal device may comprise a configuration unit for the functionality.

Referring to Figure 2, once a TTI configuration with a first TTI value (shortened TTI length, sTTI) and a second TTI value (longer TTI length, nTTI) is received in block 201, the TTI configuration is updated in block 202 to correspond the received configuration and the received configuration is used (block 202). The configuration may be received over a unicast or multicast or broadcast control signaling from a base station serving the terminal device. The configuration may be sent using a physical downlink control channel, and/or a physical downlink shared channel. For example, the configuration may be sent with radio resource control signaling.

The process described in Figure 2 is a background process. If the configuration is a semi-static configuration, i.e. valid for an unlimited time until next configuration is received, a new configuration may be received in an interval of one or multiple radio frames, for example in an interval of 10 milliseconds, or the new configuration may be received more randomly, with longer and/or changing time periods between two configurations . The configuration may be a dynamic one, for example received for each transmission.

The configuration may be terminal device –specific configuration, a cell –specific configuration, or a system –wide configuration, or a configuration according to standard definitions. Further, the configuration may, instead of having one or more values, mere indicate that a short TTI is used for downlink in addition to the normal TTI used for uplink and downlink, or that only the short TTI or the only the normal TTI is used for uplink and downlink, the value(s) already being known by the terminal device. At the simplest the received TTI configuration may indicate whether or not the short TTI (first TTI) is used in downlink. However, when the configuration contains at least a value for the short TTI (or the first TTI), the base station, or the network, may choose amongst multiple TTI lengths more freely.

Figure 3 is a flow chart illustrating an exemplified basic functionality of a terminal device, or more precisely, the feedback transmitting unit in the terminal device, configured to use at least two different lengths of TTI. In the illustrated example it is assumed that the TTI configuration comprises a short TTI (sTTI) for downlink (DL) and a normal length TTI (nTTI) for uplink (UL) as a semi-static configuration, the short TTI being shorter in time than the normal TTI.

Referring to Figure 3, when a downlink transmission (TX) that uses at least one short TTI is received in block 301 over a downlink channel, at least one time resource for transmission of feedback information on an uplink channel is determined in block 302 based on the short TTI.

If the determined at least one time resource is coincident with an uplink channel transmission (TX) configured to at least one normal TTI (block 303), determining in block 304 the at least one time resource to be on the uplink channel in at least one piece of the at least one normal TTI, wherein the duration of the at least one piece is the same as, or longer than, the duration of the at least one short TTI, the upper limit for the duration of the at least one piece being half of the at least one normal TTI. Then the transmission is caused (carried out) in block 305 according to the determination, i.e. according to the resource determined in block 304. Having the upper limit of half of the at least one normal TTI has, in view of latency, the advantage that a significant difference between the shorter TTI and the normal TTI is achieved. Further, the upper limit of half of the at least one normal TTI fulfil the criterion for a short TTI length, i.e. a short TTI should fit within a subframe.

If the determined at least one time resource is not coincident with an up-link channel transmission (TX) configured to at least one normal TTI (block 303), the transmission is caused (carried out) in block 305 according to the determination, i.e. according to the resource determined in block 302.

The feedback information may be HARQ A/N (acknowledgement/negative acknowledgement) for the received downlink transmission.

The downlink channel may be a physical downlink shared channel, over which the terminal device may also receive unicast transmissions. Further, the terminal device may be scheduled to receive with the short TTI and the normal TTI in different subframes of the physical downlink shared channel; the herein disclosed resource reservations for feedback information enables simultaneous transmission of feedback information for both short TTI and normal TTI.

The uplink channel may be a physical uplink shared channel, or a physical uplink control channel. For example, if the transmission is caused to take place according to the resource determined in block 302, the uplink channel may be a physical uplink control channel having a short TTI.

The determined at least one time resource is a kind of a virtual TTI, and the term virtual TTI is used below.

Figure 4 is a flow chart illustrating an exemplified functionality of a terminal device, or more precisely, the feedback transmitting unit in the terminal device, in an exemplified implementation in which a short TTI (sTTI) is used for downlink, the short TTI being shorter than a normal TTI (nTTI) used for uplink, and in which the virtual TTI has the same duration as the corresponding short TTI, i.e. the TTI used for transmitting the downlink transport blocks whose feedback will be transmitted in the virtual TTI. In other words, in the example of Figure 4, the virtual TTI reflects downlink short TTI length and timing inside an uplink channel transmission of the normal TTI length, such as legacy TTI on physical uplink shared channel. Further, in the example it is assumed that the normal TTI, or at least its length, is configured so that the uplink TTI configuration may be interpreted as a static configuration, whereas the downlink TTI configuration is configured more dynamically without restricting the example to such a solution. Implementing the example of Figure 4 with more dynamically changing uplink TTI configuration is a straightforward process to one skilled in the art.

Referring to Figure 4, when a TTI configuration configuring the downlink with short TTI is received in block 401, the number (A) of short TTIs fitting within a subframe is determined in block 402. For example, if the short TTI is 2 symbols, the number A is 7, and if the short TTI is 7 symbols, the number A is 2. Then the uplink channel allocation having the normal TTI is subdivided in block 403 into A virtual TTIs. In other words, the normal duration uplink channel allocation is subdivided into as many virtual TTIs (time resources) as there are short TTIs in the downlink within a subframe.

Once a downlink transmission, such as a transport block (TB) is received in block 404 in a short TTI n, its feedback timing is determined in block 405 to be in a virtual TTI n+k, the k being a delaying kind of a parameter, such as an index used in HARQ timing. The value of k may be defined separately for different TTI lengths, or a common (fixed) value may be used. The k may be delivered as part of TTI configuration or it may be a preset value. For example, if k=4, after the end of the downlink short TTI, the terminal device has three short TTIs, for decoding the downlink data and preparing for the feedback information transmission before the start of the virtual TTI. It should be noted that if the downlink would have used the normal TTIs, the terminal device would have three normal TTIs, i.e. the same amount. However, since TTIs are short TTIs, the absolute time is shorter. Thanks to the increased processing power of terminal devices this is not a problem. Further, data packets transmitted using the short TTIs are most probably smaller than data packets transmitted using the normal TTIs.

Since the virtual TTI is actually the same as short TTI for uplink, the determination performed in block 405 can be used as such for short TTI uplink. In other words, the feedback timing can be determined in the same way regardless of whether the feedback should be transmitted on a short TTI uplink channel, like the physical uplink control channel, or on a normal TTI uplink channel, like the physical uplink shared channel.

In the illustrated example, once the timing for the feedback information on the transmission (TB) has been determined (block 405), a coincidence with an uplink transmission (TX) in the normal TTI is detected in block 406. This means that resources for the feedback information will be taken from uplink data and/or channel quality indication (CQI) in the virtual TTI. Therefore the location for the feedback information on the transmission (TB) is determined in block 407. There are several alternatives how to determine the location; the location may be in the first symbol of the virtual TTI, or in the last symbol of the virtual TTI that is not occupied by one or more reference signals, or distributed in multiple symbols.

If during the location determination it is detected (block 408), that in the intended location the feedback information would overlap with a demodulation reference signal (DMRS), the feedback information will be in the illustrated example delayed in block 409 by one symbol. Then, or if no overlap is detected (block 408), mapping of the feedback information for the discrete Fourier transform (DFT) spreading is performed in block 410. The mapping is performed so that overlapping with uplink control information of normal TTI is avoided as much as possible. The mapping may be performed from bottom upwards, i.e. first to resources at the end of the symbol, or from top downwards.

If the symbol whereto the feedback information is to be mapped, for example a certain single carrier frequency division multiple access (SC-FDMA) symbol, runs out of space, i.e. the feedback information does not fit into the symbol (block 411), a symbol next available within the virtual TTI can be taken (block 412) in use. In other words, the space for the feedback information may continue in the next available symbol.

