Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2825592 C 2016/04/19

(11)(21) 2 825 592

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(22) Date de dépôt/Filing Date: 2001/11/15

(41) Mise à la disp. pub./Open to Public Insp.: 2002/05/23

(45) Date de délivrance/Issue Date: 2016/04/19

(62) Demande originale/Original Application: 2 723 065

(30) Priorité/Priority: 2000/11/15 (US60/249,065)

(51) Cl.Int./Int.Cl. *H04W 72/04* (2009.01),
H04W 72/12 (2009.01)

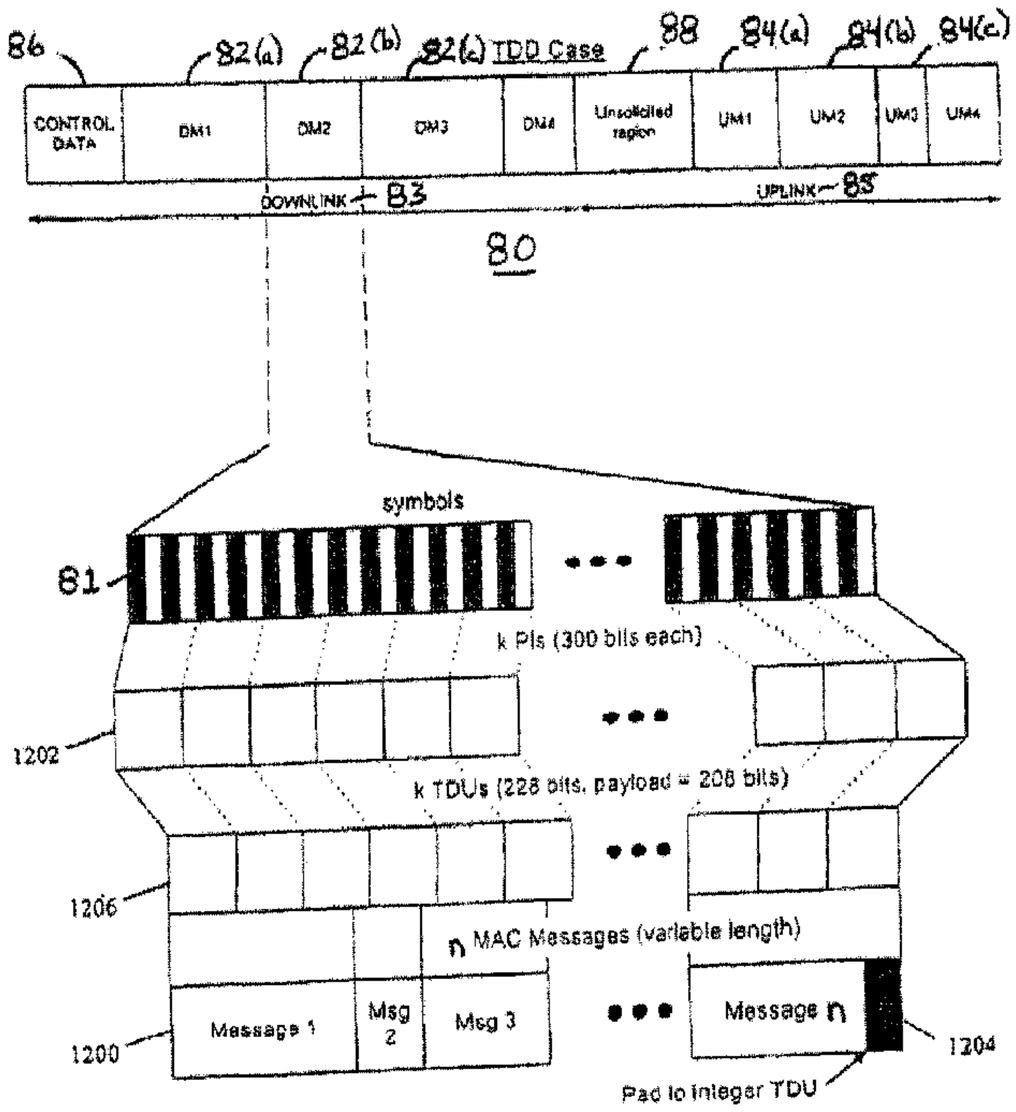
(72) Inventeurs/Inventors:
CHEN, AN, US;
KLEIN, ISRAEL J., US;
STANWOOD, KENNETH L., US;
LIN, GEORGE, US

(73) Propriétaire/Owner:
WI-LAN, INC., CA

(74) Agent: AGENCEDEBREVETS.CA
PATENTAGENCY.CA

(54) Titre : VERROUILLAGE DE TRAME AMELIORE POUR SYSTEME DE COMMUNICATION A MODULATION ADAPTATIVE

(54) Title: IMPROVED FRAME STRUCTURE FOR COMMUNICATION SYSTEM USING ADAPTIVE MODULATION



(57) Abrégé/Abstract:
A system and method for mapping a combined frequency division duplexing (FDD) Time Division Multiplexing (TDM)/Time Division Multiple Access (TDMA) downlink subframe for use with half-duplex and full-duplex terminals in a communication system. Embodiments of the downlink subframe vary Forward Error Correction (FED) types for a given modulation scheme as well as support the implementation of a smart antennae at a base station in the communication system. Embodiments of the system are also used in a TDD communication system to support the implementation of smart antennae. A scheduling algorithm allows TDM and TDMA portions of a downlink to efficiently co-exist in the same downlink subframe and simultaneously support full and half-duplex terminals. The algorithm further allows the TDM of multiple terminals in a TDMA burst to minimize the number of map entries in a downlink map. The algorithm limits the number of downlink map entries to not exceed 2n + 1, where n is the number of DL PHY modes (modulation/FEC combinations) employed by the communication system.

ABSTRACT

A system and method for mapping a combined frequency division duplexing (FDD) Time Division Multiplexing (TDM)/Time Division Multiple Access (TDMA) downlink subframe for use with half-duplex and full-duplex terminals in a communication system. Embodiments of the downlink subframe vary Forward Error Correction (FED) types for a given modulation scheme as well as support the implementation of a smart antennae at a base station in the communication system. Embodiments of the system are also used in a TDD communication system to support the implementation of smart antennae. A scheduling algorithm allows TDM and TDMA portions of a downlink to efficiently co-exist in the same downlink subframe and simultaneously support full and half-duplex terminals. The algorithm further allows the TDM of multiple terminals in a TDMA burst to minimize the number of map entries in a downlink map. The algorithm limits the number of downlink map entries to not exceed 2n + 1, where n is the number of DL PHY modes (modulation/FEC combinations) employed by the communication system.

TITLE OF THE INVENTION

IMPROVED FRAME STRUCTURE FOR A COMMUNICATION SYSTEM USING ADAPTIVE MODULATION

[0001] This application is a division of Canadian patent application Serial No. 2,723,065 which is a divisional application of Canadian Patent Application Serial No. 2,467,700.

FIELD OF THE INVENTION

[0002] This invention relates to frame structures for communication systems and more particularly to frame structures for adaptive modulation wireless communication systems.

DESCRIPTION OF RELATED ART

[0003] A wireless communication system facilitates two-way communication between a plurality of subscriber units (fixed and portable) and a fixed network infrastructure. Exemplary communication systems include mobile cellular telephone systems, personal communication systems (PCS), and cordless telephones. The key objective of these wireless communication systems is to provide communication channels on demand between the plurality of consumer subscriber units and their respective base stations in order to connect the subscriber unit user with the fixed network infrastructure.

[0004] Subscriber units typically communicate through a terminal with the base station using a "duplexing" scheme thus allowing the exchange of information in both directions of connection. Transmissions from the base station to the terminals are commonly referred to as "downlink" transmissions. Transmissions from the terminals to the base station are commonly referred to as "uplink" transmissions. In wireless systems having multiple access schemes a time "frame" is used as the basic information transmission unit.

[0005] Depending upon the design criteria of a given system, systems have typically used either time division duplexing (TDD) or frequency division duplexing

(FDD) methods to facilitate the exchange of information between the base station and the terminals. In a TDD communication system, the base station and the terminals use the same channel, however, their downlink and uplink transmissions alternate one after the other to prevent interference. In a FDD communication system, the base station and the terminals use different channels for their downlink and uplink transmissions, respectively. Thus, the concern for interference between uplink and downlink transmissions is mitigated in a FDD communication system as compared to a system using TDD. However, the increased cost and complexity in deploying a FDD communication system often outweighs this obvious advantage over a TDD communication system.

[0006] In both TDD and FDD systems, each base station and terminal includes a modem configured to modulate an outgoing signal and demodulate an incoming signal. If the modem is configured to modulate and demodulate simultaneously, the modem is a "full-duplex" modem. If the modem is not configured to modulate and demodulate simultaneously, but rather switches between modulating and demodulating, the modem is a "half-duplex" modem.

[0007] In an exemplary FDD communication system, each terminal's modem operates simultaneously to transmit and receive information in a full-duplex manner. Such a terminal can continually receive data from the base station. By continually receiving information, the terminal is able to maintain its synchronization with the base station. By maintaining its synchronization, the terminal is less dependent on the base station transmitting control information and preambles to assist the terminal in locating its data within the downlink.

[0008] Because a half-duplex terminal does not receive information from the base station when the terminal transmits it uplink to the base station, it may fall out of synchronization with the base station. When this occurs, the terminal may require the base station to downlink additional control information or a preamble to allow the terminal to re-synchronize prior to it receiving downlink data from the base station.

SUMMARY OF THE INVENTION

[0009] The systems and methods have several features, no single one of which is solely responsible for its desirable attributes. Without limiting the scope as expressed by

the claims which follow, its more prominent features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled "Detailed Description" ne will understand how the features of the system and methods provide several advantages over traditional framing techniques.

[0010] According to a first broad aspect there is disclosed a method for scheduling modulation/forward error correction (PHY) modes for a frequency division duplex (FDD) communication system which includes a plurality of terminals and a base station, both configured to communicate using adaptive modulations in a downlink subframe and an uplink subframe, with each of the plurality of terminals having an associated preferred downlink PHY mode, D_1, D_2,... D_N, wherein D_1, is a most robust modulation and DN is a least robust modulation, and wherein each of the plurality of terminals and their associated preferred downlink PHY mode have an associated uplink PHY mode, U_1, U_2, U_N, and wherein U_1 is associated with the plurality of terminals that have the preferred downlink PHY mode D_1, and wherein UN is associated with the plurality of terminals that have the preferred downlink PHY mode DN, such that a number of downlink map entries does not exceed 2N + 1, the method comprising: grouping the plurality of terminals based on preferred downlink PHY modes; allocating uplink bandwidth in an uplink subframe such that the plurality of terminals are put in order of their preferred downlink PHY modes, from a second most robust preferred downlink PHY mode and continuing in order of decreasing robustness with a most robust preferred downlink PHY mode last; allocating the plurality of terminals that use a D_1 PHY mode to begin at a start of a downlink subframe; if a time duration of the D, PHY mode is less than a time duration of a U_2 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use a D_2 PHY mode, beginning at a time that the U_2 PHY mode ends; if the time duration of the D_1, PHY mode is greater than or equal to the time duration of the U_2 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_2 PHY mode, beginning at an end of the D_1 PHY mode; if a time duration of the D_2 PHY mode is less than a time duration of a U_3 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use a D_3 PHY mode, beginning at a time that the U_3 PHY mode ends; if the time duration of the D_2 PHY mode is greater than or equal to the time duration of the U_3 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_3 PHY mode, beginning

at an end of the D_2 PHY mode; if the time duration of the D_3 PHY mode is greater than the sum of a time duration of a U_4 PHY mode, a U_5 PHY mode, and a U_1 PHY mode, segmenting the plurality of terminals that use the D_3 PHY mode and inserting the segments into any gaps in the downlink subframe; if a time duration of the D_3 PHY mode is less than a time duration of the U_4 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use a D_4 PHY mode, beginning at a time that the U_4 PHY mode ends; if the time duration of the D_3 PHY mode is greater than or equal to the time duration of the U_4 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_4 PHY mode, beginning at an end of the D_3 PHY mode; if a time duration of the D_4 PHY mode is less than a time duration of the U_5 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use a D_5 PHY mode, beginning at a time that the U_5 PHY mode ends; if the time duration of the D_4 PHY mode is greater than or equal to the time duration of the U_5 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_5 PHY mode, beginning at an end of the D_4 PHY mode; the time duration of the plurality of terminals that use the D_5 PHY mode is longer in duration than a combined time duration of the U_1 PHY mode and gaps that are not aligned with the U_5 PHY mode, rearranging allocated downlink bandwidth of the downlink subframe to accommodate a remainder of the D_5 PHY mode such that the remainder is not aligned with the U_5 PHY mode; and if the time duration of the plurality of terminals that use the D_5 PHY mode is shorter in duration than the combined time duration of the U_1 PHY mode and the gaps that are not aligned with the U_5 PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_5 PHY mode beginning at the end of the D_4 PHY mode and also interleaved in the gaps in the downlink subframe.

[0011] According to another broad aspect there is disclosed a method for scheduling modulation/forward error correction (PHY) modes for a frequency division duplex (FDD) communication system which includes a plurality of terminals and a base station, both configured to communicate using adaptive modulations in a downlink subframe and an uplink subframe, with each of the plurality of terminals having an associated preferred downlink PHY mode, D_1, D_2,... D_N, wherein D_1 is a most robust modulation and D_N is a least robust modulation, and wherein each of the plurality of terminals and their associated preferred downlink PHY mode have an associated uplink

PHY mode, U_1, U_2, U_N, and wherein U_1 is associated with the plurality of terminals that have the preferred downlink PHY mode D_1, and wherein U_N is associated with the plurality of terminals that have the preferred downlink PHY mode D_N, such that a number of downlink map entries does not exceed 2N + 1, the method comprising: grouping the plurality of terminals based on preferred downlink PHY modes; allocating uplink bandwidth in an uplink subframe such that the plurality of terminals are put in order of their preferred downlink PHY modes, from a second most robust preferred downlink PHY mode and continuing in order of decreasing robustness with a most robust preferred downlink PHY mode last; allocating the plurality of terminals that use a D_1 PHY mode to begin at a start of a downlink subframe; if a time duration for the plurality of terminals that have a D_N PHY mode is less than a time duration for the plurality of terminals that are assigned to a U_{N+1} PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_N PHY mode, beginning at a time that a U_N PHY mode ends; if the time duration for the plurality of terminals that have the D_N PHY mode is greater than or equal to the time duration for the plurality of terminals that are assigned to the U_{N+1} PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_N PHY mode, beginning at an end of a D_{N-1} PHY mode; if the time duration of the plurality of terminals that have the D_N PHY mode is longer in duration than a combined time duration of a U_1 PHY mode and gaps that are not aligned with the U_N PHY mode, rearranging downlink bandwidth of the downlink subframe to accommodate a remainder of the D_N PHY mode such that the remainder is not aligned with the U_N PHY mode; and if the time duration of the plurality of terminals that have the D_N PHY mode is shorter in duration than the combined time duration of the U_1 PHY mode and the gaps that are not aligned with the U_N PHY mode, allocating bandwidth of the downlink subframe to the plurality of terminals that use the D_N PHY mode, beginning at the end of the D_{N-1} PHY mode and also interleaved in the gaps in the downlink subframe.

