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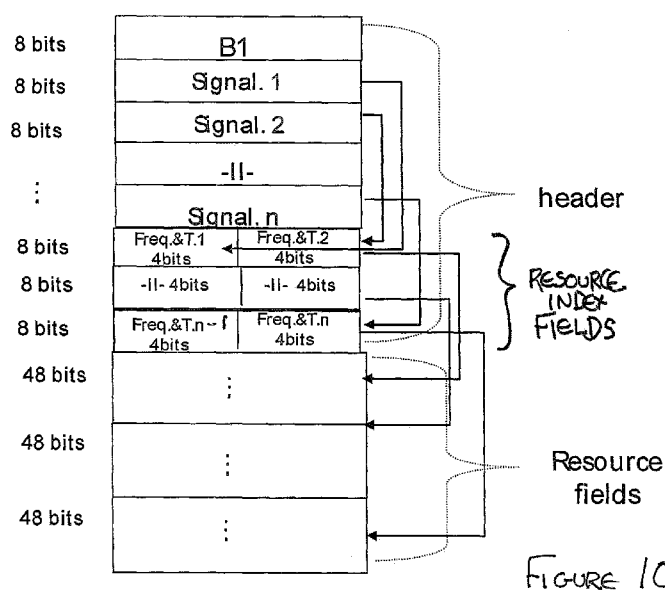
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(54) Title: RANDOM ACCESS CHANNEL MESSAGE BUNDLING



(57) **Abstract:** Disclosed herein are methods, computer program instructions and apparatus for performing random access procedures in a wireless communication system. A method includes receiving random access preamble sequences individual ones of which are associated with one of a plurality of time and frequency resources; and bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single transmitted downlink control channel assignment and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles. A further method includes transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence; and receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

ble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

RANDOM ACCESS CHANNEL MESSAGE BUNDLING

TECHNICAL FIELD:

The exemplary and non-limiting embodiments of this invention relate generally to wireless communication systems, methods, devices and computer programs and, more specifically, relate to random access channel signaling techniques between a mobile node and a network access node.

BACKGROUND:

This section is intended to provide a background or context to the invention that is recited in the claims. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived, implemented or described. Therefore, unless otherwise indicated herein, what is described in this section is not prior art to the description and claims in this application and is not admitted to be prior art by inclusion in this section.

The following abbreviations that may be found in the specification and/or the drawing figures are defined as follows:

3GPP	third generation partnership project
DL	downlink (eNB towards UE)
eNB	EUTRAN Node B (evolved Node B)
EPC	evolved packet core
EUTRAN	evolved UTRAN (LTE)
FDD	frequency division duplex
FDMA	frequency division multiple access
LTE	long term evolution
MAC	medium access control
MM/MME	mobility management/mobility management entity
Node B	base station
OFDMA	orthogonal frequency division multiple access
O&M	operations and maintenance

PDCP	packet data convergence protocol
PDCCH	physical downlink control channel
PDSCH	physical downlink shared channel
PHY	physical (layer 1)
PRACH	physical random access channel
RA-RNTI	random access radio network temporary identity
RACH	random access channel
RLC	radio link control
RRC	radio resource control
SGW	serving gateway
SC-FDMA	single carrier, frequency division multiple access
TDD	time division duplex
T-CRNTI	temporary cell random access radio network temporary identity
TTI	transmission timing interval
UE	user equipment
UL	uplink (UE towards eNB)
UTRAN	universal terrestrial radio access network

The specification of a communication system known as evolved UTRAN (EUTRAN, also referred to as UTRANLTE or as EUTRA) is currently nearing completion within the 3GPP. As specified the DL access technique is OFDMA, and the UL access technique is SC-FDMA.

One specification of interest is 3GPP TS 36.300, V8.6.0 (2008-09), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (EUTRA) and Evolved Universal Terrestrial Access Network (EUTRAN); Overall description; Stage 2 (Release 8), incorporated by reference herein in its entirety.

Figure 1 reproduces Figure 4.1 of 3GPP TS 36.300, and shows the overall architecture of the EUTRAN system. The EUTRAN system includes eNBs, providing the EUTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards

the UE. The eNBs are interconnected with each other by means of an X2 interface. The eNBs are also connected by means of an S1 interface to an EPC, more specifically to a MME (Mobility Management Entity) by means of a S1 MME interface and to a Serving Gateway (SGW) by means of a S1 interface. The S1 interface supports a many to many relationship between MMEs / Serving Gateways and eNBs.

The eNB hosts the following functions:

functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling);

IP header compression and encryption of the user data stream;

selection of a MME at UE attachment;

routing of User Plane data towards Serving Gateway;

scheduling and transmission of paging messages (originated from the MME);

scheduling and transmission of broadcast information (originated from the MME or O&M); and

a measurement and a measurement reporting configuration for use in mobility and scheduling.

In the present LTE system preamble responses are sent utilizing both the PDCCH and the PDSCH. Each RACH resource (time and frequency resource reserved for preamble transmission) is associated with a RA-RNTI (random access radio network temporary identity). When the base station (eNB) observes a preamble, it transmits the preamble response on the PDSCH on a resource that is indicated by a PDCCH addressed with the RA-RNTI. More specifically, when a Random Access Response message is transmitted, the CRC word of the corresponding PDCCH is masked by RA-RNTI. When searching a preamble response the UE tries to find a RA-RNTI masking corresponding to the frequency and time resource that the UE had used when sending its preamble. In this manner the preamble response on the PDSCH is unambiguously associated with preambles transmitted on a certain time-frequency resource.

The system is flexible in the sense that the base station can acknowledge in the same PDSCH message several preambles that have been transmitted in the same RACH resource, but that carry different signatures (preamble sequences). In addition, the responses can be sent in a time window that is configurable up to a duration of 10 ms.

In the present LTE system the responses to a set of UEs that listen to the same RA-RNTI can be combined into the same message. However, responses corresponding to different RA-RNTI cannot be combined, and PDCCH and PDSCH messages must be sent separately for each RA-RNTI (i.e., each RACH time-frequency resource). Considering the limited PDCCH resources this is not an efficient procedure. Because the base station does not know the channel state of the UEs, a PDCCH entry for a preamble response must be heavily coded, which consumes significant PDCCH resources. This can lead to problems, especially in the TDD system of LTE where several PRACH resources can exist in one subframe, and where random access responses cannot be distributed in time as flexibly as in the FDD system. This is true at least for the reason that in the TDD system there are gaps in the PDCCH due to subframes reserved for UL.

One LTE specification of interest herein is 3GPP TS 36.211 V8.4.0 (2008-09) Technical Specification 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (Release 8). As is stated in subclause 4.2, the frame structure type 2 is applicable to TDD. Each radio frame of length $T_f = 307200 \cdot T_s = 10 \text{ ms}$ consists of two half-frames of length $T_f = 153600 \cdot T_s = 5 \text{ ms}$ each. Each half-frame consists of five subframes of length $30720 \cdot T_s = 1 \text{ ms}$. The supported uplink-downlink configurations are listed in Table 4.2-2 (the seven configurations 0-6 are shown below) where, for each subframe in a radio frame, “D” denotes the subframe is reserved for downlink transmissions, “U” denotes the subframe is reserved for uplink transmissions and “S” denotes a special subframe with the three fields DwPTS, GP and UpPTS. All subframes which are not special subframes are defined as two slots of length $T_{\text{slot}} = 15360 \cdot T_s = 0.5 \text{ ms}$ in each subframe. Uplink-downlink configurations with both 5 ms and 10 ms downlink-to-uplink switch-point periodicity are supported. In case of 5 ms downlink-to-uplink switch-point periodicity, the special subframe exists in both half-frames. In case of 10 ms

downlink-to-uplink switch-point periodicity, the special subframe exists in the first half-frame only. Subframes 0 and 5 and DwPTS are always reserved for downlink transmission. UpPTS and the subframe immediately following the special subframe are always reserved for uplink transmission.

Table 4.2-2: Uplink-downlink configurations.

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

The PRACH is described in subclause 5.7 of 3GPP TS 36.211.

Another LTE specification of interest herein is 3GPP TS 36.321 V8.3.0 (2008-09) Technical Specification 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol definition (Release 8). The specification describes in subclause 5.1 the overall Random Access procedure followed by the UE.

As currently specified in subclause 5.1.4, Random Access Response reception, once the Random Access Preamble is transmitted, and regardless of the possible occurrence of a measurement gap, the UE shall monitor the PDCCH for Random Access response(s) identified by the RA-RNTI defined below, in the TTI window A_WINDOW_BEGIN—A_WINDOW_END which starts at the subframe that contains the end of the preamble transmission plus three subframes, and has length ra-ResponseWindowSize subframes.

The RA-RNTI associated with the PRACH resource in which the Random Access Preamble is transmitted, is computed as:

$$\text{RA-RNTI} = t_id + 10 * f_id,$$

where t_id is the index of the first subframe of the specified PRACH resource ($0 \leq t_id < 10$), and f_id is the index of the specified PRACH resource within that subframe, in ascending order of frequency domain ($0 \leq f_id < 6$). The UE may stop monitoring for Random Access Response(s) after successful reception of a Random Access Response corresponding to the Random Access Preamble transmission. When the Random Access Response contains a Random Access Preamble identifier corresponding to the transmitted Random Access Preamble (see subclause 5.1.3), the UE shall:

- consider this Random Access Response reception successful;
- process the received Timing Alignment value (see subclause 5.2);
- process the received UL grant value and indicate it to the lower layers;
- if the Random Access Preamble was explicitly signalled (i.e., not selected by MAC):
- consider the Random Access procedure successfully completed.