Once the feedback information resource reservation (resource allocation) is ready, a transmission of the feedback information is caused in block 413. Different resource allocation examples are illustrated with Figures 7 to 14, 16 and 17.

In the above examples it is assumed that the resource reservation is performed after at least one downlink transmission in the short TTI is received. However, the resource allocation may be performed in response to receiving TTI configuration, or the resource allocation may be preconfigured to the terminal device. For example, the resource allocation may be part of system definitions.

Figures 5 and 6 illustrates different alternatives for how to handle the resource reservation for feedback information on downlink transmission received in one or more short TTIs when the resources have been reserved beforehand.

In the alternative illustrated in Figure 5, the reserved resources for the feedback information on downlink transmissions are used to send (block 502) the feedback information if a downlink transmission is received in a short TTI (block 501). In other words, the data and/or CQI on uplink channel is punctured only if feedback information for downlink transmission in a short TTI is needed. In case the feedback information for downlink transmission in a short TTI is not needed, the reserved resources are not used but all resources are used for data and uplink control information (UCI) in the uplink channel. For example, in block 502, one of the resource reservations illustrated in Figures 7 to 14 may be used, and in block 503 the resource reservation illustrated in Figure 15 may be used.

In the alternative illustrated in Figure 6, the resources for short TTI feedback information on uplink channel are reserved regardless of whether or not the short TTI feedback information, i.e. feedback information for downlink transmission in a short TTI, is needed. If a downlink transmission is received in a short TTI (block 601), the reserved resources for the feedback information on downlink transmissions are used to send (block 602) the feedback information. If a downlink transmission is not received in a short TTI (block 601), the feedback information is set in block 603 to be a negative acknowledgement (NACK), for example, and then NACK is sent. In other words, if no feedback information is needed, the resources reserved for feedback information are used to transmit dummy feedback information in a form of negative feedback information.

Figures 7 to 14 illustrate different resource reservation examples for short TTI feedback information transmitted simultaneously with normal TTI uplink transmission (UL data) and control information, whereas Figure 17 illustrate a resource reservation examples without short TTI transmission feedback. The short TTI feedback information means herein feedback information for downlink transmission in a short TTI. In the Figures, the normal TTI control information comprises channel quality indication (CQI), reference signal (RS), rank indicator (RI), and HARQ acknowledgement/negative acknowledgement (HARQ A/N), and the short TTI feedback information comprises HARQ acknowledgement/negative acknowledgement for short TTI transmission (sHARQ A/N).

Figures 7 and 8 illustrate resource reservation examples for 2-symbol virtual

TTI, Figures 9 to 13 for 7-symbol virtual TTI, and Figure 14 for alternating virtual TTIs. Figure 7 illustrates a situation in which the one or more time resources for sHARQ A/N are taken from a first SC-FDMA symbol of the virtual TTI resulting to even indexed SC-FDMA symbols of the uplink subframe being used. The resource reservation in Figure 8 differs from the one illustrated in Figure 7, that in Figure 8 CQI symbols are punctured.

Figure 9 illustrates resource reservation using the same principles as used in Figure 7, but the resource reservation is for 7-symbol virtual TTI. This alternative, i.e. using the first symbol, minimizes the delay of the sHARQ A/N (i.e. the feedback information), leaving more processing time to the base station.

Figure 10 illustrates resource reservation in which the one or more time resources for sHARQ A/N are taken from the last symbol of the 7-symbol virtual TTI. An option in which the “last free” symbol is taken will give the terminal device the most time to process the downlink data transmission. The “last free” symbol means herein a symbol that is not occupied by one or more reference signals.

Figure 11 illustrates resource reservation in which the one or more time resources for sHARQ A/N are taken by spreading them to the first and to the last virtual symbol. This option provides larger space for sHARQ A/N but in turn requires more stringent processing from the terminal device compared to the solution in Figure 10 and from the base station compared to the solution in Figure 9.

Figure 12 illustrates resource reservation in which the one or more time resources for sHARQ A/N are in symbols next to the reference symbols for improved performance of channel estimation.

The resource reservation illustrated in Figure 13 uses the same principles as the one illustrated in Figure 12, but in the example of Figure 13 CQI symbols are punctured.

Figure 14 illustrates resource reservation when downlink short TTI has an alternating length, alternating in the illustrated example between 4 and 3 symbols, and the virtual TTI is determined to be of the same length, and as a reason, virtual TTI alternates between 4-symbol and 3-symbol virtual TTI. In the illustrated example the “first free” symbol in the virtual TTI is taken in use. The “first free” means herein a symbol that is not occupied by DMRS.

It should be appreciated that the above described resource reservations do not cover all possible combinations, and they are described only to illustrate the versatile possibilities how to carry feedback information on short TTI downlink transmissions on top of normal TTI uplink transmissions. For example, an alternative normal TTI uplink subframe structure for DMRS may be defined in which structure uplink DMRSs are located in a first SC-FDMA symbol of each slot. Such a subframe structure may be defined for normal TTI uplink transmissions only, or to be used also to carry feedback information on short TTI downlink transmissions on top of the normal TTI uplink transmissions, using the above described possibilities, for example. With such a subframe structure DMRS would always be available also when a symbol carrying feedback information on short TTI downlink transmission(s) is received.

As is obvious from the examples of Figures 7 to 14, when a normal TTI is a multiple of virtual TTIs, or a multiple of altering consecutive virtual TTIs, multiplexing in consecutive subframes information originating from terminal devices having different TTI configurations, is facilitated.

Figures 16 and 17 illustrate examples how the short TTI downlink transmission feedback information may be mapped. In the examples it is assumed that 7-symbol virtual TTI and 14-symbol normal TTI are used in the uplink.

In Figure 16 virtual TTI and TTI used in the physical downlink shared channel (PDSCH) are of equal length, i.e. sTTI is 7-symbol, that resulting to the feedback information of one downlink TTI transmission to be carried in one virtual TTI, as depicted by arrows in Figure 16.

Figure 17 illustrates a situation in which a short TTI used in the physical downlink shared channel (PDSCH) is smaller than the virtual TTI, that resulting to a fact that at least some of consecutive virtual TTIs will carry feedback information on more than one short TTI downlink transmission. In the illustrated example the short TTI is 2 symbols, and every other virtual TTI carry feedback information from 4 downlink sTTI transmissions, and every other virtual TTI carry feedback information from 3 downlink sTTI transmissions, as depicted by arrows in Figure 17. The above described resource reservations for 7-symbol virtual TTIs (Figures 9-13) can be used, assuming that sHARQ A/N fields carry feedback for multiple downlink short TTIs. An advantage of the arrangement illustrated in Figure 17 is that a receiver in the base station may be simplified since thanks to 7-symbol virtual TTI every virtual TTI would include DMRS symbol even though the latency is reduced by using 2-symbol sTTI in downlink.

Another example of a short TTI not being of same length as the virtual TTI, is to use 2-symbol short TTI in the downlink, and alternating virtual TTI lengths of 4- and 3-symbols, as illustrated in Figure 14, or 4-symbol virtual TTIs overlapping on the DMRS symbol. In such a situation every fourth virtual TTIs would carry feedback information for 1 downlink sTTI, and the three remaining ones would carry feedback information for

2 downlink sTTIs. Encoding feedback information for multiple sTTIs together is beneficial, especially when the feedback information is short: when the amount of bits encoded together increases, the more efficient coding schemes, such as Reed-Muller, convolutional coding, etc., can be used. As is evident, the benefit depends on a number of feedback bits per sTTI. (In an extreme case, feedback information could be 1 bit.) Further, when the jointly coded payload, including the number of together coded short TTI feedback information bits, is large enough, additional protection mechanisms, like cyclic redundancy check CRC, may be used with an acceptable additional overhead.