[0012] According to a third broad aspect there is disclosed a method for scheduling physical slots within a downlink subframe for a first receiver and a second receiver, each receiver assigned to a operate with a level of robustness, the receivers receiving data from a single transmitter in an adaptive modulation communication system, the method comprising: providing data for a first receiver which have been assigned a level of robustness including a combination of modulation and forward error correction

(FEC) types in a time division multiplex (TDM) section of the downlink subframe having a combination of modulation and FEC at least as robust as the level assigned to the particular recipient receiver; and providing data for a second receiver in a Time Division Multiple Access (TDMA) section of the downlink subframe which provides a combination of modulation and FEC which is at least as robust as a level assigned to the receiver.

[0013] Still other aspects include methods and systems for use in a TDD communication system to support the implementation of smart antennae.

[0013a] According to a fourth broad aspect, there is disclosed a base station for wirelessly communicating with a plurality of terminals. The base station includes a receiver configured to decode data received in an uplink sub-frame and a transmitter configured to encode data into a downlink sub-frame, and an antenna system including smart antennas for transmitting a downlink sub-frame using beam-forming. The downlink sub-frame includes control information, and at least two data blocks with downlink data. The control information includes a preamble for synchronizing the base station with terminals scheduled to receive data in the downlink sub-frame, scheduling information identifying transmission resources allocated to at least two terminals scheduled to receive data in the downlink sub-frame, and respective associated physical (PHY) modes. The at least two data blocks with downlink data are for the at least two terminals scheduled to receive data in the downlink sub-frame, each data block using the transmission resources identified by the control information, the downlink data in each data block of the at least two data blocks being encoded according to the respective associated PHY mode. The control information is transmitted to the scheduled terminals using a PHY mode having a level of robustness which is at least as robust as a level of robustness that is compatible with the plurality of terminals. In some embodiments, the smart antennas are configured such that a first smart antenna transmits a first downlink sub-frame, and a second smart antenna transmits a second downlink sub-frame substantially simultaneously with the first downlink sub-frame. In some embodiments, the scheduling information comprises a downlink sub-frame map with downlink events pertaining to downlink data transmitted to terminals scheduled to receive data in the downlink sub-frame and an uplink sub-frame map with uplink events pertaining to uplink data received from terminals scheduled for uplink transmission. In some embodiments, the receiver is configured to decode the uplink data received from the terminals scheduled for uplink transmission, according to the uplink sub-frame map. In some embodiments, the transmitter is configured to encode the downlink sub-frame map and the uplink sub-frame map as a TDM signal. In some embodiments, the transmitter is configured to encode the uplink sub-frame map and the downlink sub-frame map as an OFDM signal. In some embodiments, the at least two data blocks with downlink data are modulated on sub-carriers. In some embodiments, the base station is operable to determine the associated PHY mode for a terminal of the at least two terminals based on the quality of a wireless link established between the base station and

the terminal. In some embodiments, the quality of the wireless link includes one or more of interference minimization, propagation delays and round trip delays. In some embodiments, the transmitter is further configured to change the associated PHY mode for a terminal of the at least two terminals based on the current quality of the wireless link. In some embodiments, the base station is operable to determine the associated PHY mode for a terminal of the at least two terminals based on the capabilities of the terminal. In some embodiments, the associated PHY mode comprises an UL modulation parameter used for encoding data in a respective data block of the at least two data blocks.

[0013b] According to a fifth broad aspect, there is disclosed a method of operating a base station for wireless communications with a plurality of terminals. The method includes encoding control information using a physical (PHY) mode having a level of robustness which is at least as robust as a level of robustness that is compatible with the plurality of terminals, decoding uplink data from an uplink sub-frame, encoding downlink data into a downlink sub-frame, and transmitting the downlink sub-frame using beam-forming. The downlink sub-frame has control information and at least two data blocks. The control information includes a preamble for synchronizing the base station with terminals scheduled to receive data in the downlink sub-frame, scheduling information identifying transmission resources allocated to at least two terminals scheduled to receive data in the downlink sub-frame, and respective associated physical (PHY) modes. The at least two data blocks with downlink data is for the at least two terminals, each data block using the transmission resources identified by the control information, the downlink data in each data block of the at least two data blocks being encoded according to the respective associated PHY mode. In some embodiments, the method includes transmitting a first downlink sub-frame from a first smart antenna, and transmitting a second downlink sub-frame from a second smart antenna substantially simultaneously with the first downlink sub-frame. In some embodiments, the scheduling information comprises a downlink sub-frame map with downlink events pertaining to downlink data transmitted to the terminals scheduled to receive data in the downlink sub-frame and an uplink sub-frame map with uplink events pertaining to uplink data received from terminals scheduled for uplink transmission. In some embodiments, the method includes decoding the uplink data received from the terminals scheduled for uplink transmission according to the uplink sub-frame map. In some embodiments, the method includes encoding the downlink sub-frame map and the uplink sub- frame map as a TDM signal. In some embodiments, the uplink sub-frame map and the downlink sub-frame map are encoded as an OFDM signal. In some embodiments, the least two data blocks with downlink data are modulated on sub-carriers. In some embodiments, the base station determines the associated PHY mode for a terminal of the at least two terminals based on the quality of a wireless link established between the base station and the terminal. In some embodiments, the quality of the wireless link includes one or more of interference minimization, propagation delays and round trip delays. In some embodiments, the transmitter changes the associated PHY

mode for a terminal of the at least two terminals based on the current quality of a wireless link established between the base station and the terminal. In some embodiments, the base station determines the associated PHY mode for a terminal of the at least two terminals based on the capabilities of the terminal. In some embodiments, the associated PHY mode comprises an UL modulation parameter used for encoding data in a respective data block of the at least two data blocks.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIGURE 1 is a diagram of a configuration of a communication system with a base station and several associated terminals.

[0015] FIGURE 2 is a diagram of an exemplary time division duplex ("TDD") frame structure along with an exemplary mapping structure.

[0016] FIGURE 3 is a block diagram of an exemplary transmitter.

[0017] FIGURE 4 is a block diagram of an exemplary receiver.

[0018] FIGURE 5 is the TDD frame structure from FIGURE 2 adapted for FDD operation.

[0019] FIGURE 6 shows an arrangement for user data from multiple terminals in a TDM time block.

[0020] FIGURE 7 shows a downlink conflict for a FDD unit restricted to half duplex operation.

[0021] FIGURE 8 is a mapping diagram for a combined FDD TDM/TDMA downlink subframe.

[0022] FIGURE 9 shows an exemplary downlink map structure.

[0023] FIGURE 10 shows an exemplary relationship between frame mapping data and the data it maps for a FDD communication system.

[0024] FIGURE 11 is a mapping diagram for an FDD TDM/TDMA downlink subframe which varies PHY modes based on modulation and FEC.

[0025] FIGURE 12 is a mapping diagram for a TDD TDM/TDMA downlink subframe that supports smart antennae.

[0026] FIGURE 13 is a flow chart for a scheduling algorithm.

[0027] FIGURE 14 shows an ordering of uplink PHY modes, U_2, U_3, U_4, U_5, U_1, within an uplink subframe.

[0028] FIGURE 15 represents the situation where the duration of downlink PHY mode D_1 equals or exceeds the duration of uplink PHY mode U_2.

[0029] FIGURE 16 represents the converse case to FIGURE 15, in which the duration of downlink PHY mode D_1 is less than the duration of uplink PHY mode U_2.

[0030] FIGURE 17 represents the situation where the duration of uplink PHY mode U_3 exceeds the duration of downlink PHY mode D_2.

[0031] FIGURE 18 represents the situation where the duration of downlink PHY mode D_3 exceeds the combined duration of uplink PHY modes U_4, U_5, and U_1.

[0032] FIGURE 19 represents the situation where the duration of downlink PHY mode D_3 is less than the duration of uplink PHY mode U_4.

[0033] FIGURE 20 represent the situation where the duration of downlink PHY mode D_4 is less than the duration of uplink PHY mode U_5.

[0034] FIGURE 21 represents a scheduling of downlink PHY mode D_5 within the downlink subframe that results in PHY mode D_5 having to transmit while it receives.

[0035] FIGURE 22 represents further rearrangement of downlink PHY mode D_5 with downlink PHY mode D_3 so that downlink PHY mode D_5 does not transmit while it receives.

DETAILED DESCRIPTION

[0036] The following detailed description is directed to certain specific embodiments of the invention. However, the invention can be embodied in a multitude of different systems and methods. In this description, reference is made to the drawings wherein like parts are designated with like numerals throughout.

[0037] FIGURE 1 is a diagram of an exemplary cell 10 that includes a base station 20 located centrally in cell 10 and a plurality of terminals 30, 32, 34, 36, 38 associated with the base station. FIGURE 1 does not show buildings or other physical obstructions (such as trees or hills, for example), that may cause channel interference between signals of the terminals. The terminals and the base station communicate by transmitting radio frequency signals. The term channel is used to mean a band or range of radio frequencies of sufficient width for communication, e. g., 26.500 GHz to 26.525 GHz (a 25 MHz wide channel). Although the following discussion relates to a system that transmits information within the Local Multi-Point Distribution Services (LMDS) band at frequencies of approximately 28 GHz, the system is not so limited. Embodiments of the system are designed to transmit information between the terminals and base station at frequencies, for example, of 10 GHz to 66 GHz using Quadrature Amplitude Modulation (QAM) symbols. The base station and terminals use adaptive modulation and forward error correction (FEC) schemes to communicate. Adaptive modulation, or adaptable modulation density, includes varying the bit per symbol rate modulation scheme, or modulation robustness, of signals transmitted between a terminal and a base station. Adaptive FEC includes varying the amount of error correction data that is transmitted in the signal. Both the modulation and FEC can be adapted independently to transmit data between the base station and terminals. For ease of explanation, the phrase "PHY mode" is used to indicate a combination of a selected modulation scheme with a selected FEC.

[0038] The systems and methods described herein can also be implemented in a Multichannel Multi- point Distribution Service (MMDS) which operates below 10 GHz. In the MMDS, Orthogonal Frequency Division Multiplexing (OFDM) symbols may be transmitted between the base station and terminals as an alternative to QAM modulation. In such a system, the methods and systems are applied to one or more of the OFDM subchannels.

[0039] The PHY mode(s) selected for use in the cell 10 is normally determined as a function of the geographical relationship between the BS and the terminal, the rain region, and the implementation or modem complexity of the terminals. However, the selection of a single PHY mode based on the lowest bit per symbol rate modulation scheme and maximum FEC supported by all terminals may not optimize bandwidth utilization within the cell 10. In particular, better environmental conditions, e. g., less distance, between some terminals (such as units 38,30 for example) and the BS may permit the use of a less robust PHY mode that has an error level below the maximum desirable error level.

[0040] FIGURE 2 is diagram of an exemplary physical layer frame structure for use in the cell 10 that enables adaptive PHY modes to be employed. FIGURE 2 also illustrates a process for mapping data to the physical layer frame structure for transmission to one or more terminals. The PHY mode may be modified from frame to frame or remain constant for a plurality of frames for a particular terminal. Further, a terminal may select or indicate a preferred PHY mode.

[0041] Frame 80 includes a plurality of time blocks. The total time duration of the plurality of time blocks in frame 80 can vary. For example, time durations of 0.5 msec, 1 msec, and 2 msec could be used. In this example there are ten time blocks where the first through fifth time blocks are for a downlink subframe 83. The downlink subframe contains downlink data 82(a)-82(n) (from the base station 10 to one or more terminals). The sixth through tenth time blocks form an uplink subframe 85. The uplink subframe contains uplink data 84(a)-84(n) (to the base station 10 from one or more terminals). Data within a single time block is transmitted or received using a single PHY mode.

[0042] In this example, each downlink subframe time block has a different PHY mode, e. g. DM_1, DM_2, DM_3, and DM_4. The data transmitted using each downlink PHY mode is intended for one or more terminals. The receiving terminal will retrieve data that was transmitted using its preferred PHY mode and/or a more robust PHY mode. Many terminals may be assigned to any one downlink PHY mode where each terminal retrieves its data during the same time block based on an address or identifier. Consequently, a terminal may only retrieve data from a portion of a time block.

[0043] Still referring to FIGURE 2, the uplink subframe time blocks are associated with PHY modes, e. g. UM_1, UM_2, UM_3, and UM_4. Uplink time blocks are assigned to terminals for transmission of data from one or more terminals to the base station. Multiple terminals may be assigned to a single time block based on the terminals preferred PHY mode. For example, terminals 30, 38 could be assigned to UM_1. The length of the UM_1 will account for the bandwidth requirements of both terminals. In such a case, a transition gap (not shown) may be included between the portions of the uplink subframe time block, UM_1, that are assigned to the two terminals. The transition gap can include a preamble for the base station to synchronize with the transmitting terminal. As with the downlink PHY modes, an individual terminal may be assigned more than one uplink PHY mode.

[0044] The length, or duration, of each time block can vary. The PHY modes used for the data in each time block can also vary for each downlink and uplink time block between frames. Varying the time duration of the uplink and downlink time blocks, PHY modes, is generally useful, since uplink and downlink data amounts are likely to vary. The TDD frame structure may apply adaptive PHY modes only for the downlink and use a different scheme for the uplink. For example, a fixed modulation scheme could be used for the uplink. Conversely, a different scheme (e. g. fixed modulation) can be used on the downlink, while using adaptive PHY modes on the uplink.

[0045] A scheduling approach is used to arrange data from terminals within the frame 80. An uplink scheduling approach may be selected independently from the downlink scheduling approach. The uplink/downlink scheduling approaches may be based on physical layer issues, including interference minimization, propagation delays (including round trip delays), etc., as well as modulation use (specific ordering by PHY mode). Alternatively, the uplink/downlink scheduling approaches may be based completely on data traffic requirements and not on physical layer issues.

[0046] One downlink scheduling approach arranges the PHY modes such that DM_1 (most robust) $\leq DM_2 \leq DM_3 \leq DM_4$ (least robust). Thus, the data in the downlink subframe is arranged from the most robust PHY mode to the least robust PHY mode. Each terminal listens to its preferred PHY mode and any PHY modes that are more robust than its preferred PHY mode. The terminals receive all of the data they are capable of

receiving, and can keep or discard portions of the data depending on whether the data is intended for them. By using this scheduling approach, each terminal is able to maintain its synchronization with the base station from the start of the downlink subframe, through PHY modes that are more robust than its preferred PHY mode, and finally during its preferred PHY mode.

[0047] The uplink scheduling information may be conveyed to the terminals by a map through control data 86. The control data 86 may be located at the start of the downlink subframe 83. The control data 86 can indicate where the PHY mode transitions occur within the frame 80. A typical map is a list of time indicators pointing out transmission location (such as by referencing start and end, or start and length, or offsets relative to a previous transmission). The map can also include terminal identification associating the map entry with a specific terminal. The control data 86 can be encoded using the most robust PHY mode of the system. An exemplary downlink map is discussed below with reference to FIGURE 9.

[0048] Still referring to FIGURE 2, an unsolicited region 88 of the uplink subframe 85 is used by the terminals to communicate control information, such as, bandwidth and registration requests, to the base station. Information placed in the unsolicited region 88 can be encoded using the most robust PHY mode of the system. The unsolicited region 88 can be located at the beginning of the uplink subframe 85.