The present LTE system for the signaling of preamble responses was agreed to in 3GPP in 2006. Several options were considered at that time. In many of them each acknowledged preamble reserved a separate PDCCH entry. To make efficient use of downlink resources and prevent blocking, the eNB transmitting a variable number of signature responses was discussed on a general level in 3GPP document R2-062844, 3GPP TSG-RAN WG2#55, Seoul, Korea, 9-13 October 2006, "Signature Response Capacity", Siemens. One 3GPP document describing the LTE system as presently specified is R2-062853, 3GPP TSG-RAN WG2#55, Seoul, Korea, 9-13 October 2006, "Initial Random Access Procedure for E-UTRAN", Ericsson.

Perceived problems with the presently specified RACH procedures include a non-optimum use of PDCCH resources, and the possibility for excessive delay between receipt of the preamble on the RACH and the subsequent transmission of the preamble response.

SUMMARY

The foregoing and other problems are overcome, and other advantages are realized, by the use of the exemplary embodiments of this invention.

In a first aspect thereof the exemplary embodiments of this invention provide a method that comprises receiving random access preamble sequences individual ones of which are associated with one of a plurality of time and frequency resources; and bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single downlink control channel assignment, indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

In another aspect thereof the exemplary embodiments of this invention provide a computer readable medium that stores program instructions, the execution of which by a controller results in operations comprising, in response to receiving random access preamble sequences individual ones of which are associated with one of a plurality of time and frequency resources, bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single transmitted downlink control channel assignment and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message. The operations further comprise placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

In another aspect thereof the exemplary embodiments of this invention provide an apparatus that comprises a controller configured to operate with a wireless receiver and a

wireless transmitter. The controller is further configured to respond to receiving random access preamble sequences, individual ones of which are associated with one of a plurality of time and frequency resources, to bundle random access preamble responses that are received for random access preambles in different time and frequency resources by composing a single transmitted downlink control channel assignment, and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message. The controller is further configured to place in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

In a further aspect thereof the exemplary embodiments of this invention provide a method that comprises transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence; and receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence, frequency and time resources used for transmitting the random access preamble.

In a further aspect thereof the exemplary embodiments of this invention provide a computer readable medium that stores program instructions, the execution of which by a controller results in operations comprising transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence; and receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence, and frequency and time resources used for transmitting the random access preamble.

In yet another aspect thereof the exemplary embodiments of this invention provide an apparatus that comprises a controller configured to operate with a wireless receiver and a

wireless transmitter. The controller is further configured to transmit a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence. The controller is further configured to respond to receiving a downlink control channel assignment, that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, to locate in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

BRIEF DESCRIPTION OF THE DRAWINGS

In the attached Drawing Figures:

Figure 1 reproduces Figure 4 of 3GPP TS 36.300, and shows the overall architecture of the EUTRAN system.

Figure 2A shows a simplified block diagram of various electronic devices that are suitable for use in practicing the exemplary embodiments of this invention.

Figure 2B shows a more particularized block diagram of a user equipment such as that shown at Figure 2A.

Figure 3 depicts RACH procedures in accordance with the exemplary embodiments of this invention, more specifically one executed in a RRC_IDLE UE state and one executed in a RRC_CONNECTED UE state.

Figure 4 illustrates a PRACH response operation, and contrasts the conventional approach with the approach in accordance with the exemplary embodiments of this invention.

Figure 5 is a logic flow diagram that illustrates the operation of a method, and a result of execution of computer program instructions embodied on a computer readable memory,

in accordance with the exemplary embodiments of this invention.

Figure 6 illustrates the PRACH response operation for UL/DL configuration 0 in accordance with the exemplary embodiments of this invention.

Figure 7 illustrates the PRACH response operation for UL/DL configuration 1 in accordance with the exemplary embodiments of this invention.

Figure 8 illustrates the PRACH response operation for FDD in accordance with the exemplary embodiments of this invention.

Figure 9 depicts a conventional MAC layer preamble response header format in the PDSCH.

Figure 10 depicts a MAC layer preamble response header format in the PDSCH in accordance with the exemplary embodiments of this invention.

Figure 11 is a logic flow diagram that illustrates the operation of a further method, and a result of execution of computer program instructions embodied on a computer readable memory, in accordance with the exemplary embodiments of this invention.

DETAILED DESCRIPTION

Due to the seven different UL/DL TDD configurations of the E-UTRAN frame structure (Table 4.2-2 of 3GPP TS 36.211, reproduced above), it has been specified that up to six multiple random access resources can be mapped in an UL subframe or UpPTS. The high density of PRACHs in one UL subframe (or UpPTS) may limit PDCCH resources, thus delaying the response in the following DL PDCCH (shown in Figure 4 as the line indicated with an asterisk (*)). When there are fewer DL subframes in the DL/UL TDD frame structure, the presently specified E-UTRAN system of preamble responses has at least the disadvantages of consuming unnecessarily the PDCCH resources, thus constraining PDSCH resource allocation, and possibly resulting in delay if the responses

must be postponed due to a lack of PDCCH resources.

Before describing in further detail the exemplary embodiments of this invention, reference is made to Figure 2A for illustrating a simplified block diagram of various electronic devices and apparatus that are suitable for use in practicing the exemplary embodiments of this invention. In Figure 2A a wireless network 1 is adapted for communication over a wireless link 11 with an apparatus, such as a mobile communication device which may be referred to as a UE 10, via a network access node, such as a Node B (base station), and more specifically an eNB 12. The network 1 may include a network control element (NCE) 14 that may include the MME/SGW functionality shown in Figure 1, and which provides connectivity with a network 1, such as a telephone network and/or a data communications network (e.g., the internet). The UE 10 includes a controller, such as a computer or a data processor (DP) 10A, a computer-readable memory medium embodied as a memory (MEM) 10B that stores a program of computer instructions (PROG) 10C, and a suitable radio frequency (RF) transceiver 10D for bidirectional wireless communications with the eNB 12 via one or more antennas. The eNB 12 also includes a controller, such as a computer or a data processor (DP) 12A, a computer-readable memory medium embodied as a memory (MEM) 12B that stores a program of computer instructions (PROG) 12C, and a suitable RF transceiver 12D for communication with the UE 10 via one or more antennas. The eNB 12 is coupled via a data / control path 13 to the NCE 14. The path 13 may be implemented as the S1 interface shown in Figure 1. The eNB 12 may also be coupled to another eNB via data / control path 15, which may be implemented as the X2 interface shown in Figure 1.

At least one of the PROGs 10C and 12C is assumed to include program instructions that, when executed by the associated DP, enable the device to operate in accordance with the exemplary embodiments of this invention, as will be discussed below in greater detail.

That is, the exemplary embodiments of this invention may be implemented at least in part by computer software executable by the DP 10A of the UE 10 and/or by the DP 12A of the eNB 12, or by hardware, or by a combination of software and hardware (and

firmware).

For the purposes of describing the exemplary embodiments of this invention the UE 10 may be assumed to also include a RACH function or module 10E, and the eNB 12 also includes a corresponding RACH function or module 12E, both of which are configured for operation in accordance with the exemplary embodiments of this invention.

In general, the various embodiments of the UE 10 can include, but are not limited to, cellular telephones, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, image capture devices such as digital cameras having wireless communication capabilities, gaming devices having wireless communication capabilities, music storage and playback appliances having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, as well as portable units or terminals that incorporate combinations of such functions.

The computer readable MEMs 10B and 12B may be of any type suitable to the local technical environment and 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 DPs 10A and 12A may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on multi-core processor architectures, as non-limiting examples.

Figure 2B illustrates further detail of an exemplary UE 10 in both plan view (left) and sectional view (right), and the invention may be embodied in one or some combination of those more function-specific components. At Figure 2B the UE 10 has a graphical display interface 20 and a user interface 22 illustrated as a keypad but understood as also encompassing touch-screen technology at the graphical display interface 20 and voice-recognition technology received at the microphone 24. A power actuator 26 controls the device being turned on and off by the user. The exemplary UE 10 may have a

camera 28 which is shown as being forward facing (e.g., for video calls) but may alternatively or additionally be rearward facing (e.g., for capturing images and video for local storage). The camera 28 is controlled by a shutter actuator 30 and optionally by a zoom actuator 30 which may alternatively function as a volume adjustment for the speaker(s) 34 when the camera 28 is not in an active mode.

Within the sectional view of Fig. 2B are seen multiple transmit/receive antennas 36 that are typically used for cellular communication. The antennas 36 may be multi-band for use with other radios in the UE. The operable ground plane for the antennas 36 is shown by shading as spanning the entire space enclosed by the UE housing though in some embodiments the ground plane may be limited to a smaller area, such as disposed on a printed wiring board on which the power chip 38 is formed. The power chip 38 controls power amplification on the channels being transmitted and/or across the antennas that transmit simultaneously where spatial diversity is used, and amplifies the received signals. The power chip 38 outputs the amplified received signal to the radio-frequency (RF) chip 40 which demodulates and downconverts the signal for baseband processing. The baseband (BB) chip 42 detects the signal which is then converted to a bit stream and finally decoded. Similar processing occurs in reverse for signals generated in the apparatus 10 and transmitted from it.