Figure 18 illustrates an exemplified information exchange between a base station (eNB) and a terminal device (UE). Referring to Figure 18, when the base station selects (point 18-1) one or more values for TTIs to be used in downlink and/or uplink, and/or value for virtual TTI, and/or which kind of resource reservation should be used, and/or whether to use process described with Figure 5 or with Figure 6 and/or whether or not to allow autonomous power boost for the terminal device, and/or which kind of modulation and coding scheme to use for the uplink channel, the base station informs (information 18-2) the terminal device correspondingly. It should be appreciated that the above is not an exhaustive list, other configurations and/or parameters may be selected by the base station, and then informed to the terminal device. Upon receiving the information 18-2, the terminal device, starts in point 18-3 to act accordingly. For example, if the autonomous power boost is allowed, the power of symbols carrying feedback information and other UCI may be boosted compared to power of non-UCI symbols. This way it is possible to compensate nTTI uplink channel performance degradation that the short TTI feedback information causes. The terminal device may be configured to derive the amount of power boost based on the ratio of resource elements reserved for short TTI feedback and resource elements reserved for normal TTI UCI. Information on whether to use process described with Figure 5 or with Figure 6 may be delivered by a predetermined information element of uplink grant, for example in a frequency hopping flag, or the radio resource control signaling may be used to convey the information.

For example, when the base station selects, whether to use the process described with Figure 5 or with Figure 6, it may determine the modulation and coding scheme, or bandwidth for the uplink channel, correspondingly: when the process described with Figure 6 ("dummy feedback information") is selected, the modulation and coding scheme, or at least required code rates, for physical uplink shared channel may be defined more accurately than what is defined when the process described with Figure 5 is selected, since in the process described with Figure 6 there is no downlink transmission detection. Another example includes that when sTTI is configured to downlink the base station may select the modulation and coding scheme in a more conservative manner to maintain the uplink channel performance at a desired level and yet allow room for potential short TTI feedback information.

As is evident from the above examples, it is possible to reduce latency by a short downlink transmission time interval while maintaining coverage provided by applying a longer uplink transmission time interval with possibility to transmit short TTI feedback information simultaneously with uplink control information. Hence a solution providing ultra-high reliability and ultra-low latency may be achieved by the disclosed multi-connectivity scheme.

The blocks, related functions, and information exchanges described above by means of Figures 2 to 6 and 18 are in no absolute chronological order, and some of them may be performed simultaneously or in an order differing from the given one. Other functions can also be executed between them or within them, and other information may be sent. For example, adding one or more new beta offset parameters for short TTI feedback information, like beta offset parameters defined in legacy systems (LTE release 13 and older) for HARQ, channel quality indicator and rank indicator, an amount of resources, i.e. a number of resource elements, reserved for feedback information for short TTIs may be determined based on the one or more new beta offset parameters and the modulation and coding scheme for the uplink channel, in a similar way as is done in the legacy systems. Naturally, even though not described specifically, the base station is configured accordingly, i.e. to receive the short TTI feedback information on top of normal TTI uplink transmission from the terminal device. Some of the blocks or part of the blocks or one or more pieces of information can also be left out or replaced by a corresponding block or part of the block or one or more pieces of information. For example, with a 1-symbol short TTI, instead of delaying (block 409 in Figure 4) feedback information when it would overlap with DMRS, the feedback information may be multiplexed with DMRS, for example by means of interleaved frequency division multiplexing (IFDM). Another example is that when 7-symbol short TTI, i.e. one slot short TTI, is used, the feedback information will not overlap with DMRS, and hence blocks 408 and 409 may be omitted in implementations configured to support only seven symbol short TTI.

The techniques and methods described herein may be implemented by various means so that an apparatus/ terminal device configured to support virtual transmission time interval concept based on at least partly on what is disclosed above with any of Figures 1 to 18, including implementing one or more functions/operations of a corresponding terminal device described above with an embodiment/example, for example by means of any of Figures 2 to 18, comprises not only prior art means, but also means for implementing the one or more functions/operations of a corresponding functionality described with an embodiment, for example by means of any of Figures 2 to 18, and it may comprise separate means for each separate function/operation, or means may be configured to perform two or more functions/operations. For example, one or more of the means and/or the feedback transmitting unit described above may be implemented in hardware (one or more devices), firmware (one or more devices), software (one or more modules), or combinations thereof. For a hardware implementation, the apparatus(es) of embodiments may be implemented within one or more application-specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, logic gates, other electronic units designed to perform the functions described herein by means of Figures 1 to 18, or a combination thereof. For firmware or software, the implementation can be carried out through modules of at least one chipset (e.g. procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in a memory unit and executed by processors. The memory unit may be implemented within the processor or externally to the processor. In the latter case, it can be communicatively coupled to the processor via various means, as is known in the art. Additionally, the components of the systems described herein may be rearranged and/or complemented by additional components in order to facilitate the achievements of the various aspects, etc., described with regard thereto, and they are not limited to the precise configurations set forth in the given figures, as will be appreciated by one skilled in the art.

Figure 19 provides an apparatus according to some embodiments of the invention. Figure 19 illustrates an apparatus configured to carry out the functions described above in connection with the terminal device. Each apparatus may comprise one or more communication control circuitry, such as at least one processor 1902, and at least one memory 1904, including one or more algorithms 1903, such as a computer program code (software) wherein the at least one memory and the computer program code (software) are configured, with the at least one processor, to cause the apparatus to carry out any one of the exemplified functionalities of the terminal device.

The memory 1904 may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The memory may comprise a configuration database for storing transmission time interval configuration data, as described above, for example with Figure 1.

The apparatus may further comprise different interfaces 1901, such as one or more user interfaces, for example a screen, microphone and one or more loudspeakers for interaction with the user, and one or more communication interfaces (TX/RX) comprising hardware and/or software for realizing communication connectivity according to one or more communication protocols. The communication interface may provide the apparatus with communication capabilities to communicate in the cellular communication system and enable communication between different network nodes and between the terminal device and the different network nodes, for example. The communication interface may comprise standard well-known components such as an amplifier, filter, frequency-converter, (de)modulator, and encoder/decoder circuitries and one or more antennas. The communication interfaces may comprise radio interface components providing the network node and the terminal device with radio communication capability in the cell. Further, the apparatus 1900 may comprise one or more user interfaces, such as a screen, microphone and one or more loudspeakers for interaction with the user.

Referring to Figure 19, at least one of the communication control circuitries in the apparatus 1900 is configured to provide the feedback transmitting unit, or any corresponding sub-unit, and to carry out functionalities described above by means of any of Figures 2 to 18 by one or more circuitries.

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) combinations of circuits and soft-ware (and/or firmware), such as (as applicable): (i) a combination of processor(s) or (ii) portions of processor(s)/software including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus to perform various functions, and (c) 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. 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 a 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 element, a baseband integrated circuit or applications processor integrated circuit for a mobile phone or a similar integrated circuit in a server, a cellular network device, or another network device.

In an embodiment, the at least one processor, the memory, and the computer program code form processing means or comprises one or more computer program code portions for carrying out one or more operations according to any one of the embodiments of Figures 2 to 18 or operations thereof.

Embodiments as described may also be carried out in the form of a computer process defined by a computer program or portions thereof. Embodiments of the methods described in connection with Figures 2 to 18 may be carried out by executing at least one portion of a computer program comprising corresponding instructions. The computer program may be in source code form, object code form, or in some intermediate form, and it may be stored in some sort of carrier, which may be any entity or device capable of carrying the program. For example, the computer program may be stored on a computer program distribution medium readable by a computer or a processor. The computer program medium may be, for example but not limited to, a record medium, computer memory, read-only memory, electrical carrier signal, telecommunications signal, and software distribution package, for example. The computer program medium may be a non-transitory medium. Coding of software for carrying out the embodiments as shown and described is well within the scope of a person of ordinary skill in the art.