[0049] The downlink subframe 83 transmits the control data 86 along with downlink data 82 intended for one or more terminals. Downlink data symbols 81 are used for transmitting data to the terminals. The symbols may be grouped by the PHY mode, terminal identification, and user ID. For example, symbols 81 are grouped by PHY mode, DM2. Thus, the symbols 81 destined for terminals that are scheduled to receive during DM2 were modulated using the same PHY mode. Once grouped by PHY modes, each time block is transmitted in a pre-defined modulation sequence using a scheduling approach as previously discussed. For example, DM1 is QAM-4, DM2 is QAM-16, DM3 is QAM-64, and DM4 is QAM-256. In any downlink subframe 83, any one or more of the PHY modes may be absent.

[0050] The data transmitted during frame 80 is in the form of symbols 81. Communication systems that operate using the LMDS band map Quadrature Amplitude Modulation (QAM) symbols to each time block of frame 80. Alternatively, communication systems that operate using the MMDS band do the same or may map Orthogonal Frequency Division Multiplexing (OFDM) symbols to each time block of frame 80.

[0051] FIGURE 2 also shows an exemplary downlink mapping of a stream of variable length media access control (MAC) messages 1200 to symbols 81 for transmission during the frame 80. More specifically, the mapping shown in FIGURE 2 is used for messages intended for terminals with the same preferred PHY mode, DM2. One or more MAC messages 1200 are fragmented and packed into Transmission Convergence Data Units (TDUs) 1206. Each TDU 1206 includes downlink data 82 (b) in the form of i bits which may include Transmission Convergence (TC) layer overhead. Each TDU 1206 for a given PHY mode has a fixed length. For example, in FIGURE 2, each TDU is comprised of i = 228 bits which include 20 bits of TC overhead resulting in the ability to carry 208 bits of MAC message data. Forward error correction (FEC) j bits are added to the i bits of the TDU 1206 to form Physical Information (PI) elements 1202, alternatively called FEC blocks. Each PI element 1202 has a length of k bits (i bits + j bits). The addition of j bits reduces the likelihood of bit errors occurring during demodulation by the terminals. For example, the 228-bit TDUs 1206 can be mapped to 300-bit Pls 1202 by encoding the data in the TDUs 1206. The 228- bit TDU 1206 may be encoded using the well-known Reed-Solomon coding technique to create the 300-bit PI elements 1202. Other minimum quantities of the physical and logical units can be used without departing from the scope of the present invention.

[0052] Padding may be added to a MAC message to form an integer multiple of TDUs 1206. For example, FIGURE 2 shows padding being added to "message n" so that the result will form an integer multiple of TDUs 1206 and, therefore, an integer multiple of PI elements 1202. The padding can use a fill byte, for example, 0x55. Alternatively, the last PI element 1202 may be shortened, if allowed by the FEC, resulting in a shortened TDU. The process of producing shortened PI elements 1202, a. k. a. FEC blocks, is well-know in the arts.

[0053] The PI elements 1202 are then modulated using a modulation scheme to form symbols 81. For example, QAM symbols or OFDM symbols could be used. The number of symbols 81 required to transmit the PI elements 1202 may vary with the PHY mode selected. For example, if QAM-4 is used for DM2, each resulting symbol represents two bits. If QAM-64 is used for DM2, each resulting symbol represents six bits. For convenience, multiple symbols can be further mapped to a physical slot (PS) to decrease the granularity of the data allocation boundaries. For example, a 4-symbol physical slot could be used to decrease the number of bits required to express allocation boundaries in maps.

[0054] FIGURE 3 is a block diagram of functional elements of an exemplary transmitter 40. The transmitter 40 can include a convolutional encoder 42, a block encoder 44, a M-ary Modulator 46, and an up-converter 49. The transmitter 40 receives i bits of data and encodes the data, packs the encoded bits of data into frame 80 and upconverts the frame of data to a transmission frequency. The convolutional encoder 42 and block coder 44 supply the FEC data that converts the i bits of data into FEC blocks. For example, the convolutional encoder 42 can use a selected ratio to encode i bits of data. The block coder uses the selected code level to encode the convoluted data to produce FEC blocks.

[0055] Then, the M-ary QAM modulator converts the FEC blocks into QAM symbols based on the selected bit per symbol rate for each time block. The symbols can then be inserted into the frame 80 using a scheduling technique. Up-converter 49 frequency shifts the packed frame of data to a frequency suitable for transmission between a terminal and base station based on schemes known to those of skill in the art.

[0056] FIGURE 4 is a block diagram of functional elements of an exemplary receiver 50. The receiver 50 converts the frequency shifted frame of data back into groups of bits of data. The receiver 50 includes a down- converter 59, M-ary QAM demodulator 56, block decoder 54, and convolutional decoder 52. The down-converter 59 frequency shifts the received signal back to baseband using schemes known to those of skill in the art. Block decoder 54 decodes the symbols into FEC blocks using schemes known to those of skill in the art. Then, the convolutional decoder decodes the FEC blocks to produce i bits of data. The methods and frame structures described below are performed by the

functional elements of the transmitter and receiver described above with reference to FIGURES 3 and 4.

[0057] Referring now to FIGURE 5, a frame structure 90, which has been adapted from frame structure 80 (see FIGURE 2), for use in a FDD communication system is shown. The terminals and base station communicate using a series of uplink subframes and a series of downlink subframes. FIGURE 5 illustrates two uplink subframes 92(a), 92(b) in a series of uplink subframes and two downlink subframes 94(a), 94(b) in a series of downlink subframes. The downlink subframe is transmitted simultaneously with the uplink subframe on different frequency carriers. This is not possible in the TDD system of FIGURE 2. Between the downlink and uplink subframes, the modulation regions may differ in size. This is generally useful, since uplink and downlink data amounts are likely to vary between different terminals. The different modulation densities available to different terminals will affect the transport time they require.

[0058] In the FDD frame structure 90, the uplink and the downlink operation may or may not be synchronized. For example, a frame start and a frame end, hence frame length, may be identical, or not, depending on the specific implementation. The FDD frame structure may apply adaptive modulation only for the downlink and use a different scheme for the uplink. For example, a fixed modulation scheme could be used for the uplink. Conversely, a different scheme (e. g. fixed modulation) can be used on the downlink, while using adaptive modulation on the uplink.

[0059] FIGURE 6 shows an arrangement for arranging data from multiple terminals into a single Time Division Multiplexing (TDM) time block. Terminals receiving the same modulation (or, more generally, having the same modulation and FEC, i. e. PHY mode) will often be grouped together for downlink transmissions. The data from all terminals using the same PHY mode are multiplexed together. This means that various data packets 102 associated with one terminal could be mixed with data packets of other terminals depending on the exact queuing mechanism which prepared the data for transmission. In this case, while a terminal is receiving a downlink transmission it is required to demodulate all symbols in the time block which uses its assigned modulation. A higher layer addressing mechanism, such as headers, associates the terminal with the data belonging to it.

[0060] FIGURE 7 shows a potential downlink conflict for an FDD terminal restricted to half-duplex operation. The half-duplex terminal can represent a terminal 30, 32, 34, 36, 38 (see FIGURE 1) operating in an FDD communication system. The half-duplex terminal is unable to simultaneously receive while transmitting. The half-duplex terminal has knowledge of the least robust PHY mode the base station will use to transmit, and will listen to PHY modes which are at least as robust as its preferred PHY mode. However, the half-duplex terminal will be unable to listen to PHY modes that conflict with their scheduled uplink events. Thus, a conflict can occur if the terminal was scheduled to transmit to the base station while receiving from the base station.

[0061] To prevent a conflict from occurring, the terminal's uplink transmission (Tx) event 110 is preferably not scheduled at the same time as its downlink event 112. However, the terminal may lose synchronization with the base station during its uplink Tx event 110 and be unable to re-synchronize prior to the base station transmitting its downlink event 112. The loss of synchronization may become more problematic in a communication system that includes multiple terminals restricted to half-duplex operation. For example, in a case where all of the terminals in an FDD communication system operate in a half-duplex fashion, time gaps may occur in a frame during a downlink or uplink. Such time gaps may constitute a significant part of that portion of the frame to which such a terminal's use is restricted.

[0062] The downlink subframe structure shown in FIGURE 7 alleviates this issue by allowing re- synchronization of half-duplex terminals during the downlink subframe. Specifically, the frame structure of the downlink 94 is Time Division Multiple Access (TDMA). The TDMA structure allocates a portion of the downlink subframe for preambles 106. If a terminal loses synchronization with the base station during the uplink Tx event 110, the preamble 106 allows the terminal to re-synchronize with the base station prior to receiving its downlink.

[0063] Each terminal synchronizes and picks up control data 114, including uplink and downlink mapping information, at the beginning of every downlink subframe 94. The uplink map defines when the next uplink Tx event 110 will occur for each terminal in the uplink subframe 92. Similarly, the downlink map is used by terminals to determine when downlink events 112 will occur in the downlink subframe 94. For

example, a downlink map entry can indicate when the downlink subframe will transmit data with a specific PHY mode.

[0064] Uplink and downlink events can contain data associated with more than one user of the terminal. Higher layer addressing may be applied to determine specific associations of user data. The downlink map entry is not required to contain terminal identification information. Instead, a terminal which ended its uplink transmission and is available for downlink reception can use the downlink map to determine the next event which is relevant for it, that is, the next event that uses its preferred PHY mode, i. e. modulation parameters and FEC, which correspond to its settings. This mapping information will be further explained with reference to FIGURE 9. The downlink event 112 for a terminal is preceded by a preamble 106 in the downlink subframe 94. The preamble allows the terminal to quickly re-synchronize prior to demodulating the data in the downlink event 112. When the downlink event 112 ends (meaning that demodulation process of the associated data terminates), the terminal is ready for the next uplink Tx event as defined in the uplink map.

[0065] FIGURE 8 is a mapping diagram for a combined FDD TDM/TDMA downlink subframe for use with half-duplex and full-duplex terminals. When an FDD communication system includes differing terminal types, i. e. half-duplex and full-duplex, additional scheduling difficulties may occur. The frame structure shown in FIGURE 8 alleviates these issues by combining TDMA and TDM in a single downlink subframe 124. The TDM is utilized for bandwidth efficiency and the TDMA is used for half-duplex terminal support as will be explained below. In an FDD communication system having only full-duplex terminals, there is no need to use the TDMA portion. The same is true for any individual frame in which only full-duplex terminals are scheduled to transmit in the uplink. Conversely, in a typical TDD communication system only the TDM portion needs be used even if the communication system includes half-duplex terminals. However, the use of the TDMA portion in a TDD communication system allows the base station to utilize a smart antenna for downlinks. In such a TDD system, each terminal can re-synchronize with the base station during the downlink subframe.

[0066] Each downlink subframe 124 can include a frame control header 125 and downlink data 121. The frame control header 125 can include a preamble 126, PHY

control information 127, and media access control (MAC) information 128. The preamble 126 is used for synchronizing the terminals with the base station. For example, preamble 126 allows the terminals to synchronize with the base station at the beginning of the downlink subframe 124. The preamble can be transmitted using a robust PHY mode. A robust PHY mode allows terminals that are configured for receiving only robust modulation schemes to demodulate the preamble and synchronize with the base station.

[0067] The PHY control information 127 can include a downlink map 123. The downlink map 123 indicates to the terminals where and what modulation changes occur in the downlink data 121. An exemplary downlink map 123 is discussed below with reference to FIGURE 9.

[0068] The MAC control information 128 provides terminals with instructions on transmission protocols for the uplink subframe. These instructions can include an uplink map 129. The uplink map 129 is a map of a subsequent uplink subframe that is to be transmitted by the terminals.

[0069] To minimize errors in the mapping process, the base station transmits the downlink map and the uplink map using a robust PHY mode. Moreover, the base station can allocate a minimum number of symbols for the TDM portion 122 to accommodate the time required for the terminals to process and act upon the first downlink map entry. The downlink map 123 is the first information broadcast to the terminals in a downlink subframe to maximize the amount of time between receiving the downlink map and when the first terminal is required to act based on the downlink map. All other control information 125, including the uplink map 129, can come after the broadcast of the downlink map 123.

[0070] A full-duplex terminal, and any half-duplex terminal that receives later than it transmits within a frame, can take advantage of the TDM portion 122 of the downlink subframe 121. Thus, the downlink data 124 starts with a TDM portion 122. Additionally, to increase statistical multiplexing gain, it should be noted that full-duplex terminals are also able to re-synchronize with the base station in the TDMA portion 120 to receive data. Accordingly, the downlink subframe 124 is constructed with a TDM portion 122 followed by a TDMA portion 120. The downlink map 123 for a pure TDMA

downlink subframe would have the same number of map entries as the TDM/TDMA downlink subframe of FIGURE 8. However, differences include the presence or absence of preambles 106 in the TDMA portion 120, and the desirability of ordering the TDM portion 122 by PHY mode robustness.

[0071] FIGURE 9 shows the structure of an exemplary downlink map 123 from FIGURE 8 for use with a TDM/TDMA frame structure. The downlink map 123 allows the terminals to recognize PHY mode transitions in the downlink. The exemplary downlink map 123 can be any sequence of time indicators pointing out transmission location (such as by referencing start and end, or start and length, or offsets relative to a previous transmission) and terminal identification associating the map entry with a specific terminal. The time location information can be stated as a number of symbols referenced to frame start, or as any pre-defined unit of time understandable by the terminal. For example, if there are four modulation regions then four map entries are expected. If the map elements are using modulation symbols as time ticks, then a map containing "0123", "0234", "1119", and "2123" is interpreted as DM1 starting on symbol 123, DM2 starting on symbol 234, DM3 starting on symbol 1119, and DM4 starting at symbol 2123.

[0072] The exemplary downlink map 123 of FIGURE 9 can include a sequence of 20 bit entries. In this example, four bits can contain a Downlink Interval Usage Code (DIUC) entry 142. The DIUC defines the downlink PHY mode for each PHY mode in the downlink data 121 (see FIGURE 8). The DIUC can indicate the PHY mode (i. e. modulation, FEC) and also whether the PHY mode is preceded by a preamble (TDMA) or not (TDM). For example, if a base station had five downlink PHY modes to select from for its downlink transmissions, the base station would require ten unique DIUCs to identify the possible combinations. Thus, the DIUCs could describe the transition points between PHY modes in the TDM portion 122 as well as for each PHY mode in the TDMA portion 120. For example, the downlink map 123 may include entries for a begin TDM portion, a TDM transition to Q16, a TDM transition to Q64, an end of TDM portion, and an end of TDMA portion. Some formats have flexibility in terms of channel bandwidth and frame length. In these cases, the PS start field 144 may be used to represent physical slots rather than symbols, giving lower granularity of downlink allocation.

[0073] FIGURE 10 shows one relationship between frame mapping data and the data it maps for an FDD communication system. The downlink map 123 (see FIGURE 8) is valid for the frame in which it appears. For example, the downlink map in PHY Ctrl n-1 is valid for frame n-1 131. Similarly, the downlink map in PHY Ctrl n is valid for frame n 133. The uplink map 129 (see FIGURE 8) can be valid for the next uplink subframe as shown in FIGURE 10. The uplink subframe in FIGURE 10 is shown synchronized with the downlink subframe. However, the start of the downlink subframe and the start of the uplink subframe do not have to be synchronized. In this case, the uplink map 129 in frame n-1 131 can be valid for an uplink subframe that begins during frame n-1 131.