Signals going to and from the camera 28 pass through an image/video processor 44 that encodes and decodes various image frames. A separate audio processor 46 may also be present controlling signals to and from the speakers 34 and the microphone 24. The graphical display interface 20 is refreshed from a frame memory 48 as controlled by a user interface chip 50 which may process signals to and from the display interface 20 and/or additionally process user inputs from the keypad 22 and elsewhere.

Certain embodiments of the UE 10 may also include one or more secondary radios such as a wireless local area network radio WLAN 37 and a Bluetooth® radio 39, which may incorporate an antenna on-chip or be coupled to an off-chip antenna. Throughout the apparatus are various memories such as random access memory RAM 43, read only memory ROM 45, and in some embodiments removable memory such as the illustrated

memory card 47 on which the various programs 10C are stored. All of these components within the UE 10 are normally powered by a portable power supply such as a battery 49. The processors 38, 40, 42, 44, 46, 50, if embodied as separate entities in a UE 10 or eNB 12, may operate in a slave relationship to the main processor 10A, 12A, which may then be in a master relationship to them. Embodiments of this invention may be localized, or they may be embodied across various chips and memories as shown, or disposed within another processor that combines some of the functions described above for Figure 2B. Any or all of these various processors of Fig. 2B access one or more of the various memories, which may be on-chip with the processor or separate from the processor. Similar function-specific components that are directed toward communications over a network broader than a piconet (e.g., components 36, 38, 40, 42-45 and 47) may also be disposed in exemplary embodiments of the access node 12, which may have an array of tower-mounted antennas rather than the two shown at Fig. 2B.

Note that the various integrated circuits (e.g., chips 38, 40, 42, etc.) that were described above may be combined into a fewer number than described and, in a most compact case, may all be embodied physically within a single chip.

Describing now in further detail the exemplary embodiments of this invention, there is provided an improvement over the present Random Access (RA) procedure of LTE Rel. 8. The overall procedure is presented in Figure 3. In a first step of the procedure, the UE 10 transmits a preamble sequence on a frequency and time resource reserved for preambles. The UE 10 then searches for a preamble response indicating that the base station (eNB 12) has observed the preamble and that the UE 10 is allowed to continue the RA procedure. This invention provides an efficient scheme for signaling of the preamble responses.

The exemplary embodiments of this invention enable bundling of the responses that are sent for preambles observed in different time and frequency resources. This minimizes the use of PDCCH resources, as is clearly made evident in Figure 4. In the conventional approach a PDCCH resource is needed either for each preamble or for each group of preambles sent in the same time and frequency resource. In the exemplary embodiments

of this invention an index to the relevant time and frequency resource is included in the PRACH response message.

The preambles may be indexed by a 6-bit sequence index and a frequency and time resource index. If one assumes the maximum time window of the response is 10 ms, as it is presently specified, at most 4 bits are needed for the indication of the time and frequency resource, as there are at most 10 PRACH resources in the 10 ms response window. In the presently specified E-UTRAN system a RA-RNTI is reserved for each frequency and time resource (within a 10 ms window). However, in accordance with the exemplary embodiments of this invention only one RA-RNTI is needed.

Figure 4 illustrates in the context of four RACH response windows the difference between the conventional (current solution) and the new solution, in accordance with the exemplary embodiments of this invention, and shows the relationship of the RA-RNTI to PRACHs in an UpPTS or an UL subframe. After transmitting the preamble the UE 10 searches for a PDCCH entry addressed (indexed) with the RA-RNTI. When such is found, the UE 10 checks if the corresponding PDSCH message contains a response corresponding to the preamble sequence of the UE 10, and the frequency and time of the preamble.

In Figure 4 (and Figure 6, configuration 0) the RACH response window 1 is associated with the S (special) subframe, while the RACH response windows 2, 3, 4 are associated with first, second and third U (uplink) subframes following the S subframe. In Figure 7 (configuration 1) the RACH response window 1 is associated with the S (special) subframe, while the RACH response windows 2 and 3 are associated with first and second (uplink) subframes following the S subframe. It should be noted that, although here drawn in the same figure, according to present specifications preambles are sent either in S or normal UL subframes, but not in both.

In those cases where there are fewer DL subframes in the UL/DL frame configuration, e.g., configurations 0, 1, and 6 of Table 4.2-2 of 3GPP TS 36.211 V8.4.0, reproduced above, the responses are as shown in, for example, Figures 6 and Figure 7, wherein one

PDCCH resource is used for up to 10 PRACHs in a 10 ms window. By using the bundling method of this invention on message 2 in responses to PRACHs, the use of these exemplary embodiments conserve PDCCH resources and avoid the undesirable delay as described in reference to Figure 4.

While these exemplary embodiments may also be applied to UL/DL frame configurations 2, 3, 4 and 5 of Table 4.2-2 of 3GPP TS 36.211 V8.4.0, reproduced above, they are particularly advantageous for use with configurations 0, 1, and 6 which have fewer DL opportunities (subframes).

The dashed lines in the Figures 4, 5, 6 and 7 indicate the response to a short RACH. The exemplary embodiments of this invention bundle the message 2 and thus conserve DL resources, and the location of the response to the short RACH is within its response window. That is, the location of the response to the short RACH does not necessarily have to occur in the same PDCCH as a normal subframe, as the short RACH and normal RACH cannot coexist.

The exemplary embodiments of this invention may also be used in the FDD system, when there are several PRACH time resources per 10 ms. By allowing some additional delay, responses to preambles observed in different subframes can be bundled in order to save PDCCH resources. Figure 8 illustrates the concept of bundled responses to preambles for FDD.

The implementation of these exemplary embodiments preferably includes a modification to the MAC layer preamble response header on the PDSCH. Figure 9 shows a currently specified E-UTRAN MAC layer header format of the preamble response, and depicts the header and associated resource fields. The header includes n 8-bit signal fields, each of which contains a six bit wide preamble sequence index field and is associated with a 48-bit resource field (wherein is conveyed system access-related information, for example, the timing advance (TA) and T-CRNTI).

Figure 10 illustrates a modification made to the MAC layer preamble response message

to as to provide an expanded header, in accordance with one non-limiting embodiment of the invention, where a 4-bit resource indexing field is added in the header and through which are mapped the corresponding resource field bits. This structure preserves as much as possible from the present signaling scheme, maintaining the byte aligned resource field. When there is an even number of bundled responses the header is also byte aligned. When the number of bundled responses is odd, the header includes four bits of padding. In order to find its resource field, the UE 10 first goes through the signal fields and checks if its preamble sequence index appears there. If the UE 10 finds a matching sequence index, it checks the corresponding frequency and time index field. If the frequency and time index field also matches with those of the transmitted preamble, the UE 10 reads the corresponding resource field.

Alternatively, it is within the scope of these exemplary embodiments to extend the resource field from 48 bits to 52 bits, and directly map from the header field to the corresponding resource field bits.

In either case the additional bits are used for indicating the frequency and time resource of the observed preamble at the eNB 12. Note that as presently specified 56 bits are transmitted on the PDSCH per preamble, and thus the use of these exemplary embodiments implies only a 7% increased signaling load on the PDSCH, which is favorable considering the possible savings of PDCCH resources.

One specific advantage and technical effect that is gained by the use of these exemplary embodiments is a conservation of PDCCH resources. This translates into the presence of fewer constraints for resource allocation, and the elimination of the possible delay that can result from a high density of PRACH messages associated with the limited PDCCH resources. While these advantages may be most evident with TDD UL/DL configurations 0, 1, or 6, the other TDD UL/DL configurations of 2, 3, 4 and 5 can also benefit, as may FDD implementations.

It can be noted that while these exemplary embodiments have been described primarily in the context of the E-UTRAN system, they are not limited for use with only E-UTRAN.

For example, they may be used as well for beyond-Release 8 versions of E-UTRAN (e.g., Release 9, Release 10), and may be especially beneficial in further releases of 3GPP LTE targeted towards future wireless communication systems, which may be referred to for convenience simply as LTE-Advanced (LTE-A). For example, reference can be made to 3GPP TR 36.913, V8.0.0 (2008-06), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Release X).

Based on the foregoing it should be apparent that the exemplary embodiments of this invention provide a method, apparatus and computer program(s) to conserve downlink physical control channel resources, and reduce delays, during random access procedures conducted between a base station and a plurality of user equipment.

As a review, in accordance with conventional practice there is the identity RA-RNTI that is associated with a RACH time-frequency resource. When the UE transmits a preamble, it searches a PDCCH that has been addressed with a RA-RNTI corresponding to the frequency and time of the transmitted preamble. This addressing takes place such that the CRC of the PDCCH is masked with RA-RNTI. The PDCCH points to the response message in the PDSCH. In the response message there is a header that lists the sequence indexes that have been observed. These consume 6 bits of the 8-bit "Signal. 1...n" fields. In addition there is a 1-bit "extension" field that is used for showing the last row of the header. The remaining bit is reserved for future use. The actual access information is then read from the k :th resource field if the matching sequence index found from the "Signal. k " header field.

According to the exemplary embodiments of this invention, instead of associating N RA-RNTIs with N time-frequency resources, just one RA-RNTI need be used for indicating that a PDCCH is a PDCCH for random access response. The associated PDSCH indicates the observed preamble sequence, and the time-frequency resource. Each UE 10 checks the PDCCH within its response window, where the response window is, for example, at most 10 ms long and begins 2 ms after the subframe where the preamble ends. The bundled preamble response is composed such that all bundled responses are

within their respective response windows.