Even though the invention has been described above with reference to examples according to the accompanying drawings, it is clear that the invention is not restricted thereto but can be modified in several ways within the scope of the appended claims. Therefore, all words and expressions should be interpreted broadly and they are intended to illustrate, not to restrict, the embodiment. It will be obvious to a person skilled in the art that, as technology advances, the inventive concept can be implemented in various ways. Further, it is clear to a person skilled in the art that the described embodiments may, but are not required to, be combined with other embodiments in various ways.

CLAIMS

1. A method comprising:

receiving in a terminal device at least one downlink transmission using at least one shortened length transmission time interval;

determining, by the terminal device, based on the at least one shortened length transmission time interval, at least one time resource from an uplink channel for transmission of feedback information for the at least one downlink transmission;

if the at least one time resource is coincident with an uplink channel transmission configured to at least one transmission time interval having a longer length than the length of the at least one shortened length transmission time interval, determining the at least one time resource to be on the uplink channel in at least one piece of at least one transmission time interval having the longer length, a duration of the at least one piece being equal to or longer than the duration of the at least one shortened length transmission time interval and smaller than or equal to half of the duration of the at least one transmission time interval having the longer length; and

causing the transmission of the feedback information in the at least one time resource.

2. A method as claimed in claim 1, wherein the duration of the at least one piece is the same as the duration of the at least one shortened length transmission time interval.

3. A method as claimed in claim 2, wherein the at least one transmission time interval having the longer length is subdivided into as many pieces as there are shortened length transmission time intervals in downlink within a subframe.

4. A method as claimed in claim 1, wherein the duration of the at least one piece is longer than the duration of the at least one shortened length transmission time interval, the method further comprises causing sending in the at least one piece feedback information from two or more received downlink transmissions.

5. A method as claimed in any preceding claim, wherein the at least one piece takes resources from uplink data and/or from channel quality indication.

6. A method as claimed in any preceding claim, wherein if the at least one piece overlaps with demodulation reference signal, the feedback information is delayed.

7. A method as claimed in any preceding claim, wherein if no feedback information is to be sent, causing transmission of dummy feedback information in the form of negative feedback information in the at least one time resource.

8. A method as claimed in any preceding claim 1 to 6, wherein, if no feedback information is to be sent and the at least one time resource is determined to be in the at least one piece, using also the at least one piece for transmission of uplink data and/or channel quality indication.

9. A method as claimed in any preceding claim, wherein the uplink channel configured to the at least one transmission time interval having the longer length is a physical uplink shared channel.

10. A method as claimed in claim 9, further comprising reserving resources for the feedback information starting in the at least one piece from a first symbol that is not occupied by a demodulation reference signal.

11. A method as claimed in claim 9, further comprising reserving resources for the feedback information starting in the at least one piece from a last symbol that is not occupied by one or more reference signals.

12. A method as claimed in claim 9, further comprising reserving resources for the feedback information in symbols next to reference symbols in the at least one piece.

13. A method as claimed in any preceding claims, wherein the feedback information is HARQ acknowledgement/negative acknowledgement.

14. A terminal device comprising:

at least one processor, and

at least one memory comprising a computer program code, wherein the processor, the memory, and the computer program code are configured to cause the apparatus to:

receive at least one downlink transmission using at least one shortened length transmission time interval;

determine, based on the at least one shortened length transmission time interval, at least one time resource from an uplink channel for transmission of feedback information for the at least one downlink transmission;

if the at least one time resource is coincident with an uplink channel transmission configured to at least one transmission time interval having a longer length than the length of the at least one shortened length transmission time interval, determine the at least one time resource to be on the uplink channel in at least one piece of at least one transmission time interval having the longer length, a duration of the at least one piece being equal to or longer than the duration of the at least one shortened length transmission time interval and smaller than or equal to half of the duration of the at least one transmission time interval having the longer length; and

cause the transmission of the feedback information in the at least one time resource.

15. A terminal device as claimed in claim 14, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to use as the duration of the at least one piece the duration of the at least one shortened length transmission time interval.

16. A terminal device as claimed in claim 15, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to subdivide the at least one transmission time interval having the longer length into as many pieces as there are shortened length transmission time intervals in downlink within a subframe.

17. A terminal device as claimed in claim 14, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to, if the duration of the at least one piece is longer than the duration of the at least one shortened length transmission time interval, cause sending in the at least one piece feedback information from two or more received downlink transmissions.

18. A terminal device as claimed in any of claims 14 to 17, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to take resources for the at least one piece from uplink data and/or from channel quality indication.

19. A terminal device as claimed in any of claims 14 to 18, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to, if the at least one piece overlaps with demodulation reference signal, delay the feedback information.

20. A terminal device as claimed in any of claims 14 to 19, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to, if no feedback information is to be sent, transmit dummy feedback information in the form of negative feedback information in the at least one time resource.

21. A terminal device as claimed in any of claims 14 to 19, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to, if no feedback information is to be sent and the at least one time resource is determined to be in the at least one piece, use also the at least one piece for transmission of uplink data and/or channel quality indication.

22. A terminal device as claimed in any of claims 14 to 21, wherein the uplink channel configured to the at least one transmission time interval having the longer length is a physical uplink shared channel or a physical uplink control channel.

23. A terminal device as claimed in claim 22, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to reserve resources for the feedback information starting in the at least one piece from a first symbol that is not occupied by a demodulation reference signal.

24. A terminal device as claimed in claim 22, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to reserve resources for the feedback information starting in the at least one piece from a last symbol that is not occupied by one or more reference signals.

25. A terminal device as claimed in claim 22, wherein the processor, the memory, and the computer program code are further configured to cause the terminal device to reserve resources for the feedback information in symbols next to reference symbols in the at least one piece.

26. A terminal device as claimed in any of claims 14 to 25, wherein the feedback information is HARQ acknowledgement/negative acknowledgement.

27. An apparatus comprising means for carrying out the method ac-cording to any one of claims 1 to 13.

28. A non-transitory computer readable media having stored thereon instructions that, when executed by a computing device, cause the computing device to:

be configured to receive at least one downlink transmission using at least one shortened length transmission time interval;

determine, based on the at least one shortened length transmission time interval, at least one time resource from an uplink channel for transmission of feedback information for the at least one downlink transmission;

detect if the at least one time resource is coincident with an uplink channel transmission configured to at least one transmission time interval having a longer length than the length of the at least one shortened length transmission time interval, and determine the at least one time resource to be on the uplink channel in at least one piece of at least one transmission time interval having the longer length, a duration of the at least one piece being equal to or longer than the duration of the at least one shortened length transmission time interval and smaller than or equal to half of the duration of the at least one transmission time interval having the longer length; and

cause the transmission of the feedback information in the at least one time resource.

29. A non-transitory computer readable media as claimed in claim 28, having stored thereon further instructions that, when executed by a computing device, cause the computing device further to take resources for the at least one piece from uplink data and/or from channel quality indication starting in the at least one piece from a first symbol that is not occupied by a demodulation reference signal, or starting in the at least one piece from a last symbol that is not occupied by one or more reference signals or in symbols next to reference symbols in the at least one piece.

30. A computer program product comprising program instructions configuring an apparatus to perform any of the steps of a method as claimed in any of claims 1 to 13 when the computer program is run.