[0074] FIGURE 11 is a mapping diagram for a FDD TDM/TDMA downlink subframe that varies FEC types for a given modulation scheme. The downlink subframe 130 is the same as described with respect to FIGURE 8 except that a TDM portion 132 and a TDMA portion 134 both use a plurality of different FEC types in combination with different modulation types. For example, QAM-4 is used with FEC a in the TDM portion 132. FEC a is the most robust FEC and is used for weak channels. Slightly stronger channels may use QAM-4 with a somewhat less robust FEC b in the TDM portion. A less forgiving modulation, such as QAM-64, may be used with different levels of FEC, such as FEC d and FEC e, in the TOM portion 132. The TDMA portion 134 may also be defined by modulation type in combination with FEC type. For example, QAM-x is used with both FEC d and FEC c in the TDMA portion 134 of the downlink subframe 130.

[0075] FIGURE 12 is a mapping diagram for a TDM/TDMA downlink subframe that supports smart antennae. The downlink subframe 150 is the same as described with respect to FIGURE 8 except that the TDMA portion is used for all of the downlink data 121. While not recommended for efficiency, a downlink could be scheduled to be entirely TDMA. In practice, the TDMA portion need only be used in the presence of half-duplex terminals in a FDD communication system, and then only when the half-duplex terminals cannot be scheduled to receive earlier in the frame than they transmit. However, by extending the TDMA resynchronization capability to the entire downlink data 121 the base station could use smart antenna for its transmissions. This would allow the base station 20 to transmit to an individual terminal or a group of terminals within cell

10. Each individual terminal or group of terminals would be able to re-synchronize with the base station 20 at the beginning of their burst.

[0076] Full-duplex terminals and half-duplex terminals that receive before they transmit could both use TDMA. The order of the PHY modes within the downlink subframe 150 could be varied. Each terminal would still receive a broadcast preamble 126 from the base station which would indicate when their preamble 106 would be transmitted by the base station. The use of a smart antenna would increase the gain of the received signal at the terminal. However, some bandwidth would be lost due to the addition of preambles and map entries.

[0077] A TDD communication system could also use the design of the TDMA downlink subframe 150 to incorporate a base station smart antenna. In the TDD communication system, only one channel is used for uplinks and downlinks. The terminals do not lose synchronization between the broadcast preamble 126 and the transmission of their data. Thus, if the PHY modes are ordered in the downlink and broadcast to an entire cell without a smart antenna, the terminals are able to maintain their synchronization. By incorporating a smart antenna at the base station, the terminals within the cell will lose synchronization. However, the use of a TDMA downlink subframe 150 and its preambles 106 as described above would allow the terminals to resynchronize with the base station prior to receiving their data.

[0078] When building an FDD communication system, full-duplex terminals are more efficiently served by a TDM downlink. Half-duplex terminals, however, are better served by a TDMA downlink. However, in communication systems where both full and half-duplex terminals exist, scheduling the downlink and uplink transmission opportunities for the half-duplex terminals is non-trivial, since these terminals cannot transmit and receive simultaneously. Some half-duplex terminals may be scheduled to receive before they transmit. In this case, the base station can transmit downlink data to such half-duplex terminals in the TDM portion, since these terminals get synchronization from the preamble at the beginning of the downlink subframe. However, some half-duplex terminals are unable to be scheduled to transmit after they receive their data. Such terminals would lose the synchronization as they transmit, because they complete the

transmission in the middle of the downlink subframe and hence have no preamble to use to synchronize their receiver to the base station.

[0079] One solution is to schedule the downlink data transmissions of these half-duplex terminals in a TDMA portion. This allows the terminals to receive the preamble at the beginning of the TDMA burst for receiver synchronization. Although this approach resolves the problem of half duplex terminal receiver synchronization, each burst in the TDMA portion requires a DIUC message. The number of DIUC or map entries may grow if the number of TDMA bursts increases, wasting bandwidth for actual data transmission. Furthermore uplink maps are typically built only one frame ahead of time. Therefore, it is not possible to know the size of the downlink data for those half-duplex terminals in order to properly schedule the downlink data reception before transmission.

Scheduling Algorithm

[0080] A scheduling algorithm will now be described to allow TDM and TDMA portions of a downlink to co-exist in the same downlink subframe. The algorithm allows maximum flexibility and efficiency for FDD communication systems that must simultaneously support full and half-duplex terminals. The algorithm further allows the TDM of multiple terminals in a TDMA burst to minimize the number of map entries in a downlink map. The algorithm limits the number of downlink map entries to (2 x n) +1, where n is the number of PHY modes. The algorithm works for pure TDMA downlinks (see FIGURE 12), and for downlinks where TDM and TDMA co-exist (see FIGURES 8 and 11). The scheduling algorithm is intended to be used in communication systems which allocate the uplink subframe ahead of building the downlink subframe.

Algorithm Description

[0081] First, all terminals are grouped together by the modulation/FEC (PHY mode) in which they receive downlink data. The number of groups formed will be equal to the number of PHY modes being used for downlink in the communication system. Uplink bandwidth is allocated to the terminals such that the uplink transmission opportunities of terminals belonging to the same group are kept contiguous in time.

[0082] Within these groupings, the uplink bandwidth allocated to an individual terminal is contiguous in time. The groups themselves can be ordered in a particular order

to maximize the TDM portion of the downlink. To avoid the problem of scheduling the downlink and uplink transmission simultaneously in time for the terminals within the same group, the downlink data of the first group is scheduled first to overlap with the uplink bandwidth of the next group to be allocated. This proceeds until all the downlink data has been allocated.

Notations used in the Scheduling Algorithm

[0083] *n*: the number of downlink (DL) PHY modes (e. g. FEC-type/Modulation combinations) used by system.

S_n: set of DL PHY modes, where PHY mode *j*, is more robust (comes earlier in the downlink TDM section) than DL PHY mode $j + 1$, $j \in S_n$.

U_j: total amount of uplink bandwidth, in symbols (or in time, in an asymmetric FDD system), allocated for all terminals that receive downlink data using DL PHY mode *j*, where $j \in S_n$.

D_j: total amount of downlink bandwidth, in symbols (or in time, in an asymmetric FDD system), allocated for all terminals that receive downlink data using DL PHY mode *j*, where $\in S_n$.

T: total amount of bandwidth, in symbols (or in time, in an asymmetric FDD system), available on the downlink channel.

U_k: total amount of uplink bandwidth, in symbols (or in time, in an asymmetric FDD system), allocated for an individual terminal, k.

d_k: total amount of downlink bandwidth, in symbols (or in time, in an asymmetric FDD system), allocated for an individual terminal, k.

System Constraints

[0084] The worst case scheduling is the case where all terminals are half-duplex.

[0085] For a half duplex terminal k, $d_k + u_k \leq T$.

[0086] There can only be one *j*, such that $D_j + U_j \geq T$.

[0087] Worst case is when $\sum_{j \in S_n} (D_j + U_j) = 2T$ (The link is full, both uplink and downlink).

[0088] The following description is shown for the case when $n = 5$. Those skilled in the art will understand that the algorithm may readily be extended to any value of n.

[0089] FIGURE 13 is a flow chart for a scheduling algorithm. The scheduling algorithm process begins at a start state 1300. Next at a state 1320, all of the terminals are grouped by their downlink PHY modes. Flow proceeds to a state 1340 where uplink bandwidth is allocated for the terminals. The uplink bandwidth transmission opportunities are contiguous for terminals with the same downlink PHY mode. The total uplink bandwidth allocated for group j is U_j, where $j \in S_n$. Flow moves to a state 1360 where the groups are ordered in the downlink subframe. The uplink groups, U_j, are put in order of the robustness of their PHY modes, starting with the second most robust downlink ($j = 2$) and continuing in order of decreasing robustness. The terminal group with the most robust DL PHY mode, Un, last. This is shown in FIGURE 14.

[0090] Flow continues to a state 1360 where the terminal group identified as D_j, $j = 1$, is allocated downlink bandwidth at the start of the downlink subframe. Next, at a decision state 1380, the process determines whether $D_1 \geq U_2$. If $D_1 \geq U_2$then flow continues to a state 1400 were the scheduling algorithm allocates downlink bandwidth for D_1 at the start of the downlink subframe. This is shown in FIGURE 15.

[0091] Flow continues to a decision block 1420 to determine whether $D_1 + U_1 \geq T$. If $+ U_1 \geq T$, the process continues to a state 1440 where D_1 is arranged such that an individual terminal's bandwidth does not overlap on the uplink and downlink, even while guaranteeing that the downlink map will not exceed $2n + 1$. In this case there must be more than one terminal represented by D_1.

[0092] Returning to decision block 1420, if $D_1 + U_1 \geq T$ is not true, then the process continues to a state 1460 where the downlink scheduling becomes easier since U_2 will not be transmitting while receiving. Subsequent allocations of downlink bandwidth

are placed adjacent to the prior allocations. For example, D_2 is placed next to D_1 in FIGURE 15.

[0093] Returning to decision block 1380, if $D_1 < U_2$, then the process moves to a state 1480 where the scheduling algorithm allocates downlink bandwidth for D_1, at the start of the downlink subframe. This is shown in FIGURE 16.

[0094] Flow continues to a decision block 1500 where a determination is made whether $D_2 < U_3$. If $D_2 < U_3$ is not true, flow continues to state 1460 where the downlink scheduling becomes easier since Us will not be transmitting while receiving. Subsequent allocations of downlink bandwidth are placed adjacent to the prior allocations. For example, D_3 is placed next to D_2.

[0095] Returning to decision block 1500, if $D_2 < U_3$, flow continues to a state 1520 where the scheduling algorithm allocates downlink bandwidth for D_2 at the end of the uplink bandwidth that was allocated for U_2. In this case, once the half-duplex terminal assigned to U_2 finishes its uplink transmission, it will begin receiving its downlink transmission during D_2 from the base station. A gap in the downlink subframe is left between D_1 and D_2. This is shown in FIGURE 17. If D_2 had been allocated downlink bandwidth adjacent to D_1, a terminal assigned to D_2/U_2 would have possibly had a conflict. Note that in an event that D_2 overlaps with U_2, terminals can be arranged such that no terminal in this group has uplink and downlink bandwidth overlap.

[0096] Next, at decision block 1540, a determination is made whether $D_3 > U_4 + U_5 + U_1$. If $D_3 > U_4 + U_5 + U_1$ is true, the process continues to a state 1560 where D_3 is broken into multiple pieces. The pieces are then inserted in the remaining gaps in the downlink subframe. This is shown in FIGURE 18. Note that if D_3 overlaps with U_3, terminals assigned to D_3 can be arranged such that no terminal in this group has uplink and downlink bandwidth overlap. The process continues to a state 1570 where the remaining downlink bandwidth, located between D_2 and D_3 is allocated for downlink transmissions by terminals assigned to D_4 and D_5.

[0097] Returning to decision block 1540, if a determination is made that $D_3 > U_4 + U_5 + U_1$ is not true, flow continues to decision block 1580 where a determination is

made as to whether $D_3 < U_4$. If $D_3 < U_4$ is not true, the process returns to state 1460 where the downlink scheduling becomes easier since U_4 will not be transmitting while receiving.

[0098] Returning to decision block 1580, if $D_3 < U_4$, the process moves to a state 1600 where D_3 is allocated a portion of the downlink subframe beginning from the end of U_3. A gap in the downlink subframe is left between D_2 and D_3. This is shown in FIGURE 19.

[0099] Next at decision block 1620, a determination is made whether $D_4 < U_5$. If $D_4 < U_5$ is not true, the process returns to state 1460 where the scheduling is easier. D_4 is placed at the end of its assigned uplink U_4, so that D_4 will downlink once it finishes receiving its uplink, U_4. Subsequent allocations of downlink bandwidth are placed adjacent to the prior allocations. For example, D_5 is placed next to D_4.

[00100] Returning to decision block 1620, if $D_4 < U_5$, the process continues to a state 1640 where D_4 is placed at the end of U_4. This is shown in FIGURE 20. Next, at a decision state 1660, the algorithm determines whether the last downlink segment D_5 is longer in duration than U_1 and all remaining fragments excluding any fragment that is aligned with U_5. If the algorithm determines downlink segment D_5 is longer in duration than U_1 and all remaining fragments excluding any fragment that is in aligned with U_5 (as shown in FIGURE 21), the process continues to a state 1680 where bandwidth rearrangement is performed. There will be other downlink bandwidth allocations that can be moved in line with U_5 to make room for the remainder of D_5. The final rearrangement of downlink scheduling is shown in FIGURE 22.

[00101] Returning to decision block 1660, if the last downlink segment D_5 is shorter in duration than U_1 and all remaining fragments excluding any fragment that is aligned with U_5, then the process moves to a state 1700 where D_5 is placed at the end of D_4 and interleaved in the gaps in the downlink subframe. No subsequent rearrangement is required. The foregoing algorithm ensures that the number of map entries will not exceed $2n + 1$. However, after employing the algorithm, under many circumstances further rearrangement of the downlink will be possible to further reduce the number of downlink map elements below $2n$.

[00102] While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art.

What is claimed is:

1. A base station for wirelessly communicating with a plurality of terminals, comprising:

a receiver configured to decode data received in an uplink sub-frame;

a transmitter configured to encode data into a downlink sub-frame, the downlink sub-frame having:

control information including:

a preamble for synchronizing the base station with terminals scheduled to receive data in the downlink sub-frame;

scheduling information identifying transmission resources allocated to at least two terminals scheduled to receive data in the downlink sub-frame; and

respective associated physical (PHY) modes; and

at least two data blocks with downlink data for the at least two terminals scheduled to receive data in the downlink sub-frame, each data block using the transmission resources identified by the control information, the downlink data in each data block of the at least two data blocks being encoded according to the respective associated PHY mode; and

an antenna system comprised of smart antennas for transmitting the downlink sub-frame using beam-forming,

wherein the control information is transmitted to the scheduled terminals using a PHY mode having a level of robustness which is at least as robust as a level of robustness that is compatible with the plurality of terminals.

2. A base station according to claim 1, wherein the smart antennas are configured such that a first smart antenna transmits a first downlink sub-frame, and a second smart antenna transmits a second downlink sub-frame substantially simultaneously with the first downlink sub-frame.

3. A base station according to claim 1, wherein the scheduling information comprises a downlink sub-frame map with downlink events pertaining to downlink data transmitted to terminals scheduled to receive data in the downlink sub-frame and an uplink sub-frame map with uplink events pertaining to uplink data received from terminals scheduled for uplink transmission.

4. A base station according to claim 3, wherein the receiver is configured to decode the uplink data received from the terminals scheduled for uplink transmission, according to the uplink sub-frame map.

5. A base station according to claim 3, wherein the transmitter is configured to encode the downlink sub-frame map and the uplink sub-frame map as a TDM signal.

6. A base station according to claim 3, wherein the transmitter is configured to encode the uplink sub-frame map and the downlink sub-frame map as an OFDM signal.