Figure 5 is a logic flow diagram that illustrates the operation of a method, and a result of execution of computer program instructions, in accordance with the exemplary embodiments of this invention. In accordance with these exemplary embodiments a method performs, at Block 5A, a step of receiving random access preamble sequences individual ones of which are associated with one of a plurality of time and frequency resources. At Block 5B there is a step of bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single transmitted downlink control channel assignment and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message, including placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

Figure 11 is a logic flow diagram that illustrates the operation of a further method, and a result of execution of computer program instructions, in accordance with the exemplary embodiments of this invention. In accordance with these exemplary embodiments a method performs, at Block 11A, a step of transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence. The method further includes, at Block 11B, a step of receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble..

The various blocks shown in Figures 5 and 11 may be viewed as method steps, and/or as operations that result from operation of computer program code, and/or as a plurality of coupled logic circuit elements constructed to carry out the associated function(s), such as the functions of the RACH modules 10E and 12E of Figure 2A.

In general, the various exemplary embodiments may be implemented in hardware or special purpose circuits, software, logic or any combination thereof. For example, some aspects may be implemented in hardware, while other aspects may be implemented in firmware or software which may be executed by a controller, microprocessor or other computing device, although the invention is not limited thereto. While various aspects of the exemplary embodiments of this invention may be illustrated and described as block diagrams, flow charts, or using some other pictorial representation, it is well understood that these blocks, apparatus, systems, techniques or methods described herein may be implemented in, as non-limiting examples, hardware, software, firmware, special purpose circuits or logic, general purpose hardware or controller or other computing devices, or some combination thereof.

It should thus be appreciated that at least some aspects of the exemplary embodiments of the inventions may be practiced in various components such as integrated circuit chips and modules, and that the exemplary embodiments of this invention may be realized in an apparatus that is embodied as an integrated circuit. The integrated circuit, or circuits, may comprise circuitry (as well as possibly firmware) for embodying at least one or more of a data processor or data processors, a digital signal processor or processors, baseband circuitry and radio frequency circuitry that are configurable so as to operate in accordance with the exemplary embodiments of this invention.

Various modifications and adaptations to the foregoing exemplary embodiments of this invention may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings. However, any and all modifications will still fall within the scope of the non-limiting and exemplary embodiments of this invention.

It should be noted that the terms "connected," "coupled," or any variant thereof, mean any connection or coupling, either direct or indirect, between two or more elements, and may encompass the presence of one or more intermediate elements between two elements that are "connected" or "coupled" together. The coupling or connection between the elements

can be physical, logical, or a combination thereof. As employed herein two elements may be considered to be "connected" or "coupled" together by the use of one or more wires, cables and/or printed electrical connections, as well as by the use of electromagnetic energy, such as electromagnetic energy having wavelengths in the radio frequency region, the microwave region and the optical (both visible and invisible) region, as several non-limiting and non-exhaustive examples.

Further, the various names used for the described parameters (e.g., RA-RNTI) are not intended to be limiting in any respect, as these parameters may be identified by any suitable names. Further, any formulas and expressions that use these various parameters may differ from those expressly disclosed herein. Further, the various names assigned to different channels (e.g., PRACH, PDCCH, PDSCH, etc.) are not intended to be limiting in any respect, as these various channels may be identified by any suitable names.

Furthermore, some of the features of the various non-limiting and exemplary embodiments of this invention may be used to advantage without the corresponding use of other features. As such, the foregoing description should be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

CLAIMS

What is claimed is:

1. A method, comprising:

receiving random access preamble sequences individual ones of which are associated with one of a plurality of time and frequency resources; and

bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single transmitted downlink control channel assignment and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

2. The method of claim 1, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in a medium access control message, each index field identifying one combination of time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

3. The method of claim 1, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in an m -bit resource field in a medium access control message, each index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

4. The method of either claims 2 or 3, where $n=4$ and $m=48$.

5. A computer readable medium that stores program instructions, the execution of which by a controller results in operations comprising:

in response to receiving random access preamble sequences, individual ones of which are associated with one of a plurality of time and frequency resources, bundling random access preamble responses that are received for random access preambles in different time and frequency resources by transmitting a single transmitted downlink control channel assignment and indicating by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and placing in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

6. The computer readable medium of claim 5, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in a medium access control message, each index field identifying one combination of time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

7. The computer readable medium of claim 5, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in an m -bit resource field in a medium access control message, each index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

8. The computer readable medium of either claims 6 or 7, where $n=4$ and $m=48$.

9. An apparatus, comprising:

a controller configured to operate with a wireless receiver and a wireless transmitter, said controller further configured to respond to receiving random access preamble sequences, individual ones of which are associated with one of a plurality of time and frequency resources, to bundle random access preamble responses that are received for random access preambles in different time and frequency resources by composing a single transmitted downlink control channel assignment and indicating by using a radio network

temporary identity that the assignment is an assignment for a preamble response message, said controller further configured to place in an associated downlink shared channel message a plurality of preamble responses individual ones of which are indexed by the preamble sequences and frequency and time resources associated with each of the random access preambles.

10. The apparatus of claim 9, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in a medium access control message, each index field identifying one combination of time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

11. The apparatus of claim 9, where the plurality of preamble responses are indexed by inclusion of an n -bit index field in an m -bit resource field in a medium access control message, each index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

12. The apparatus of either claims 10 or 11, where $n=4$ and $m=48$.

13. A method, comprising:

transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence; and

receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

14. The method of claim 13, where the preamble response is indexed by an n -bit index field in a medium access control message, the index field identifying one combination of

time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

15. The method of claim 13, where the preamble responses is indexed by an n -bit index field in an m -bit resource field in a medium access control message, the index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

16. The method of either claims 14 or 15, where $n=4$ and $m=48$.

17. A computer readable medium that stores program instructions, the execution of which by a controller results in operations comprising:

transmitting a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence; and

receiving a downlink control channel assignment that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, and locating in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

18. The computer readable medium of claim 17, where the preamble response is indexed by an n -bit index field in a medium access control message, the index field identifying one combination of time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

19. The computer readable medium of claim 13, where the preamble responses is indexed by an n -bit index field in an m -bit resource field in a medium access control message, the index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

20. The computer readable medium of either claims 18 or 19, where $n=4$ and $m=48$.

21. An apparatus, comprising:

a controller configured to operate with a wireless receiver and a wireless transmitter, said controller further configured to transmit a random access preamble using one of a plurality of time and frequency resources, the random access preamble including a preamble sequence, said controller further configured to respond to receiving a downlink control channel assignment, that indicates by using a radio network temporary identity that the assignment is an assignment for a preamble response message, to locate in an associated downlink shared channel message a corresponding preamble response indexed by the preamble sequence and frequency and time resources used for transmitting the random access preamble.

22. The apparatus of claim 21, where the preamble response is indexed by an n -bit index field in a medium access control message, the index field identifying one combination of time and frequency resources and being associated with one m -bit resource field of the medium access control message that comprises system access-related information.

23. The apparatus of claim 21, where the preamble responses is indexed by an n -bit index field in an m -bit resource field in a medium access control message, the index field identifying one combination of time and frequency resources, the m -bit resource field comprising system access-related information.