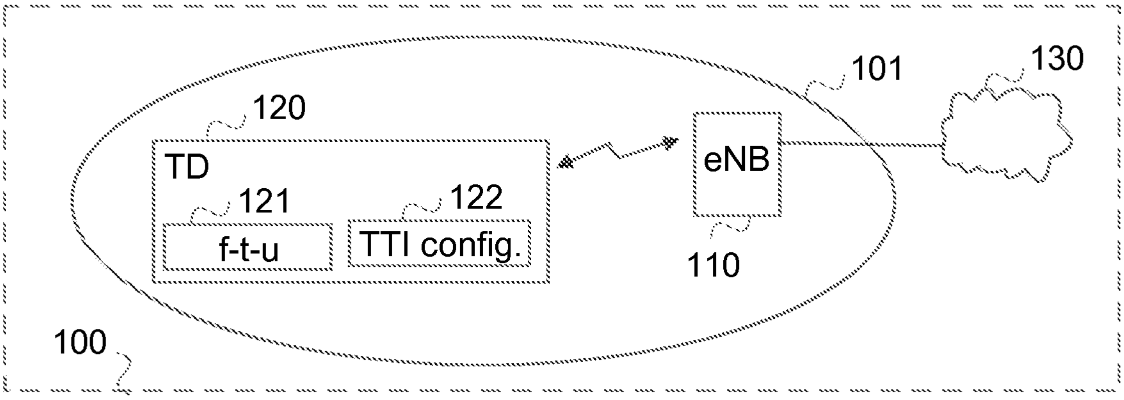

FIG.1

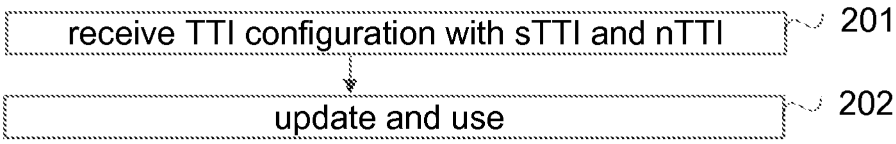

FIG.2

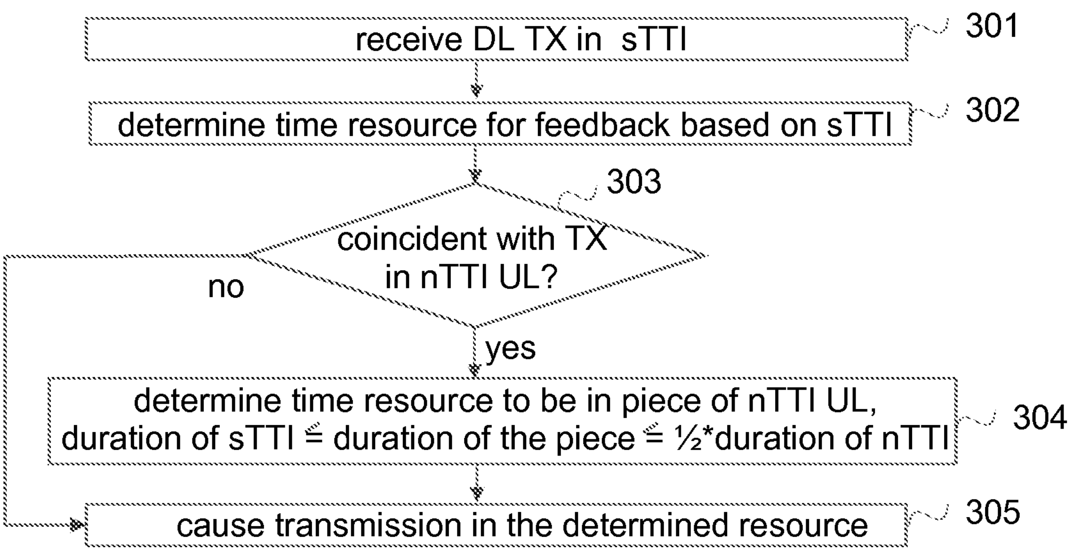

FIG.3

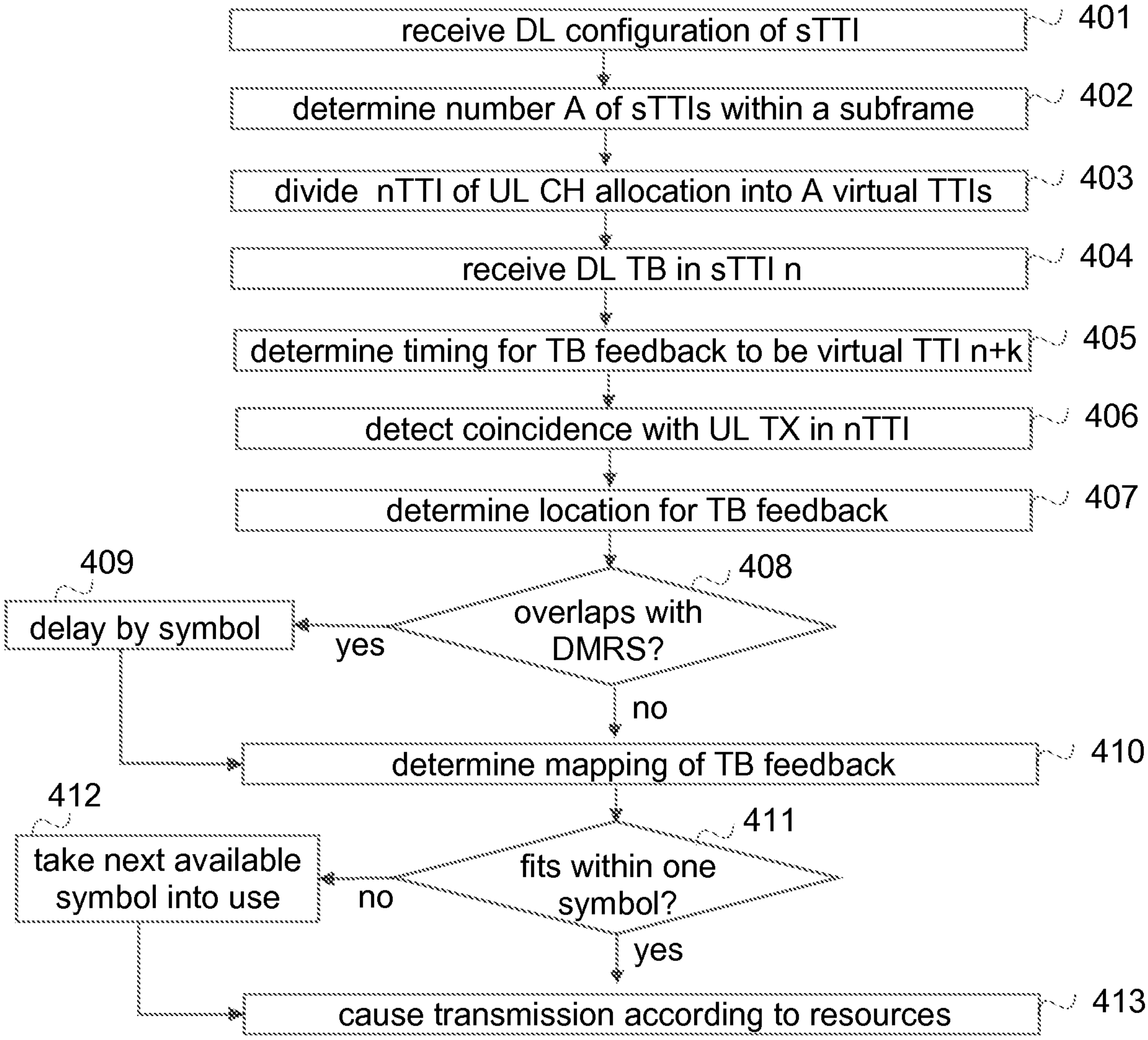

FIG.4

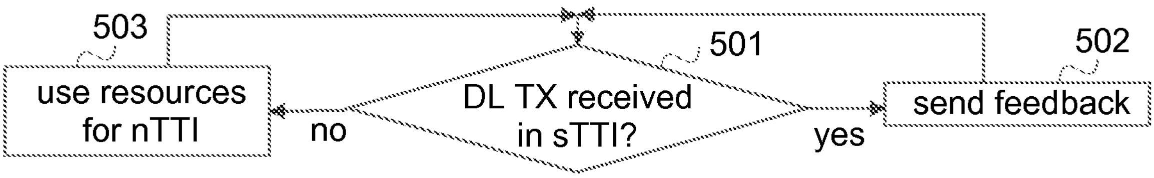

FIG.5

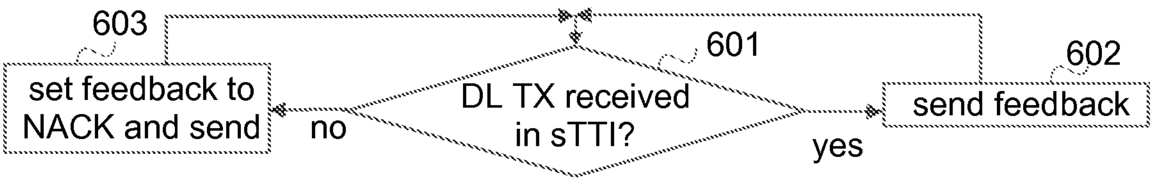

FIG.6

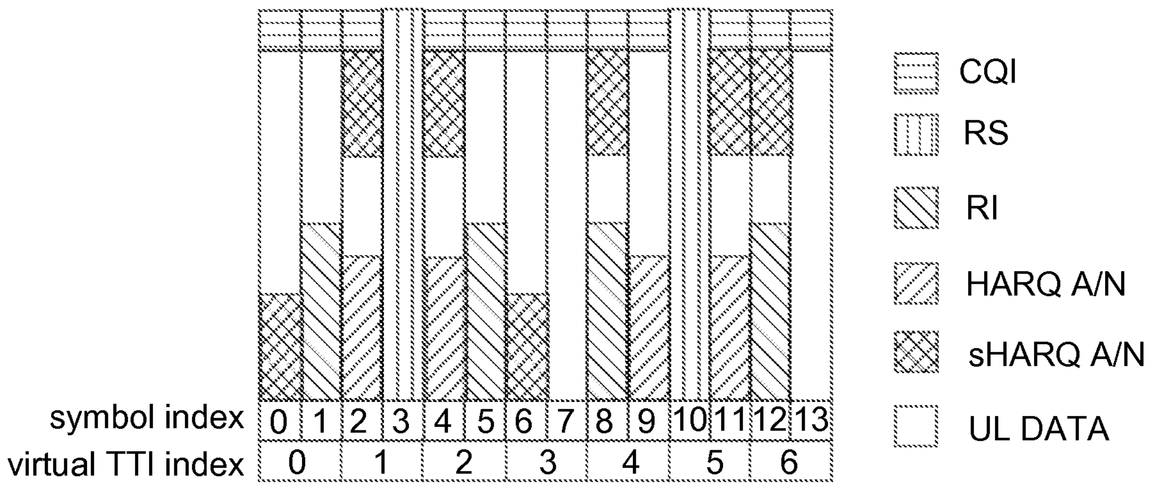

FIG.7

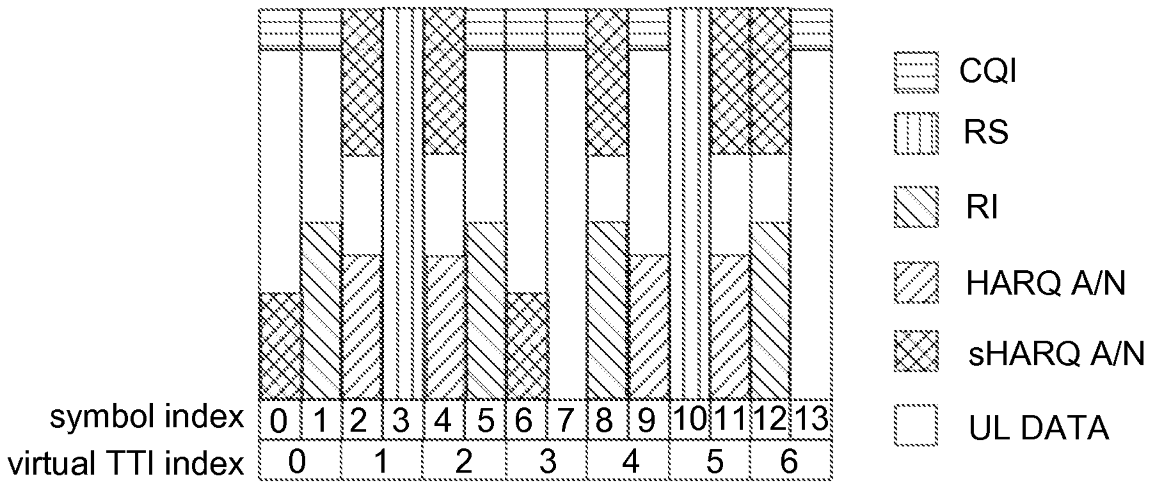

FIG.8

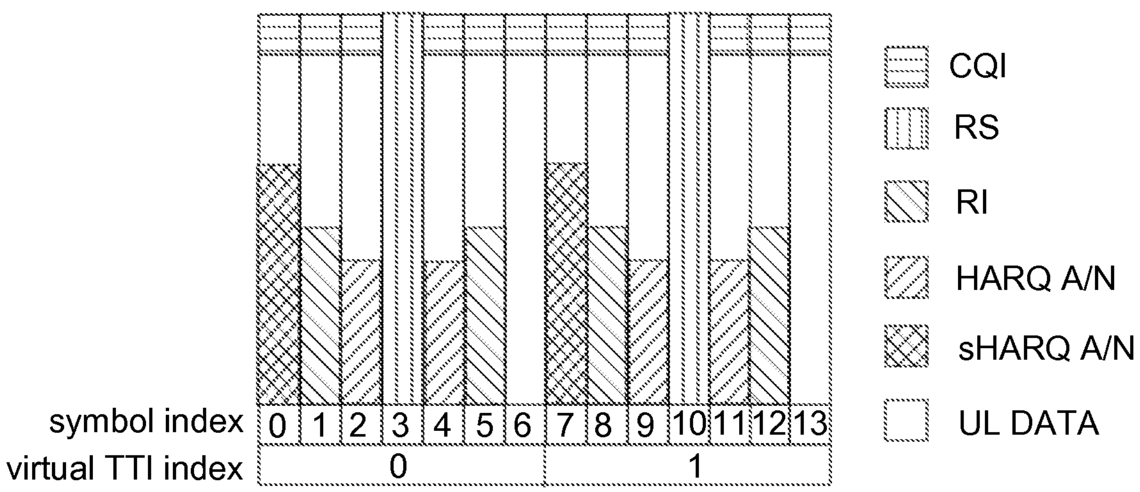

FIG.9

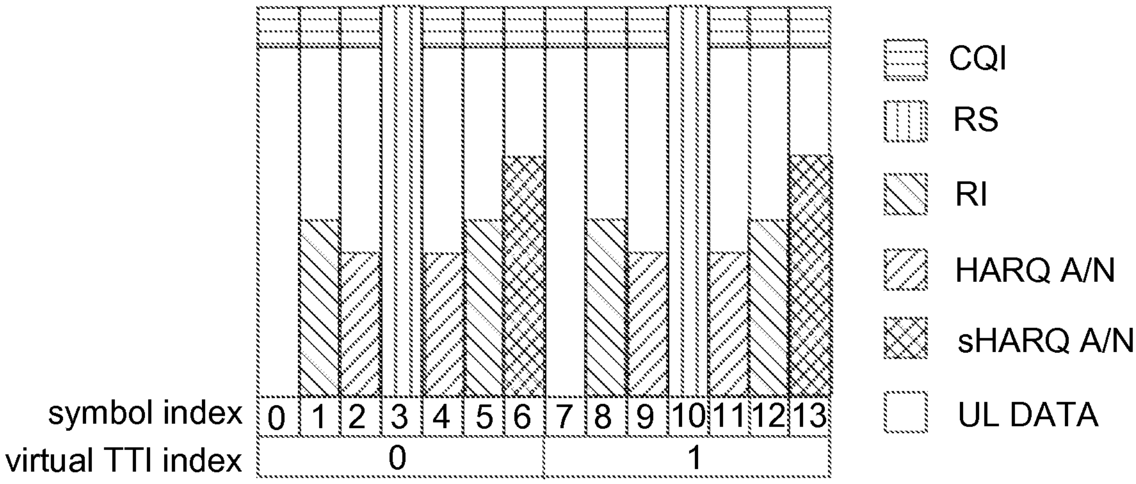

FIG.10

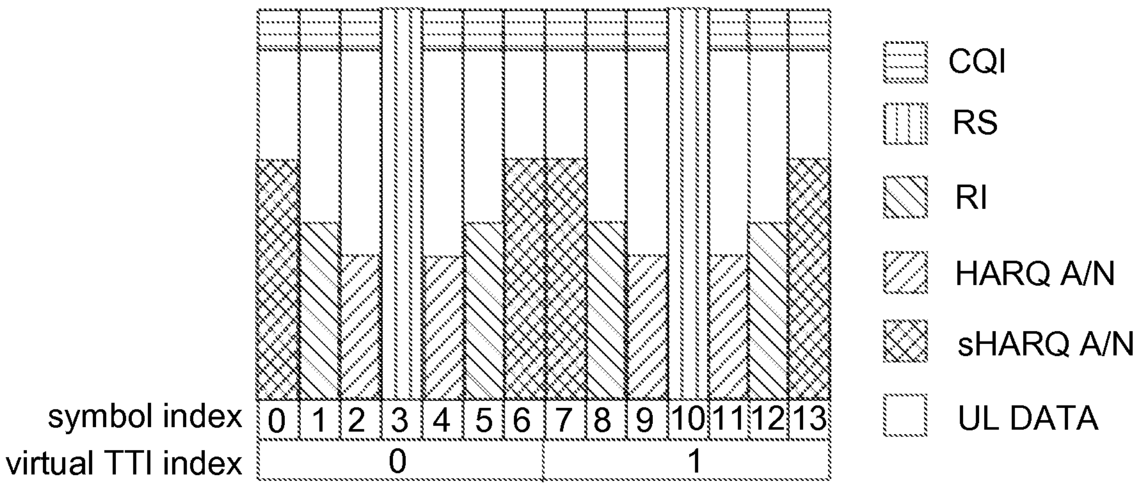

FIG.11

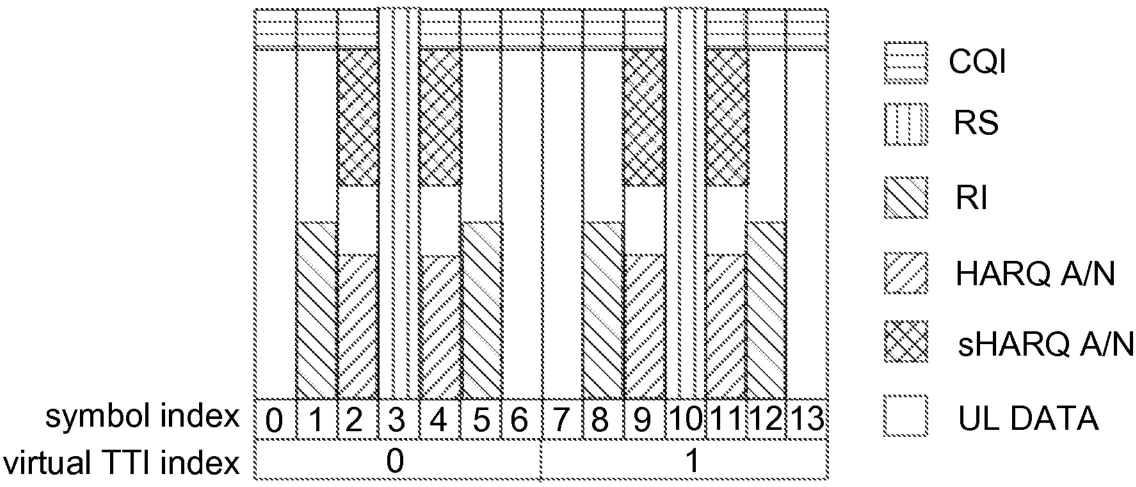

FIG.12