7. A base station according to claim 1, wherein the at least two data blocks with downlink data are modulated on sub-carriers.

8. A base station according to claim 1, operable to determine the associated PHY mode for a terminal of the at least two terminals based on the quality of a wireless link established between the base station and the terminal.

9. A base station according to claim 8, wherein the quality of the wireless link includes one or more of interference minimization, propagation delays and round trip delays.

10. A base station according to claim 8, wherein the transmitter is further configured to change the associated PHY mode for a terminal of the at least two terminals based on the current quality of the wireless link.

11. A base station according to claim 8, operable to determine the associated PHY mode for a terminal of the at least two terminals based on the capabilities of the terminal.

12. A base station according to claim 8, wherein the associated PHY mode comprises an UL modulation parameter used for encoding data in a respective data block of the at least two data blocks.

13. A method of operating a base station for wireless communications with a plurality of terminals, comprising:

encoding control information using a physical (PHY) mode having a level of robustness which is at least as robust as a level of robustness that is compatible with the plurality of terminals;

decoding uplink data from an uplink sub-frame;

encoding downlink data into a downlink sub-frame, the downlink sub-frame having:

control information including:

a preamble for synchronizing the base station with terminals scheduled to receive data in the downlink sub-frame;

scheduling information identifying transmission resources allocated to at least two terminals scheduled to receive data in the downlink sub-frame; and

respective associated physical (PHY) modes; and

at least two data blocks with downlink data for the at least two terminals, each data block using the transmission resources identified by the control information, the downlink data in each data block of the at least two data blocks being encoded according to the respective associated PHY mode; and

transmitting the downlink sub-frame using beam-forming.

14. A method according to claim 13, further comprising transmitting a first downlink sub-frame from a first smart antenna, and transmitting a second downlink sub-frame from a second smart antenna substantially simultaneously with the first downlink sub-frame.

15. A method according to claim 13, wherein the scheduling information comprises a downlink sub-frame map with downlink events pertaining to downlink data transmitted to the terminals scheduled to receive data in the downlink sub-frame and an uplink sub-frame map with uplink events pertaining to uplink data received from terminals scheduled for uplink transmission.

16. A method according to claim 15, further comprising decoding the uplink data received from the terminals scheduled for uplink transmission according to the uplink sub-frame map.

17. A method according to claim 15, further comprising encoding the downlink sub-frame map and the uplink sub- frame map as a TDM signal.

18. A method according to claim 15, wherein the uplink sub-frame map and the downlink sub-frame map are encoded as an OFDM signal.

19. A method according to claim 13, wherein the at least two data blocks with downlink data are modulated on sub-carriers.

20. A method according to 19, wherein the base station determines the associated PHY mode for a terminal of the at least two terminals based on the quality of a wireless link established between the base station and the terminal.

21. A method according to claim 19, wherein the quality of the wireless link includes one or more of interference minimization, propagation delays and round trip delays.

22. A method according to 19, wherein the transmitter changes the associated PHY mode for a terminal of the at least two terminals based on the current quality of a wireless link established between the base station and the terminal.

23. A method according to claim 19, wherein the base station determines the associated PHY mode for a terminal of the at least two terminals based on the capabilities of the terminal.

24. A method according to claim 19, wherein the associated PHY mode comprises an UL modulation parameter used for encoding data in a respective data block of the at least two data blocks.

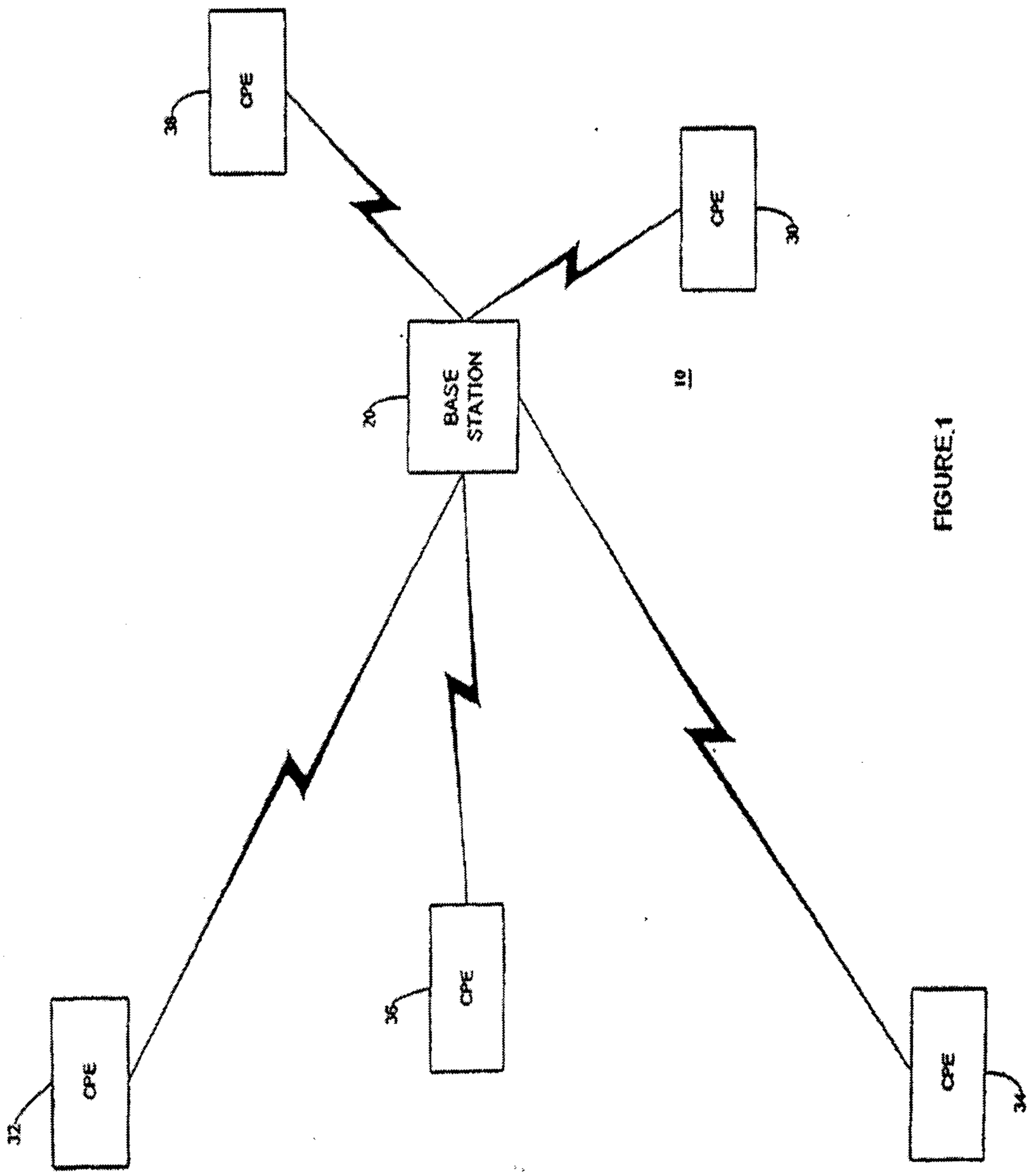


FIGURE 1

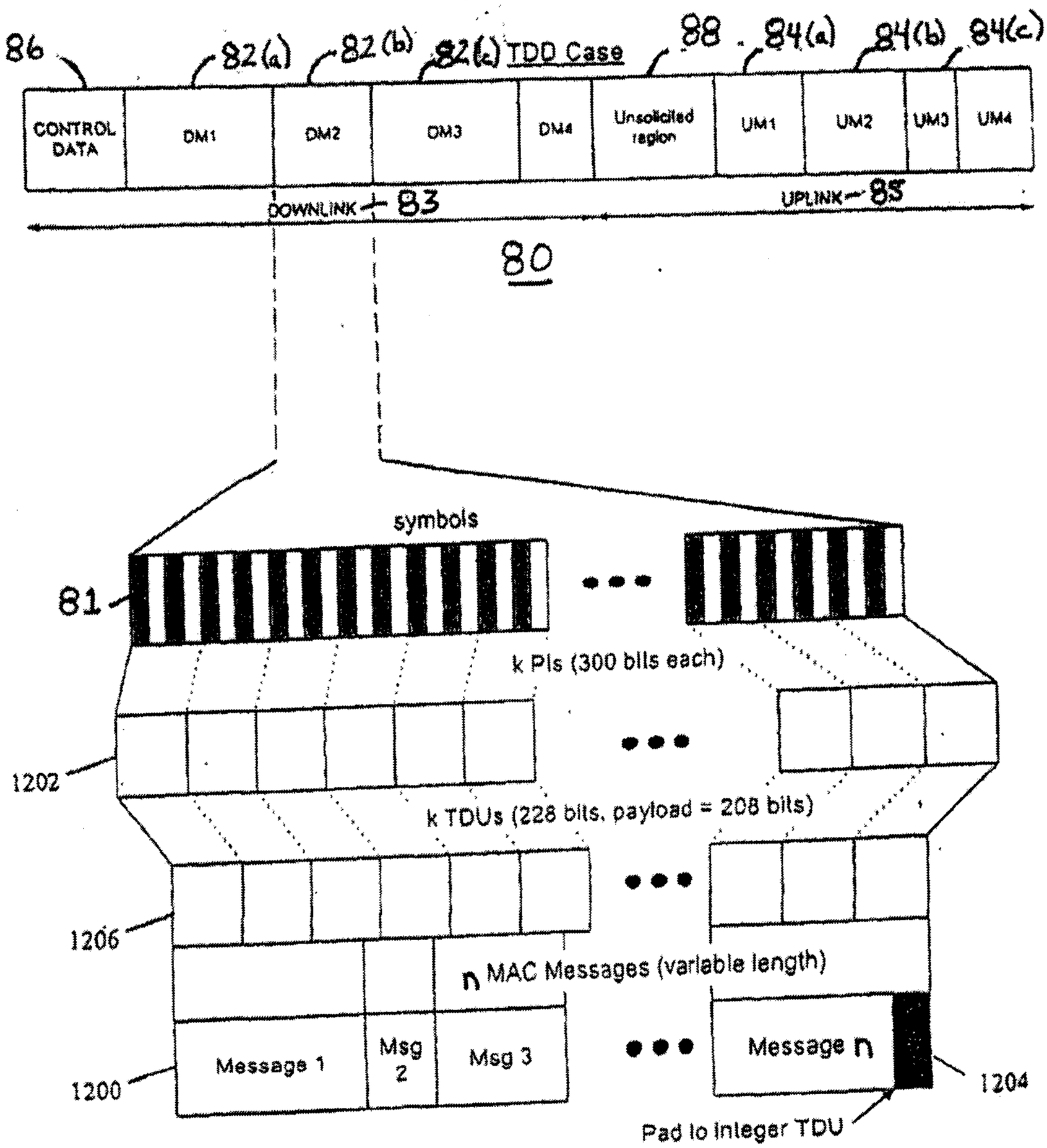

86
82(a)
82(b)
82(c) TDD Case
88
84(a)
84(b)
84(c)
CONTROL DATA
DM1
DM2
DM3
DM4
Unsolicited region
UM1
UM2
UM3
UM4
DOWNLINK 83
UPLINK 85
80
symbols
81
k Pls (300 bits each)
1202
k TDUs (228 bits, payload = 208 bits)
1206
n MAC Messages (variable length)
Message 1
Msg 2
Msg 3
Message n
1200
1204
Pad to Integer TDU