24. The apparatus of either claims 22 or 23, where $n=4$ and $m=48$.

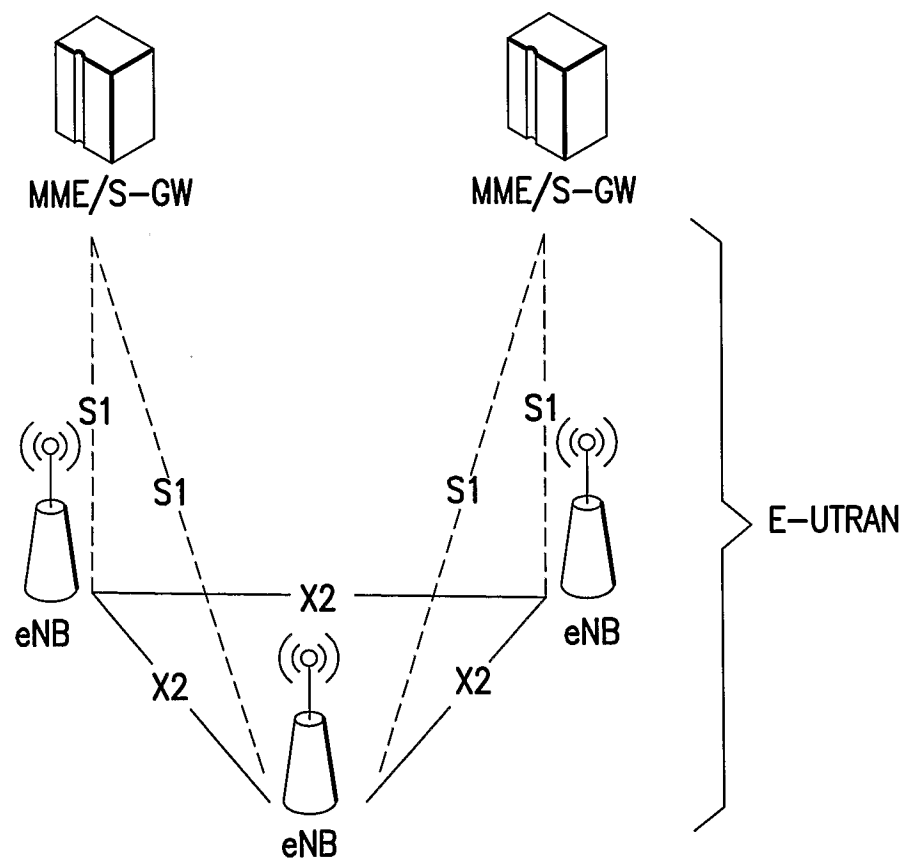
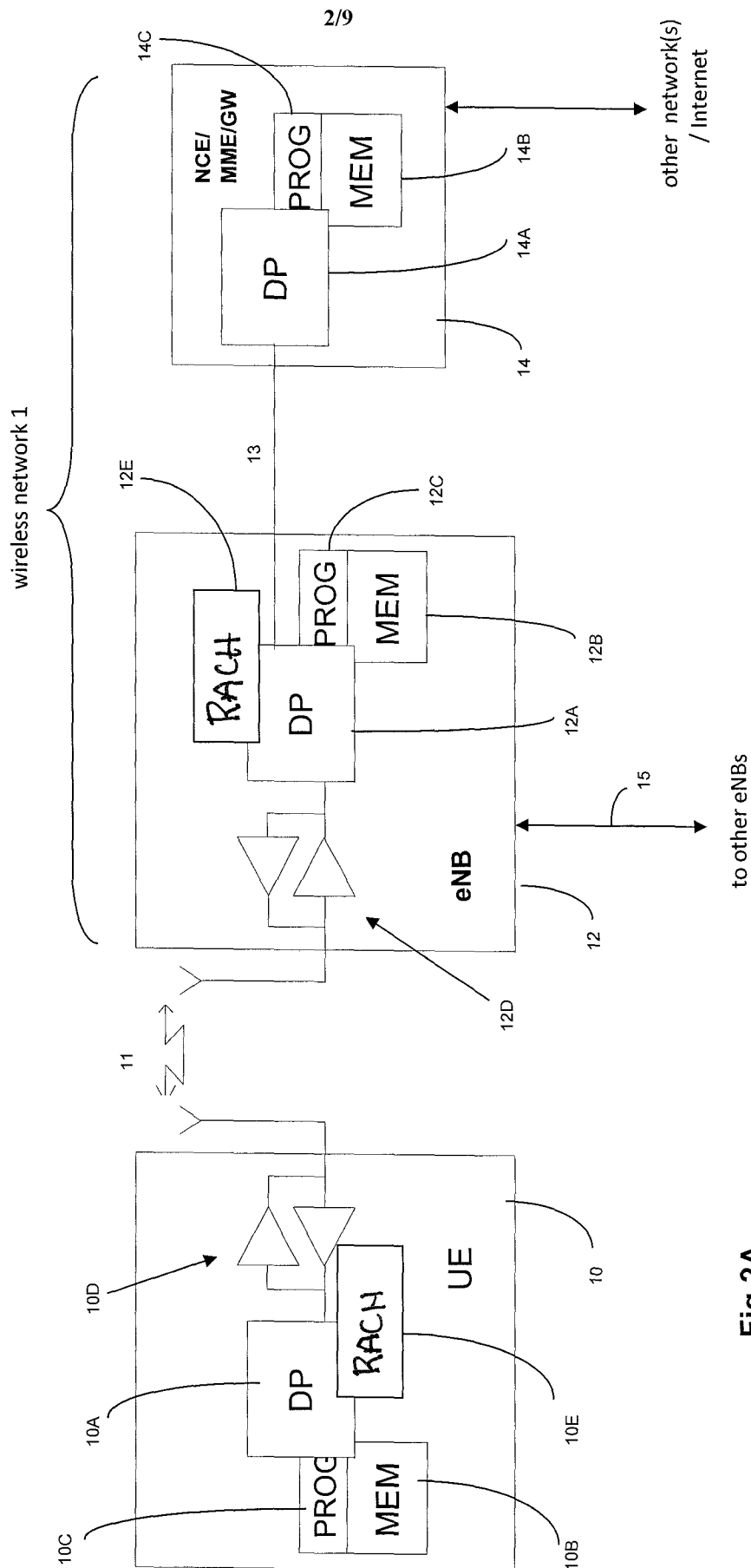


FIG.1
PRIOR ART



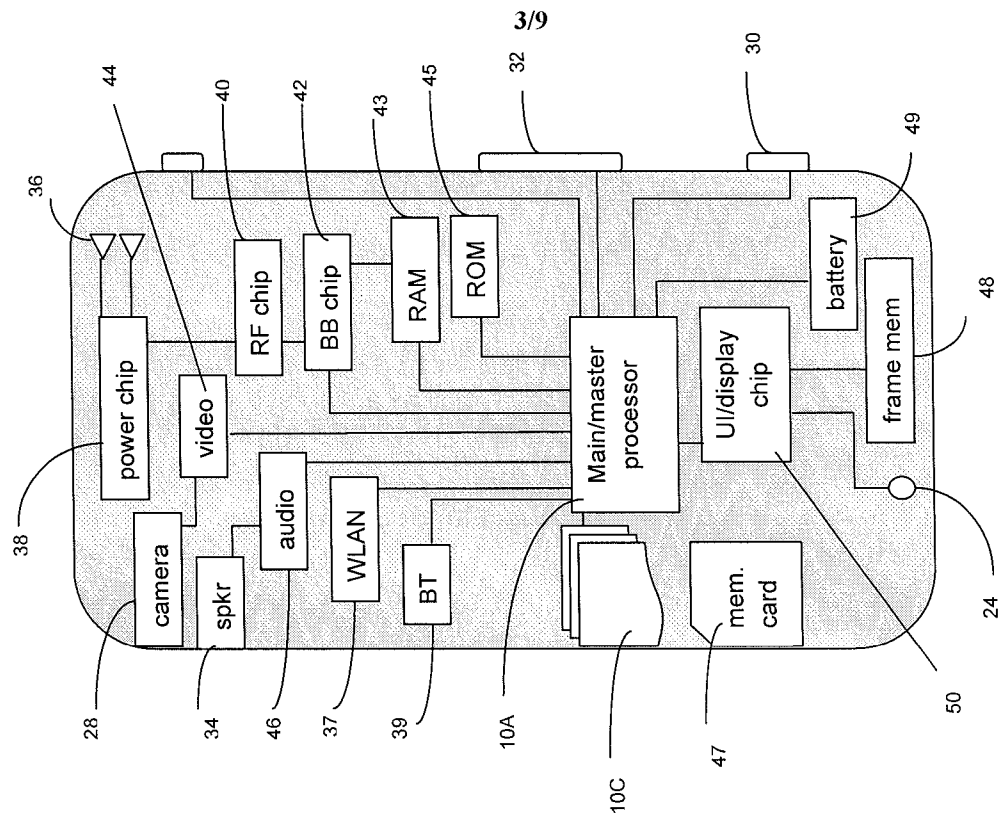
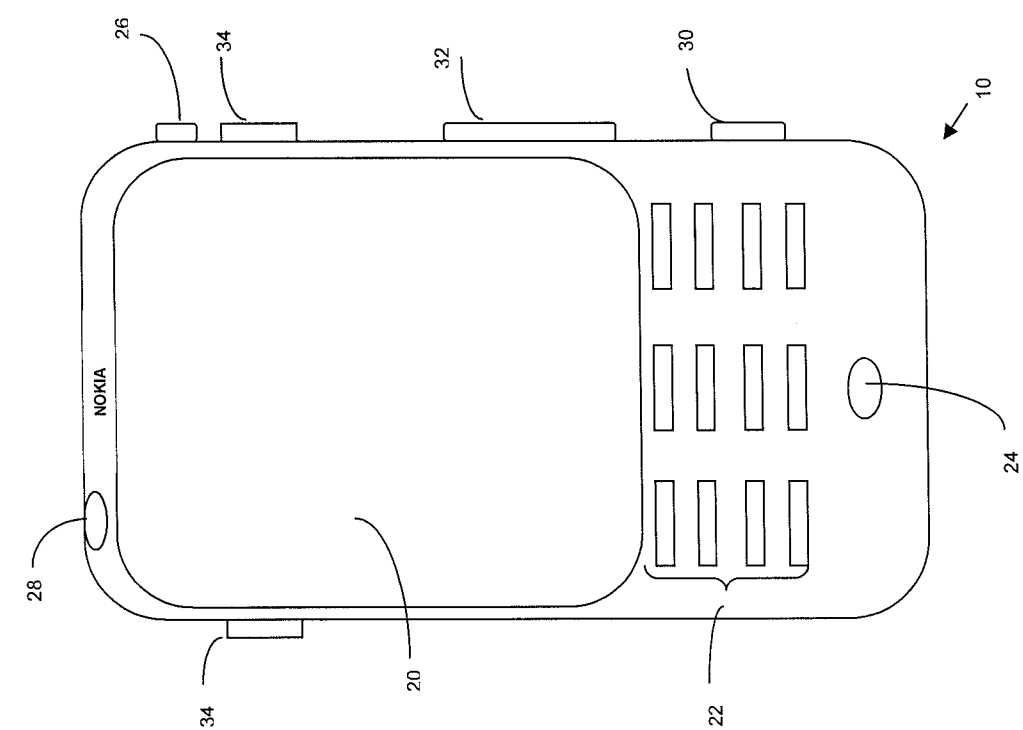