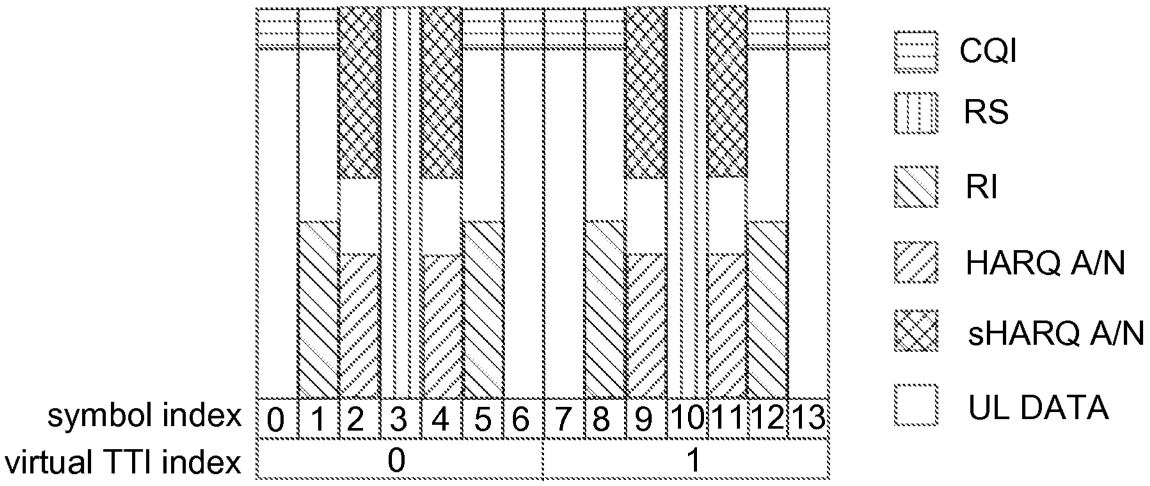

FIG.13

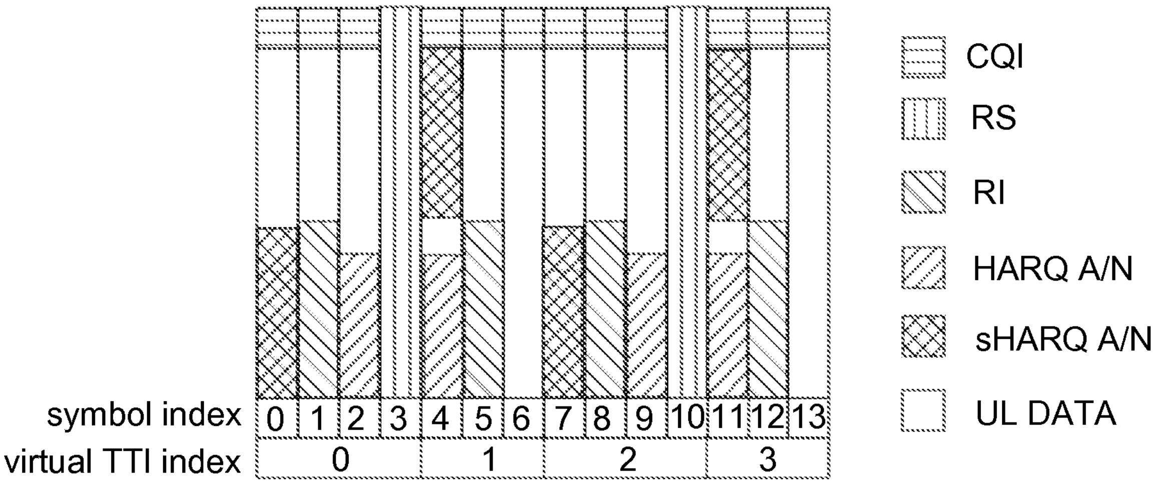

FIG.14

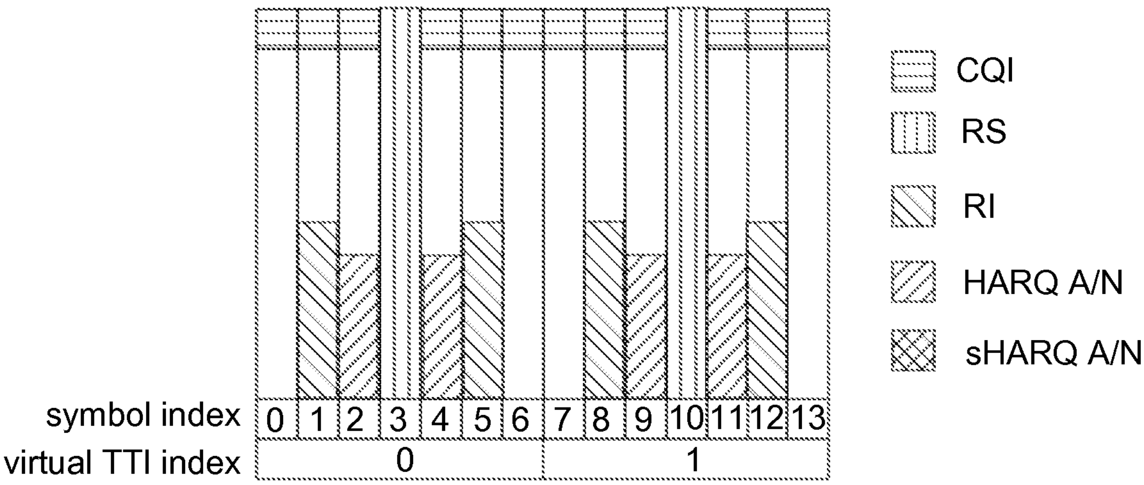

FIG.15

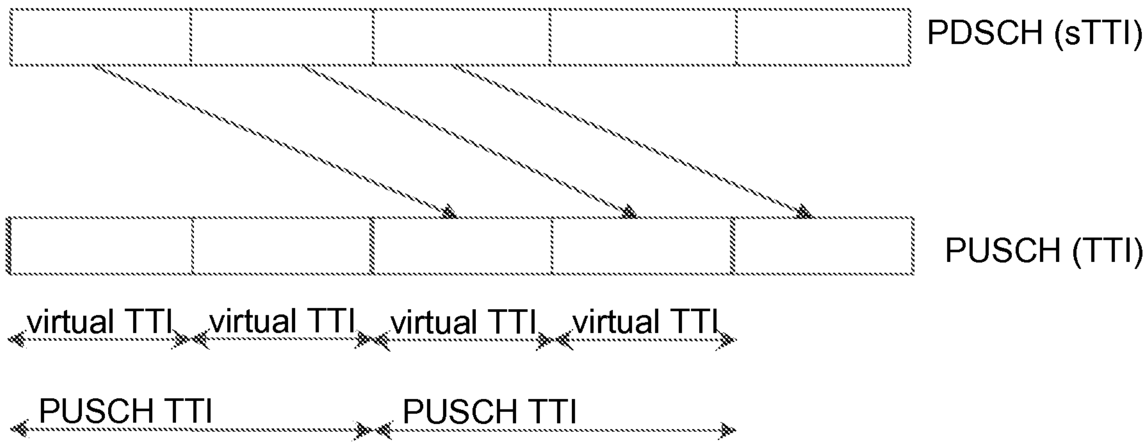

FIG.16

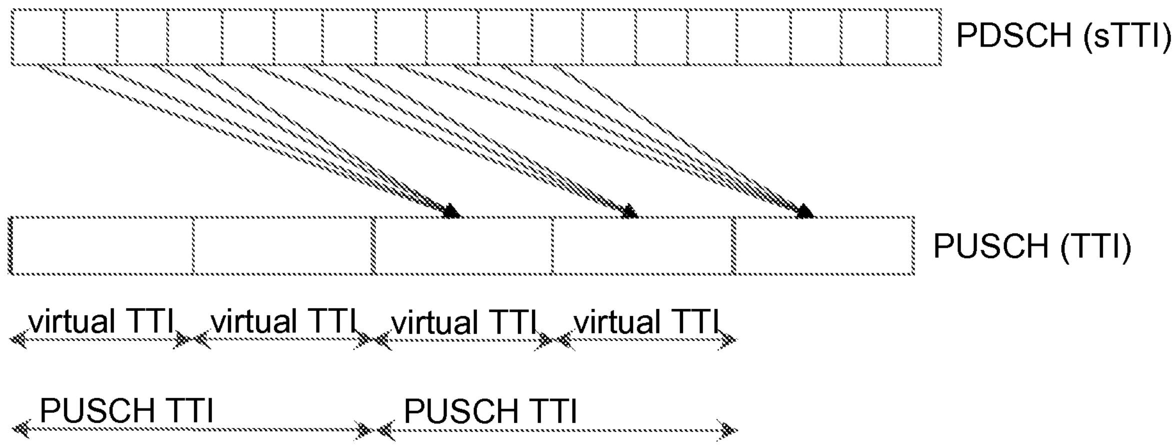

FIG.17

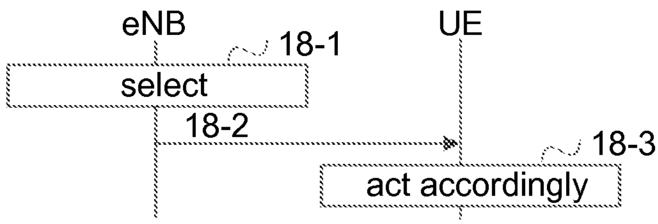

FIG.18

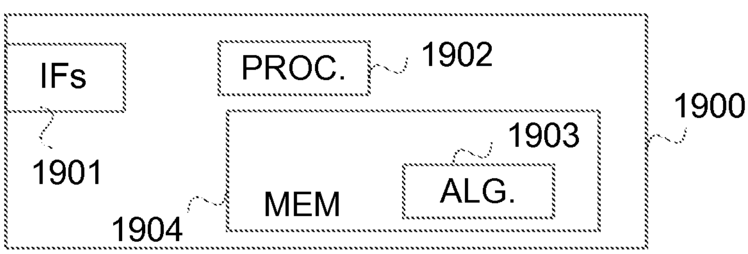

FIG.19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2016/050199

A. **CLASSIFICATION OF SUBJECT MATTER**

See extra sheet

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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base, and, where practicable, search terms used)