Figure 2

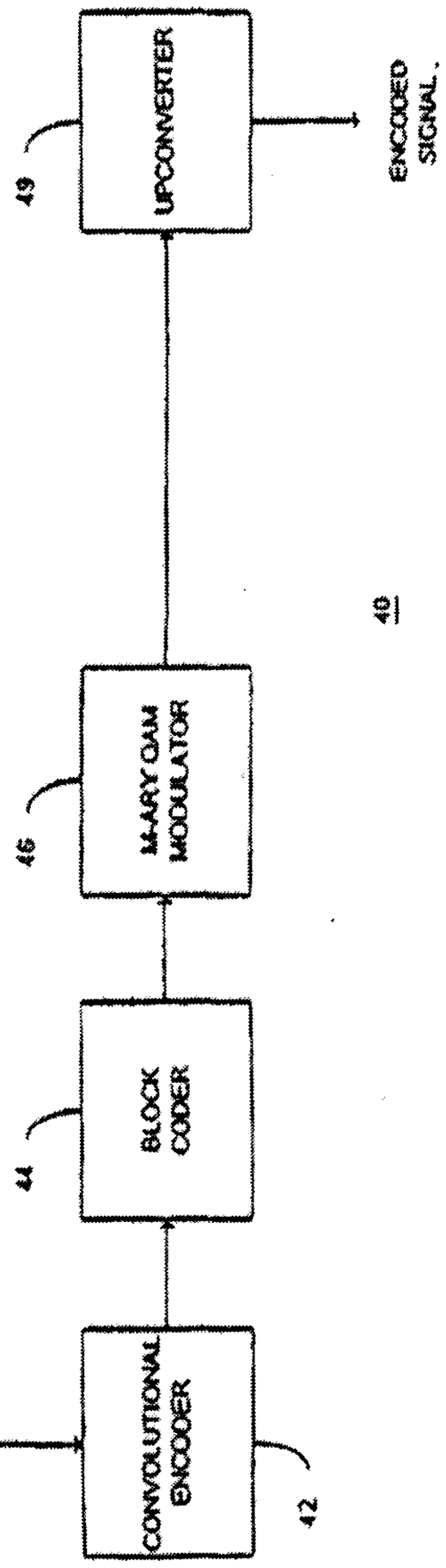


FIGURE 3

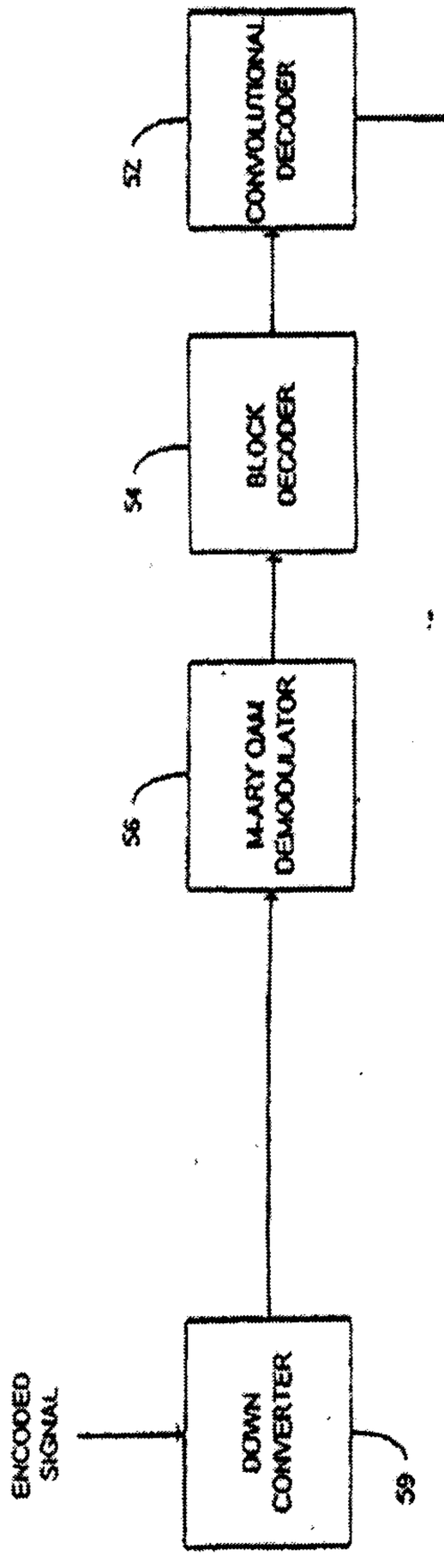


FIGURE 4

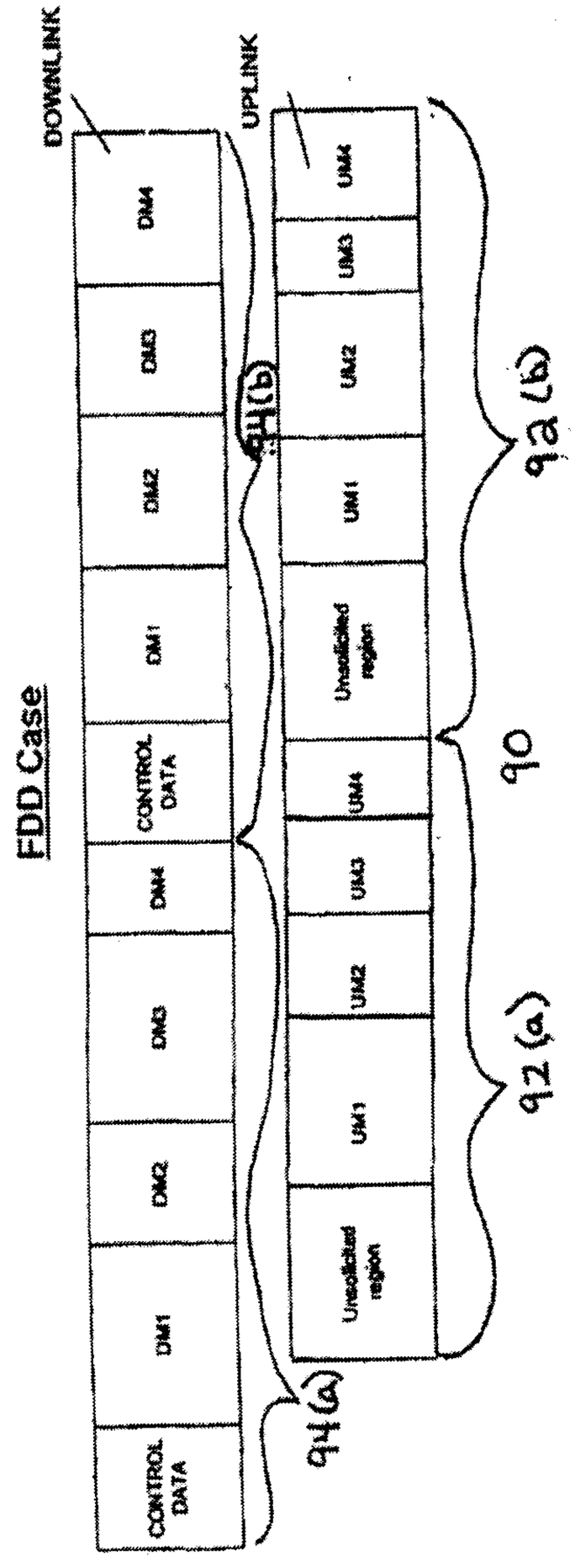

FDD Case
DOWNLINK
UPLINK
CONTROL DATA
DM4
DM3
DM2
DM1
CONTROL DATA
UM4
UM3
UM2
UM1
Unscheduled region
94(a)
94(b)
90
92(a)
92(b)

Figure 5

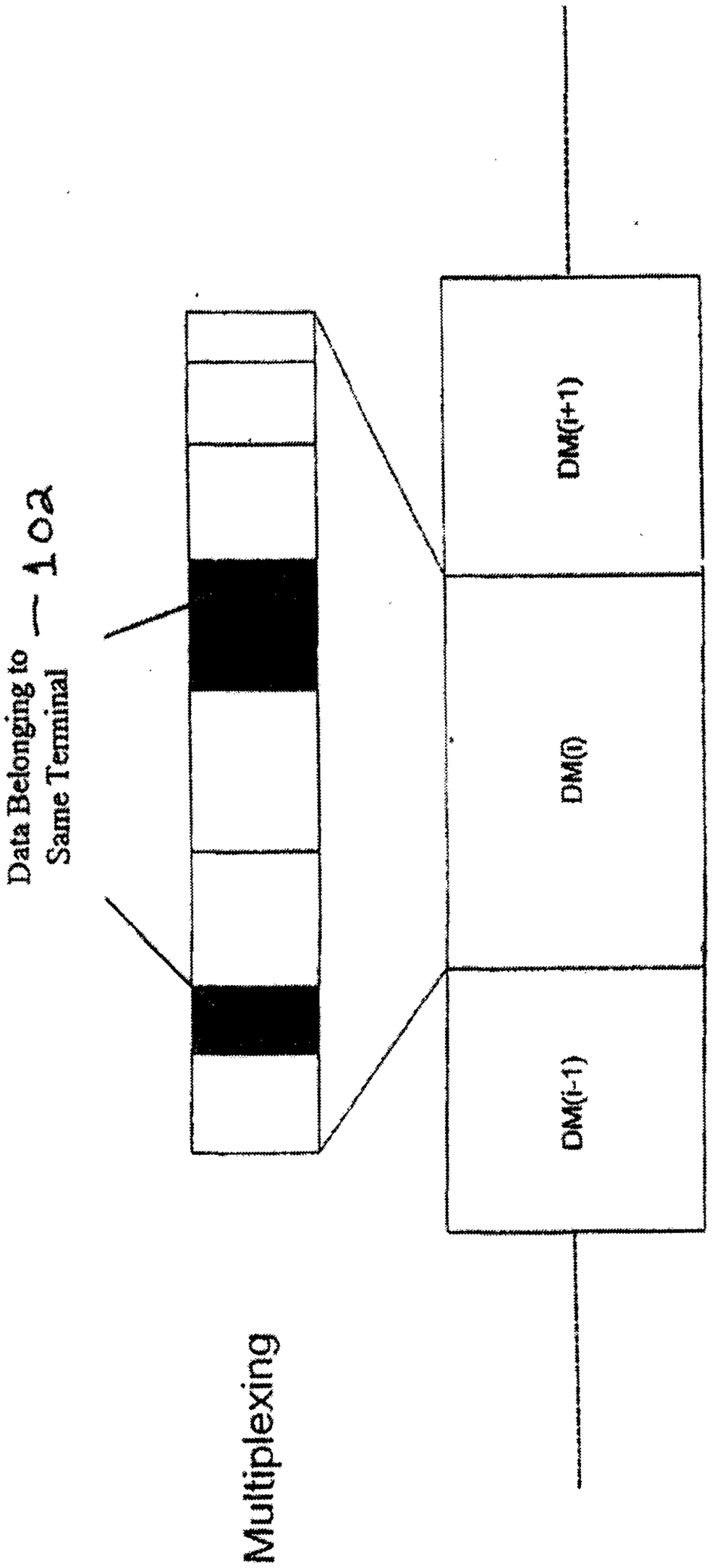

Data Belonging to
Same Terminal
102
DM(i+1)
DM(i)
DM(i-1)
Multiplexing

Figure 6

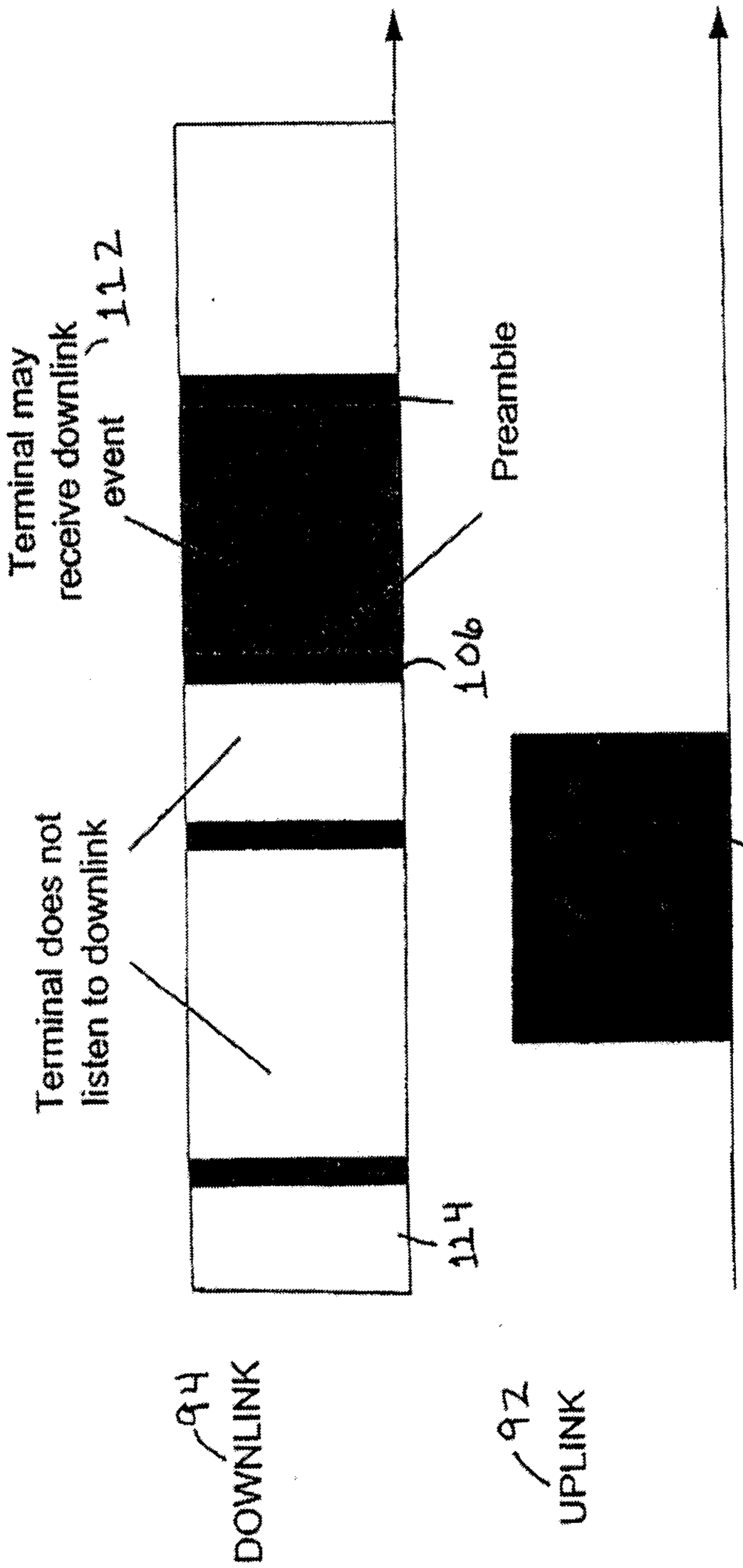

Terminal may receive downlink event
112
Preamble
106
Terminal does not listen to downlink
114
94
DOWNLINK
92
UPLINK
Uplink Tx event — 110

Figure 7

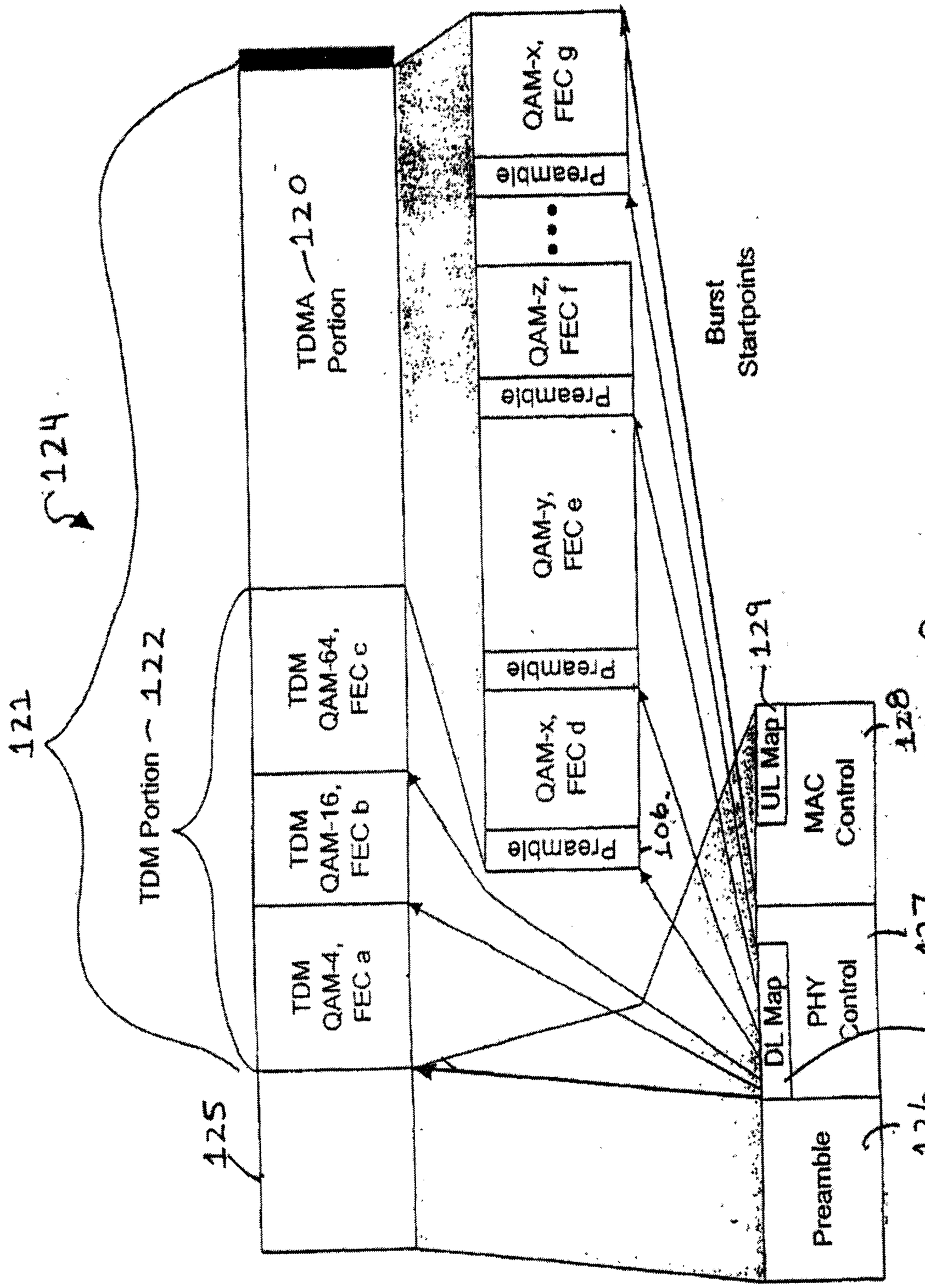

124
121
TDM Portion ~ 122
125
TDM QAM-4, FEC a
TDM QAM-16, FEC b
TDM QAM-64, FEC c
TDM Portion ~ 120
Preamble
QAM-x, FEC d
Preamble
QAM-y, FEC e
Preamble
QAM-z, FEC f
Preamble
QAM-x, FEC g
Burst Startpoints
106
129
UL Map
MAC Control
128
DL Map
PHY Control
127
123
126
Preamble