Fig 2B



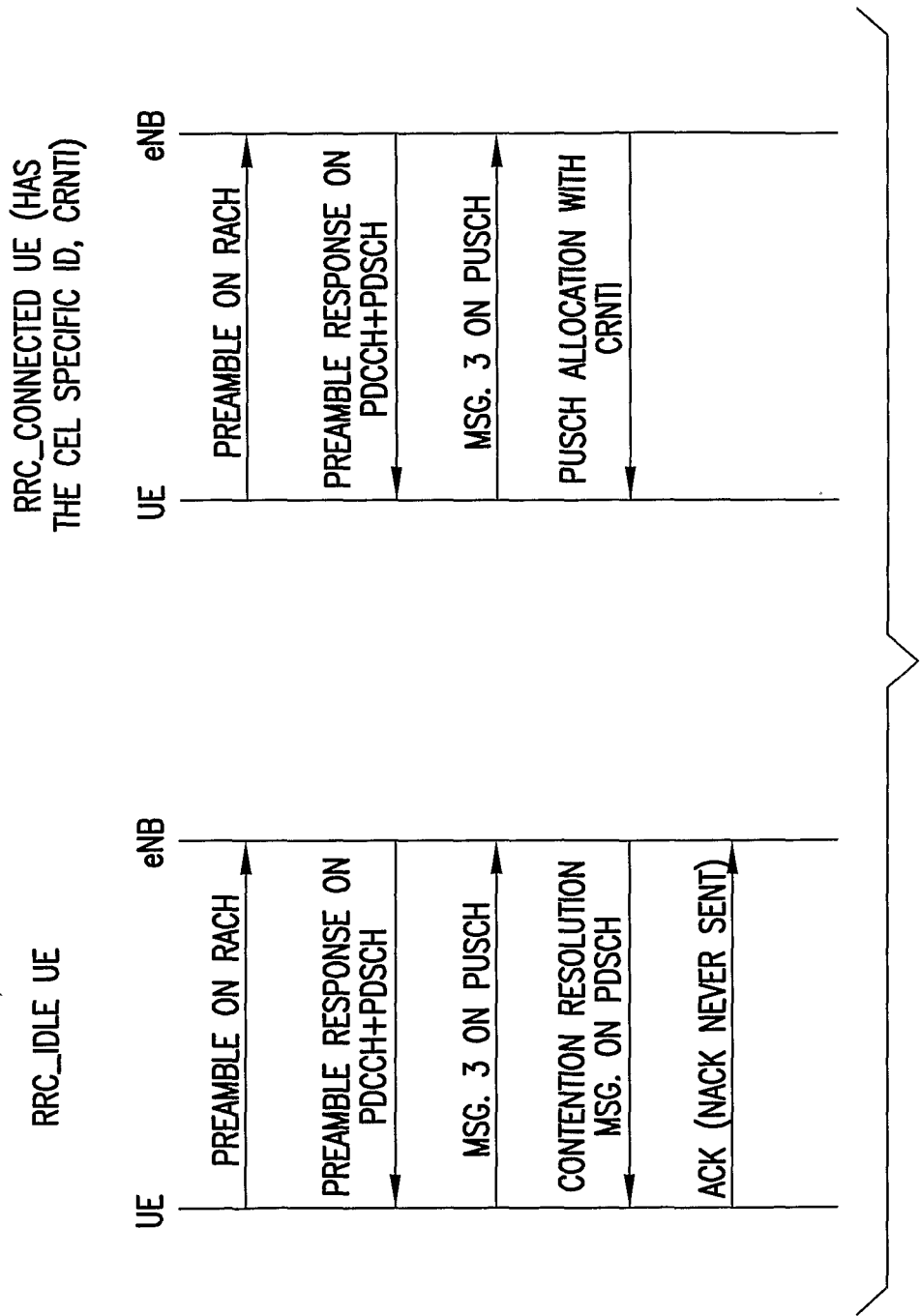


FIG.3

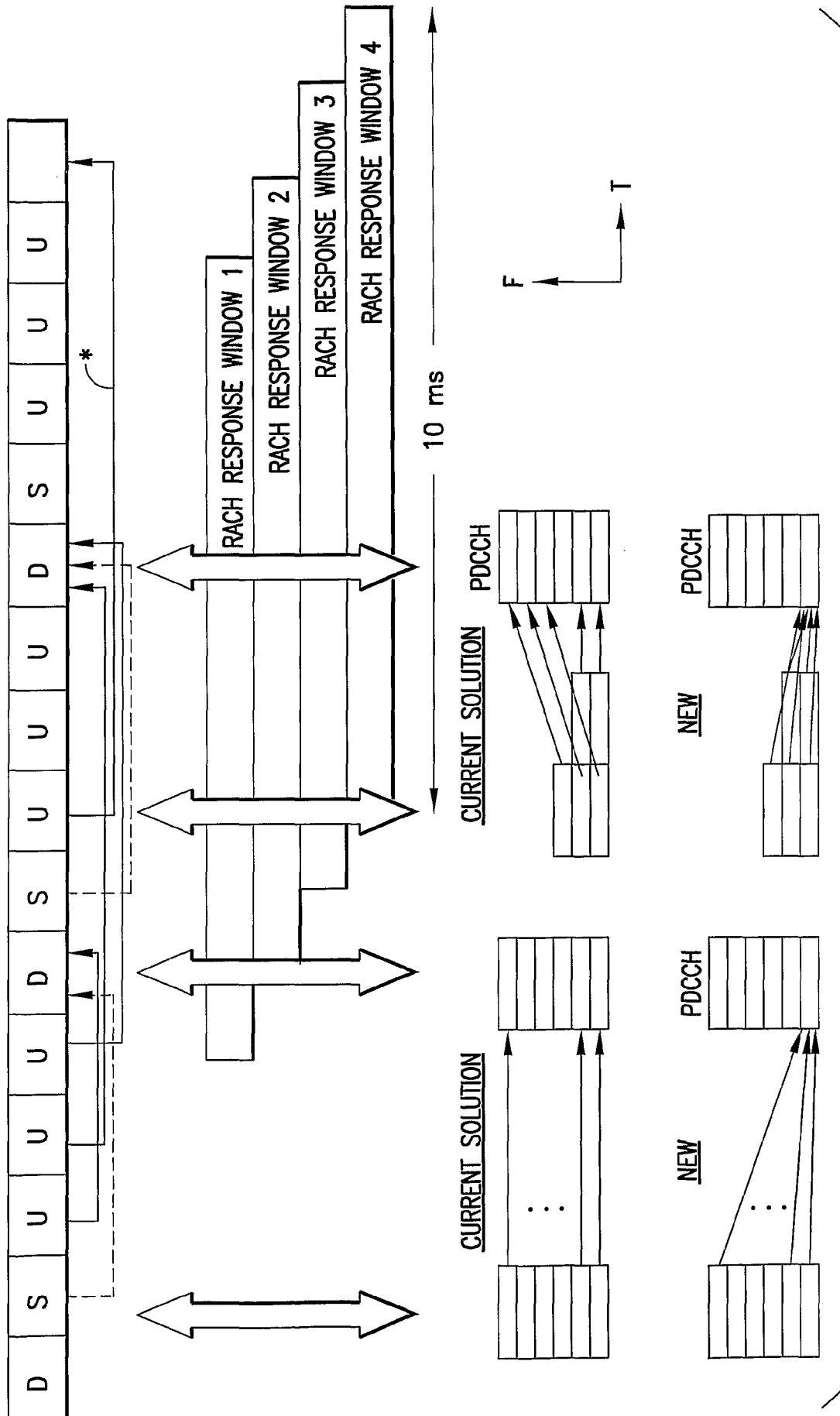
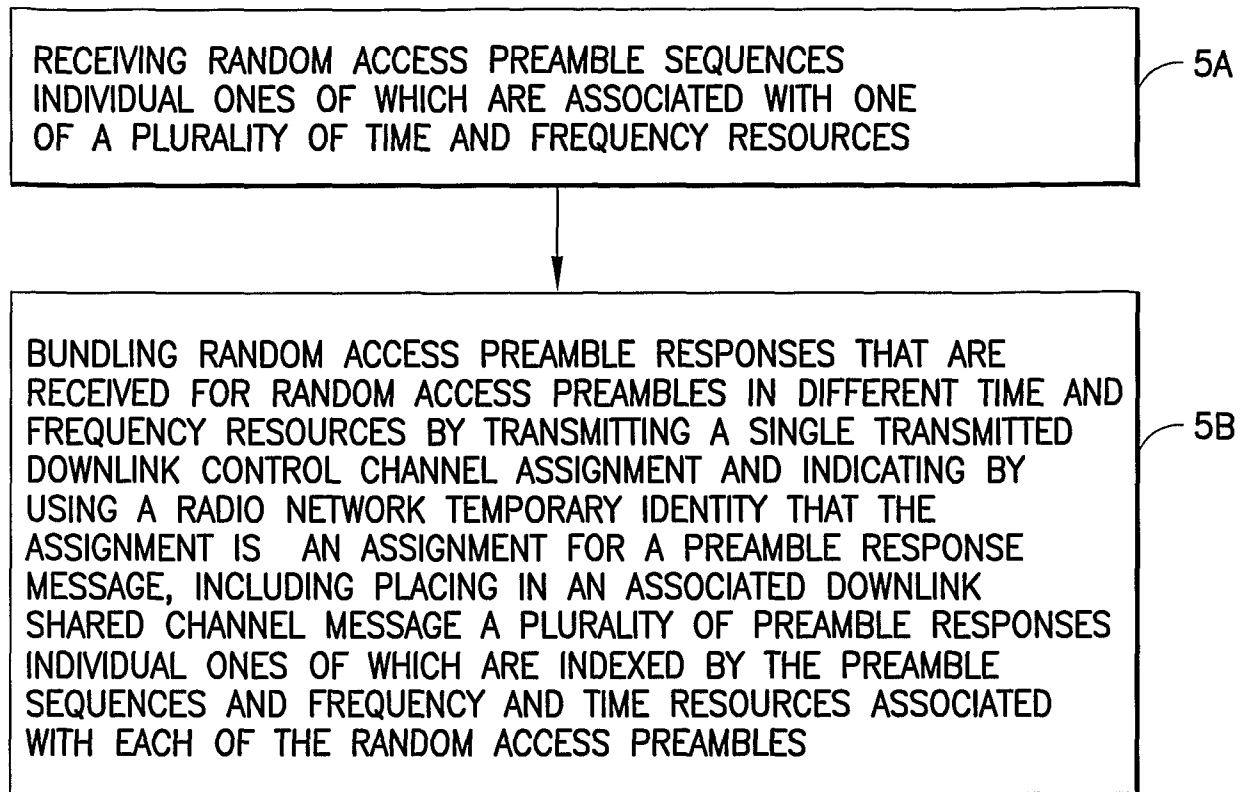
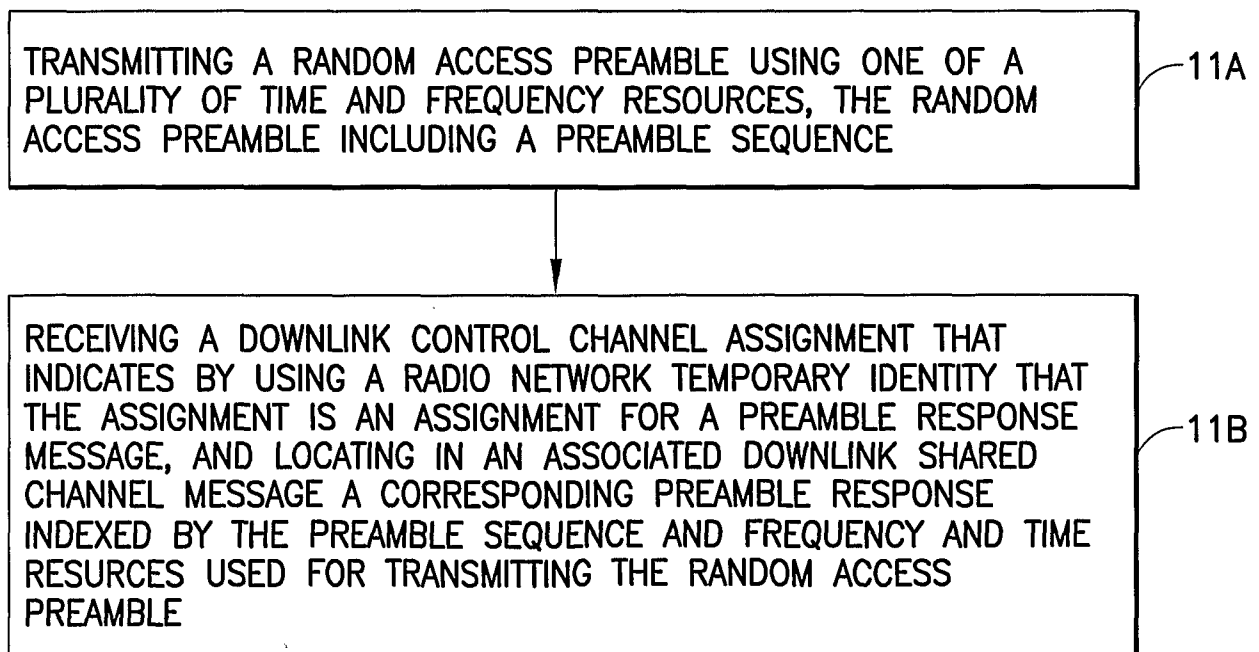