EPO-Internal, WPIAP, XP3GPP, XPAIP, XPESP, XPETSI, XPI3E, XPIEE, XPIETF, XPIOP, XPIPCOM, XPJPEG, XPMISC, XPOAC, XPRD, XPTK

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013112703 A2 (INTERDIGITAL PATENT HOLDINGS [US]) 01 August 2013 (01.08.2013) abstract, paragraphs [0181]-[0186]	1-30
A	WO 2009104922 A2 (LG ELECTRONICS INC [KR]) 27 August 2009 (27.08.2009) abstract	1-30
A	EP 2635082 A1 (PANASONIC CORP [JP]) 04 September 2013 (04.09.2013) abstract	1-30
A	WO 2015139795 A1 (ERICSSON TELEFON AB L M [SE]) 24 September 2015 (24.09.2015) abstract	1-30

☐ 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
12 August 2016 (12.08.2016)	17 August 2016 (17.08.2016)

Name and mailing address of the ISA/FI	Authorized officer
Finnish Patent and Registration Office P.O. Box 1160, FI-00101 HELSINKI, Finland	Tapio Ikäheimo
Facsimile No. +358 9 6939 5328	Telephone No. +358 9 6939 500

CLASSIFICATION OF SUBJECT MATTER

IPC
H04W 72/04 (2009.01)
H04W 28/06 (2009.01)

INTERNATIONAL SEARCH REPORT
Information on Patent Family Members

International application No.
PCT/FI2016/050199

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