Figure 8

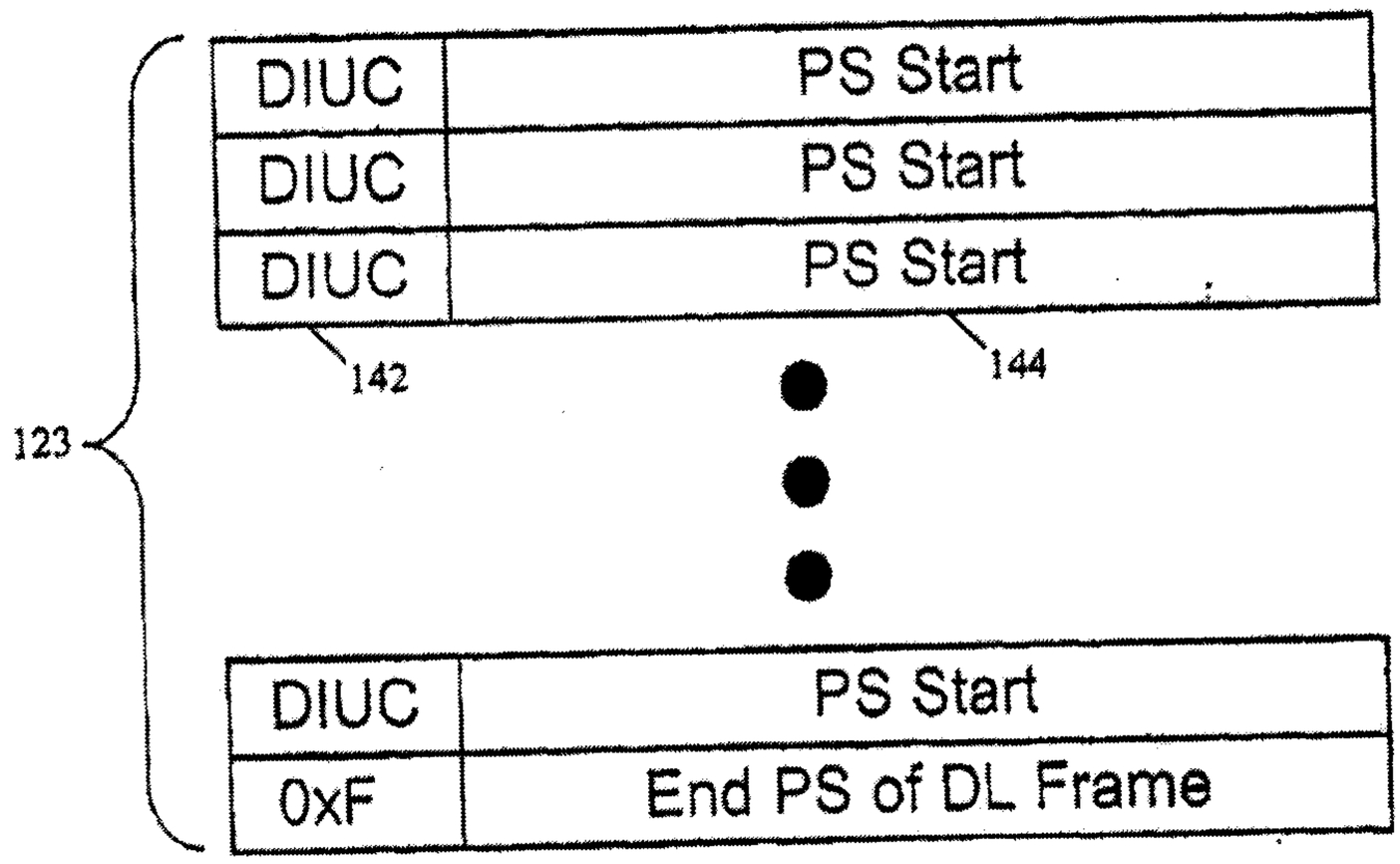

DIUC
PS Start
DIUC
PS Start
DIUC
PS Start
142
144
123
DIUC
PS Start
0xF
End PS of DL Frame

Figure 9

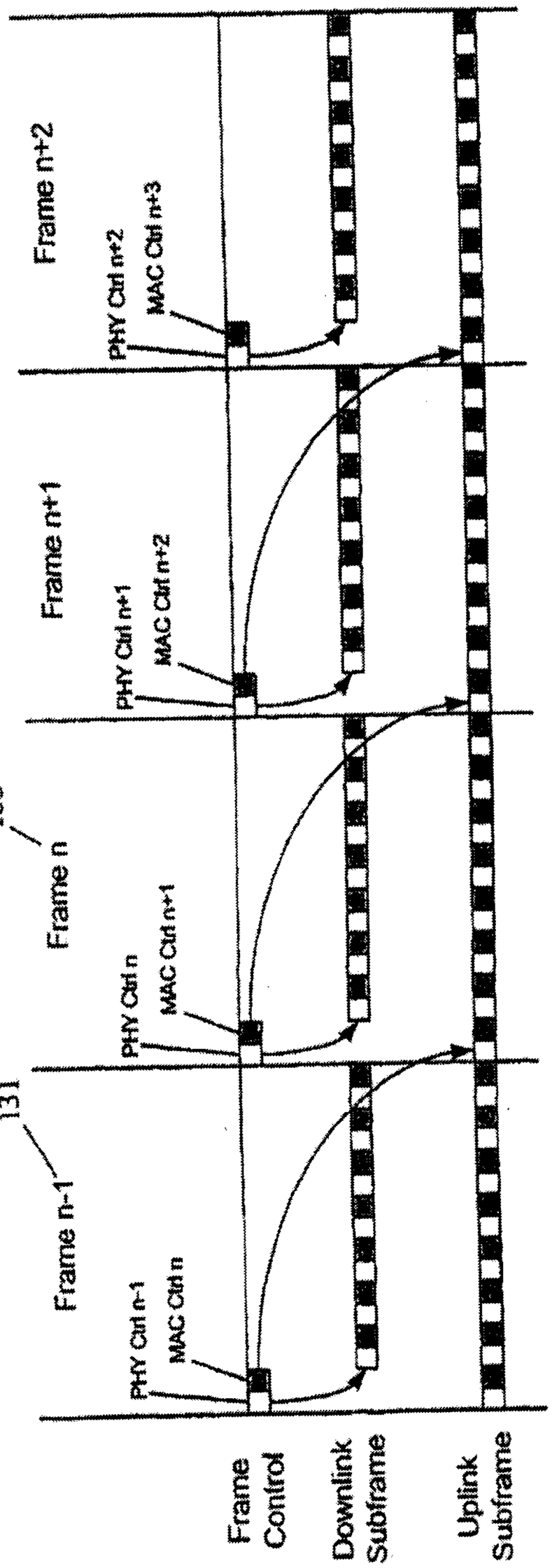

Frame n+2
PHY Ctrl n+2
MAC Ctrl n+3
Frame n+1
PHY Ctrl n+1
MAC Ctrl n+2
133
Frame n
PHY Ctrl n
MAC Ctrl n+1
131
Frame n-1
PHY Ctrl n-1
MAC Ctrl n
Frame Control
Downlink Subframe
Uplink Subframe

Figure 10

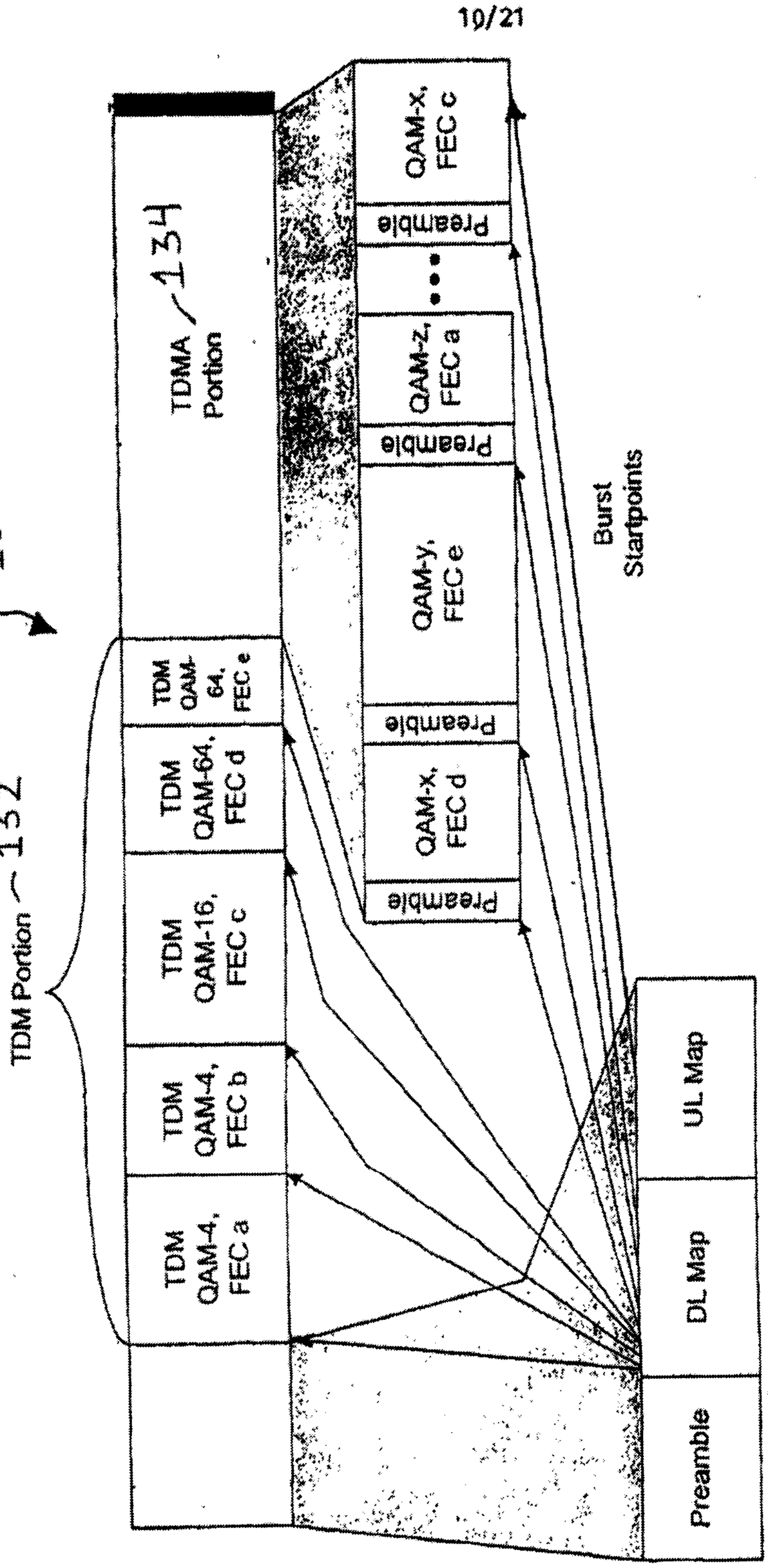

130
132
TDM Portion
TDM QAM-4, FEC a
TDM QAM-4, FEC b
TDM QAM-16, FEC c
TDM QAM-64, FEC d
TDM QAM-64, FEC e
134
TDMA Portion
QAM-x, FEC c
Preamble
QAM-z, FEC a
Preamble
QAM-y, FEC e
Preamble
QAM-x, FEC d
Preamble
Burst Startpoints
UL Map
DL Map
Preamble

Figure 11

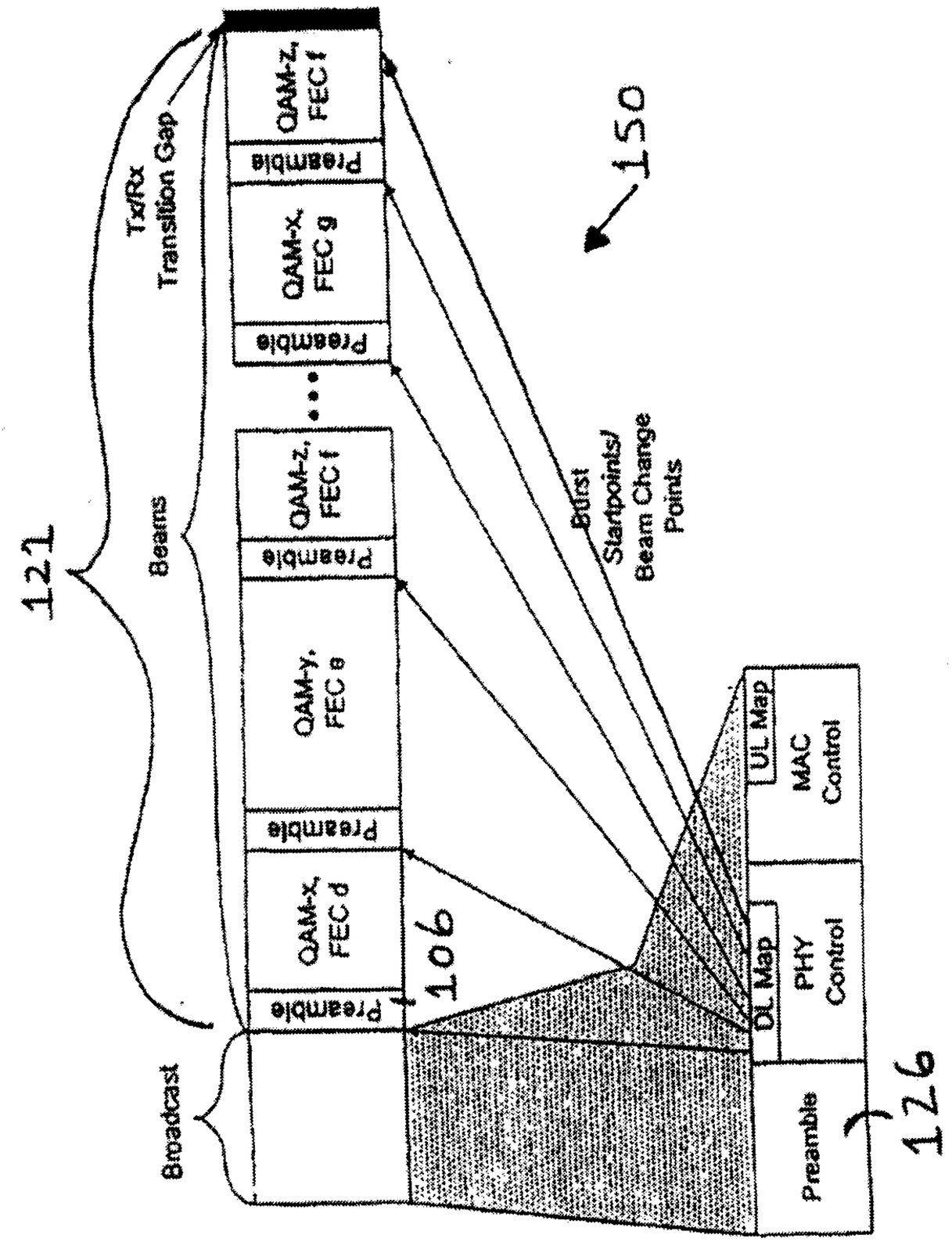

121
Beams
Tx/Rx Transition Gap
Broadcast
Preamble
QAM-y, FEC e
QAM-x, FEC d
QAM-z, FEC f
QAM-x, FEC g
QAM-z, FEC f
Preamble
Preamble
Preamble
Preamble
106
150
Burst Startpoints/ Beam Change Points
UL Map
MAC Control
DL Map
PHY Control
Preamble
126