FIG.4

**FIG.5****FIG.11**

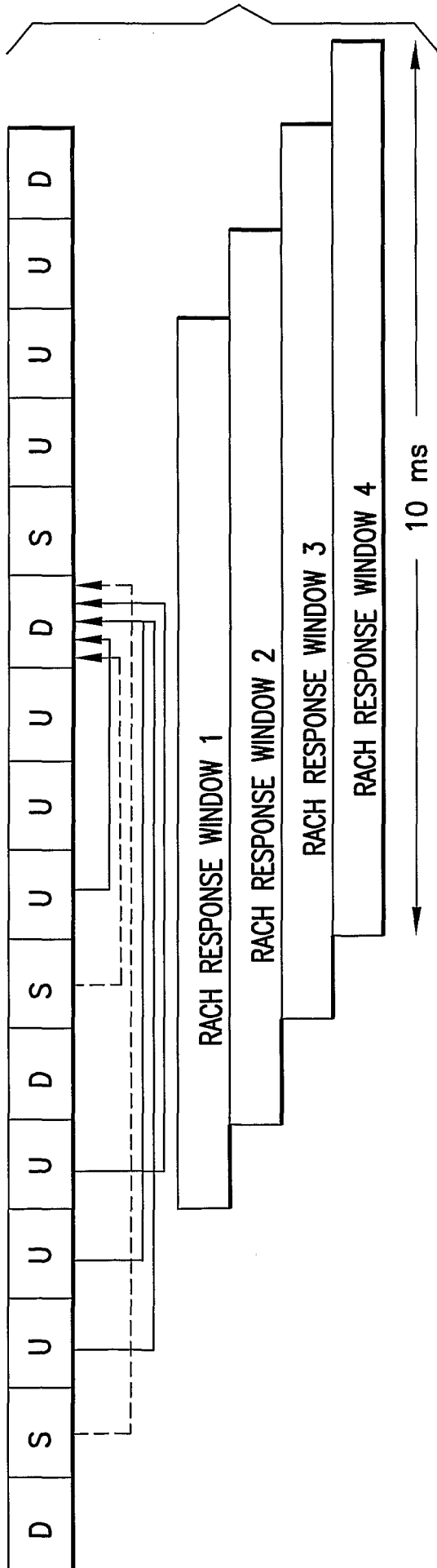


FIG. 6

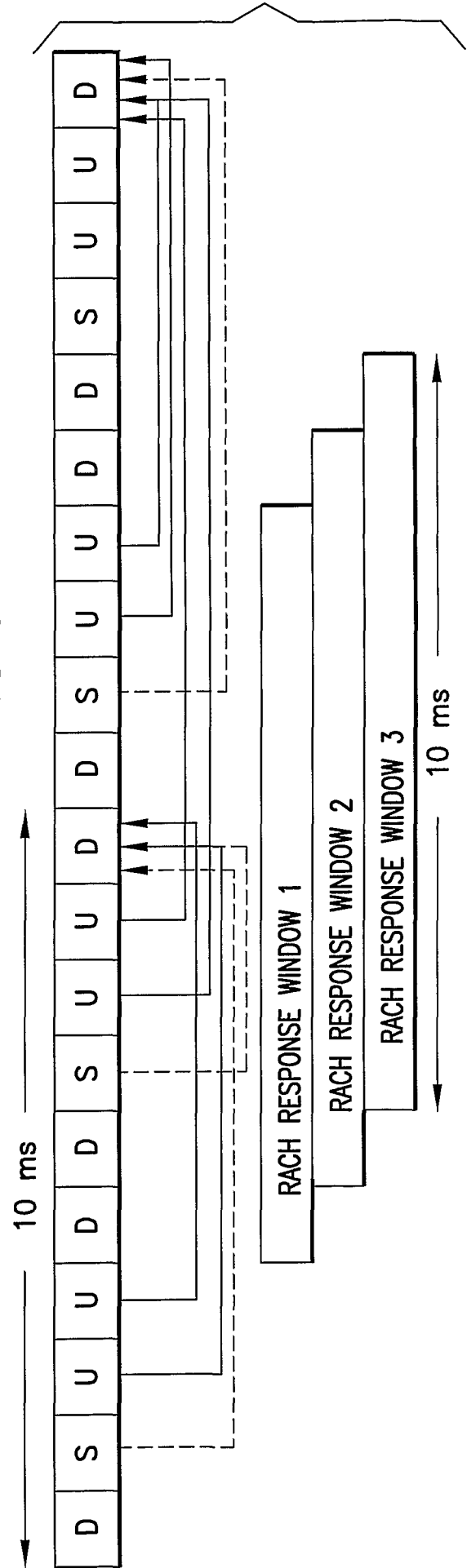


FIG. 7

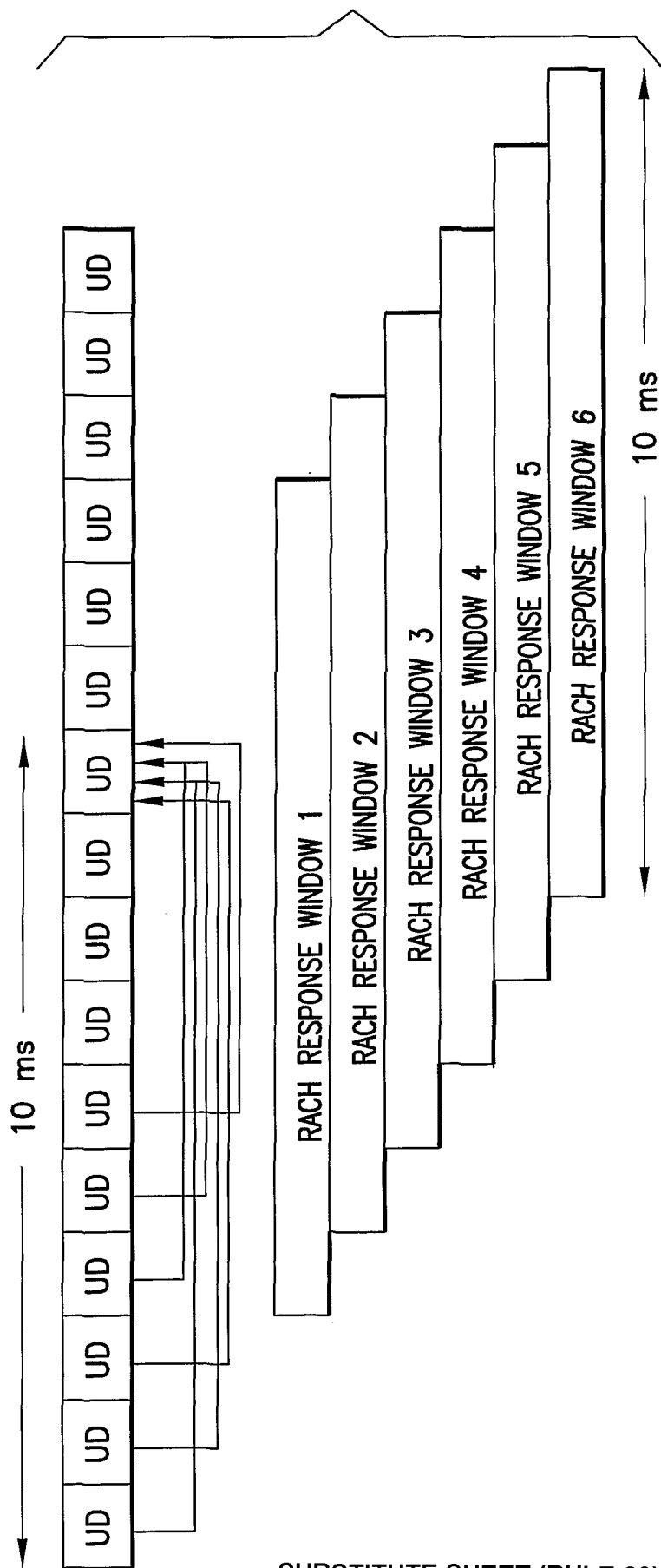
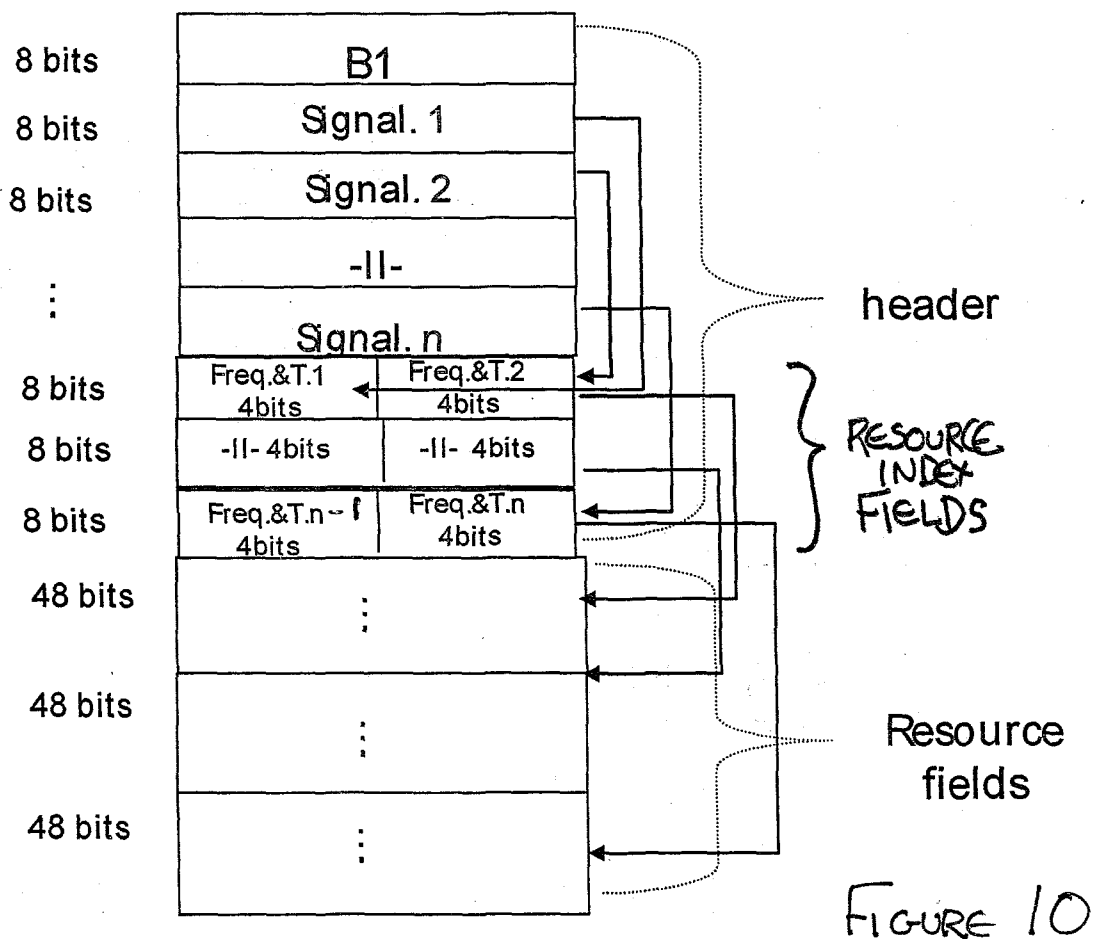
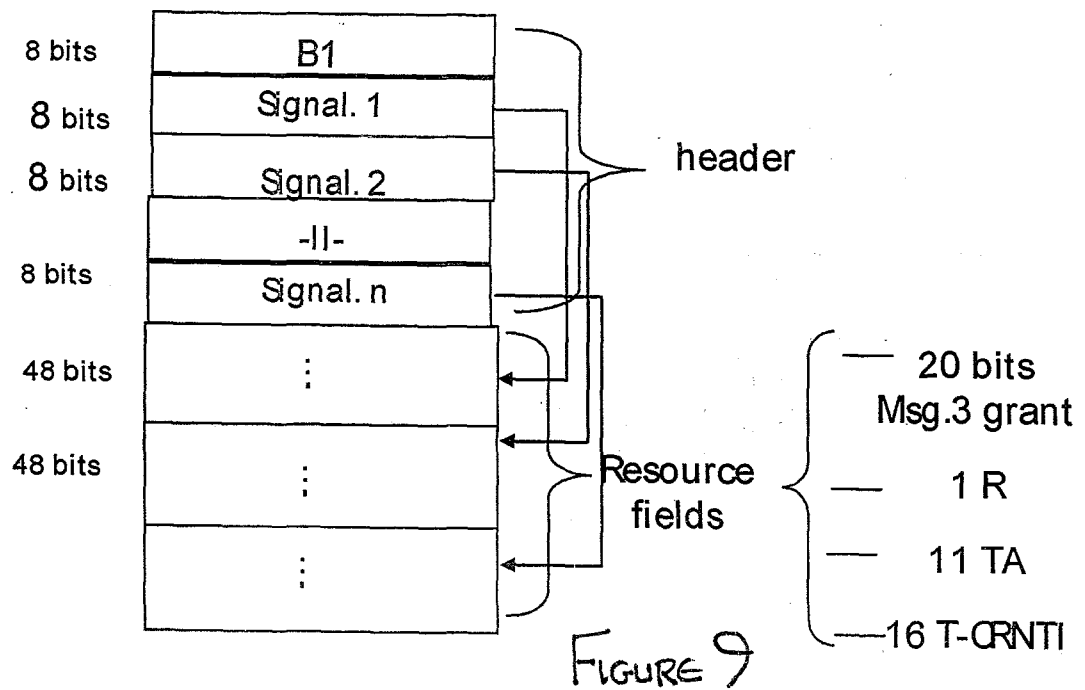


FIG.8



INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2008/054680

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W74/08

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/206531 A1 (PAJUKOSKI KARI [FI] ET AL) 6 September 2007 (2007-09-06) paragraph [0037] - paragraph [0040] -----	1,5,9, 13,17,21
Y	WO 2008/042967 A (QUALCOMM INC [US]; DAMNJANOVIC ALEKSANDAR [US]; MONTOJO JUAN [US]; MAL) 10 April 2008 (2008-04-10) paragraph [0031] - paragraph [0035] -----	1,5,9, 13,17,21
A	WO 97/13379 A (MOTOROLA INC [US]) 10 April 1997 (1997-04-10) page 2, line 7 - line 17 page 3, line 19 - line 36 -----	1-24



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

24 August 2009

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2008/054680

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