FIGURE 12

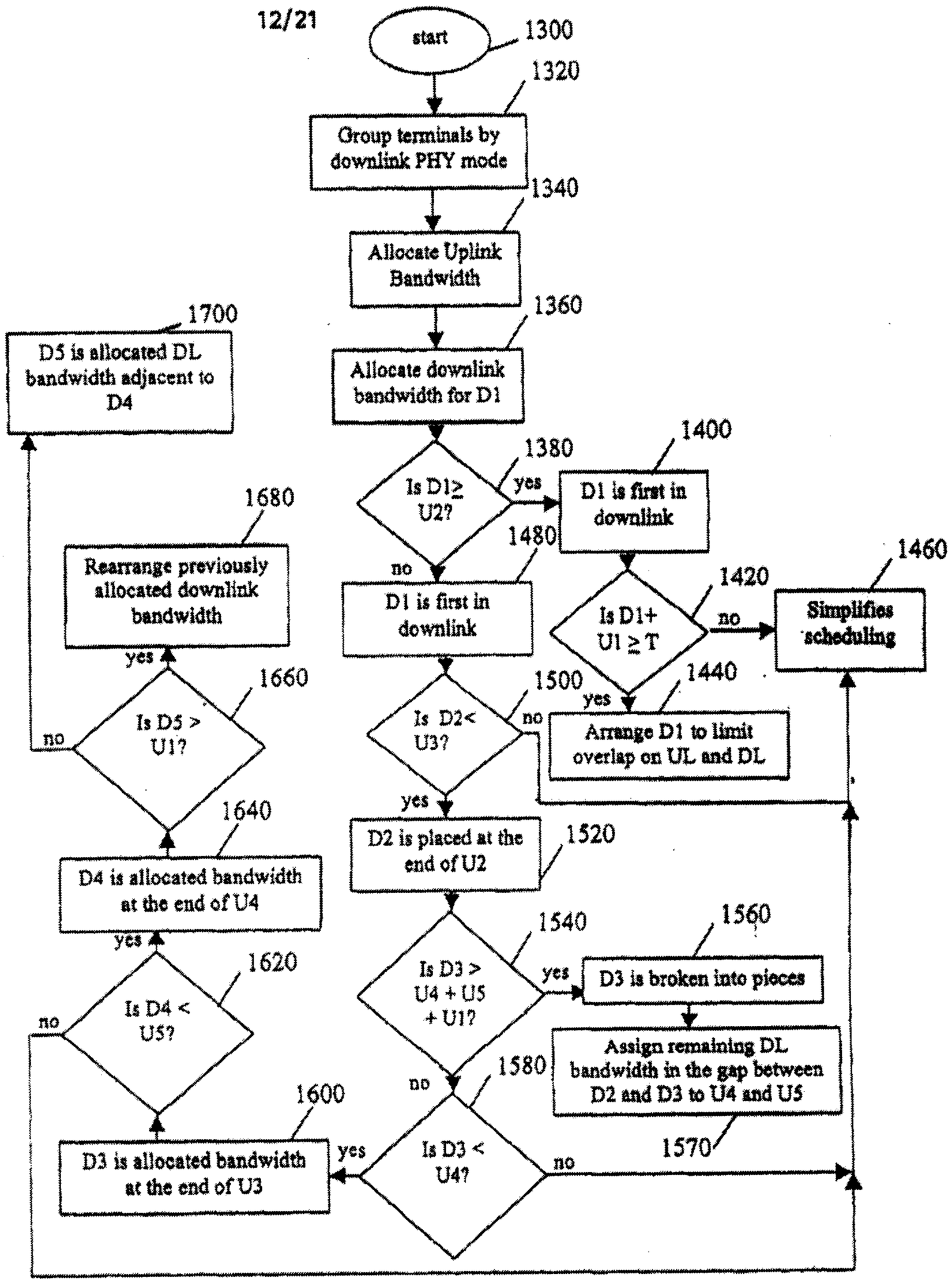

start
1300
1320
Group terminals by downlink PHY mode
1340
Allocate Uplink Bandwidth
1360
Allocate downlink bandwidth for D1
1380
Is D1≥ U2?
yes
1400
D1 is first in downlink
no
1480
D1 is first in downlink
1420
Is D1+ U1 ≥ T
no
1460
Simplifies scheduling
yes
1440
Arrange D1 to limit overlap on UL and DL
1500
Is D2< U3?
no
yes
D2 is placed at the end of U2
1520
1540
Is D3 > U4 + U5 + U1?
yes
1560
D3 is broken into pieces
Assign remaining DL bandwidth in the gap between D2 and D3 to U4 and U5
1570
no
1580
Is D3 < U4?
yes
1600
D3 is allocated bandwidth at the end of U3
no
1620
Is D4 < U5?
yes
D4 is allocated bandwidth at the end of U4
1640
Is D5 > U1?
yes
1660
Rearrange previously allocated downlink bandwidth
1680
no
D5 is allocated DL bandwidth adjacent to D4
1700

Figure 13

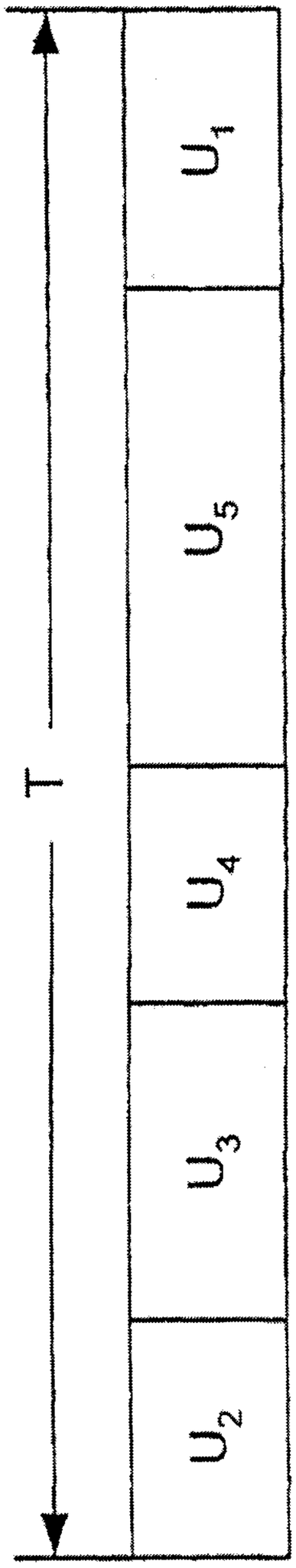


Figure 14

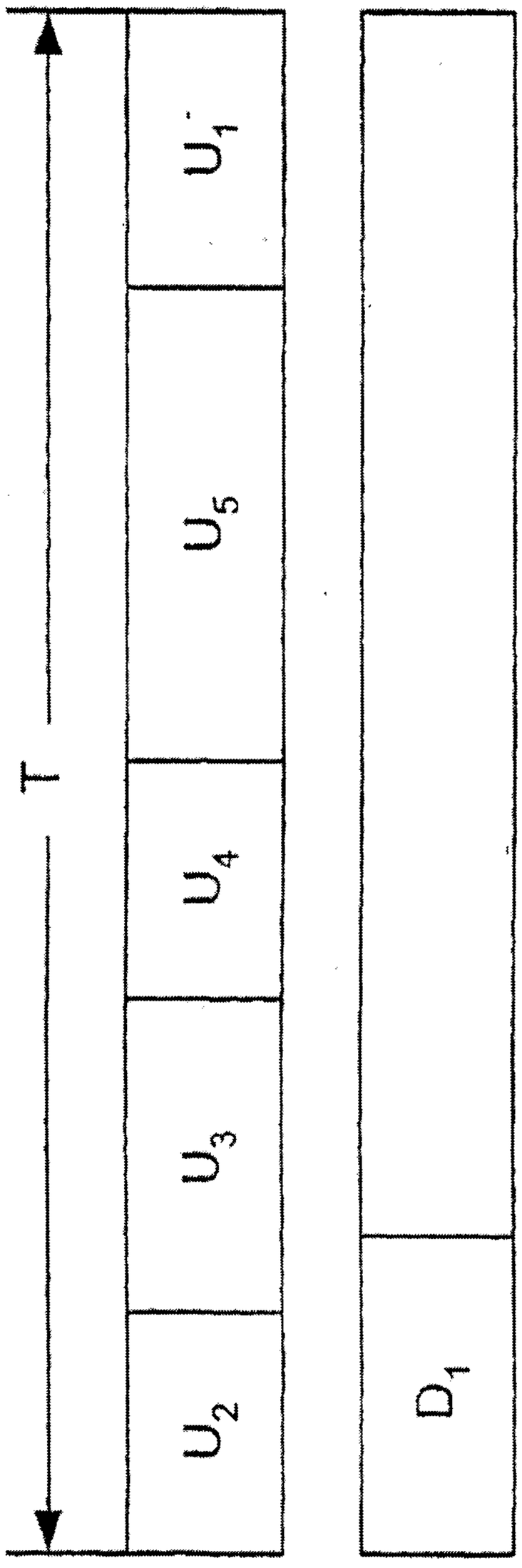


Figure 15: $D_1 \geq U_1$

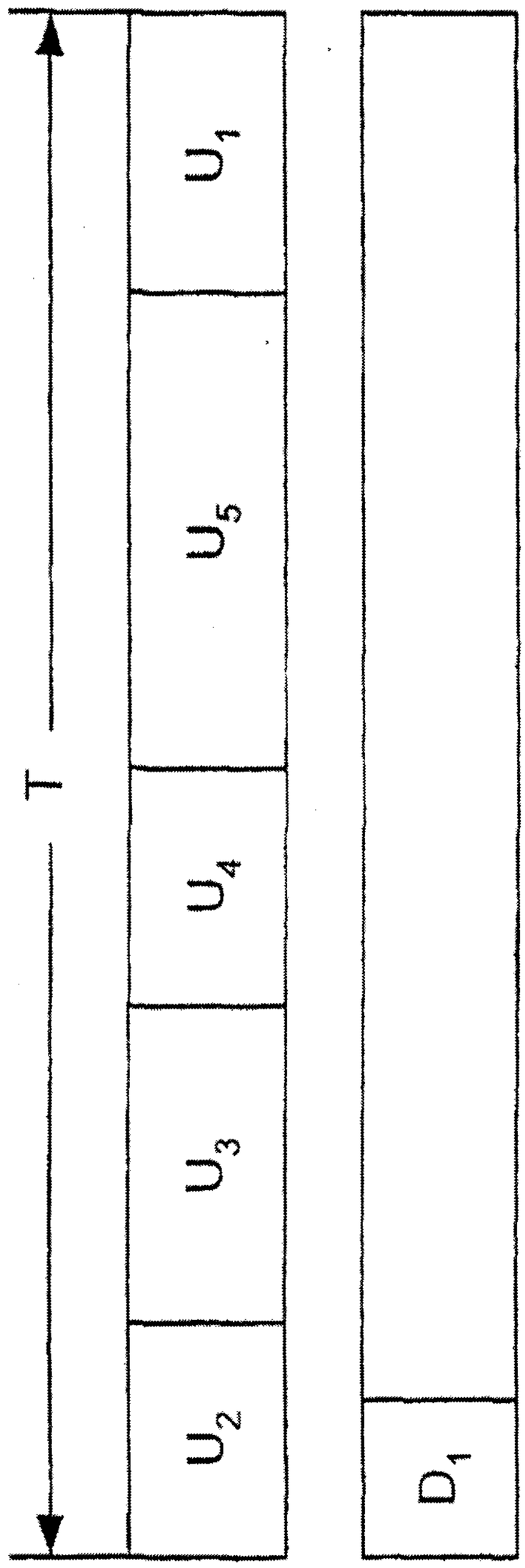


Figure 16: $D_1 < U_2$

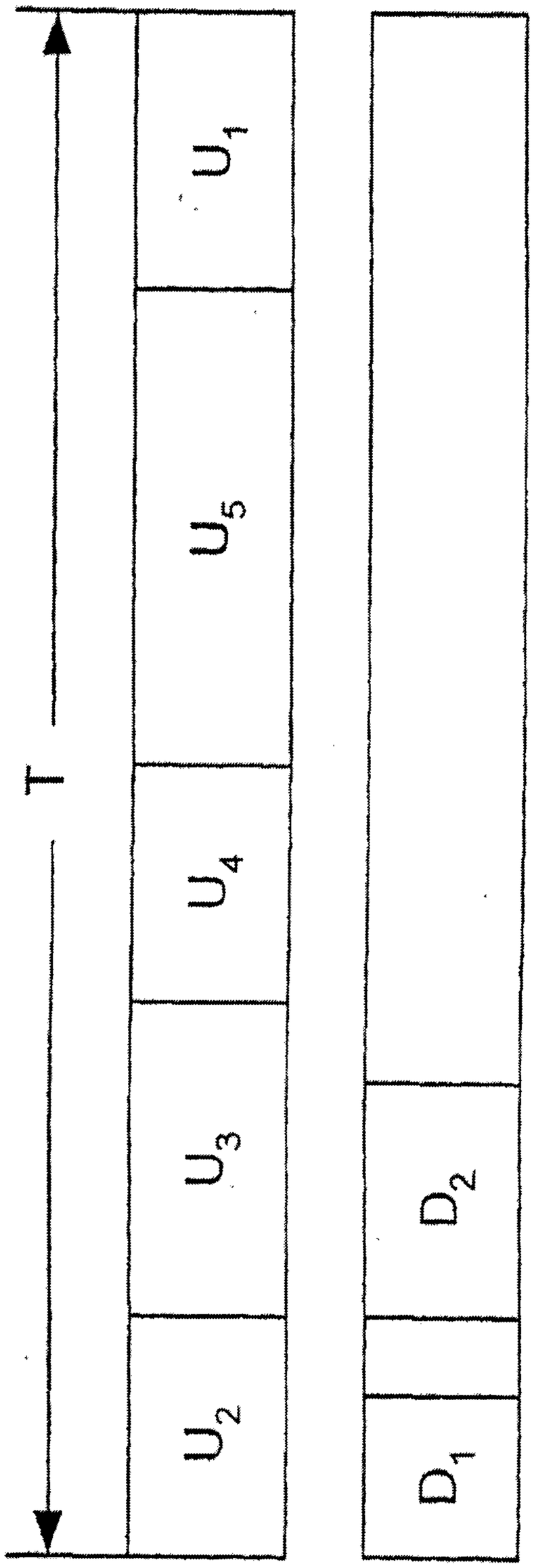


Figure 17: $D_1 < U_3$

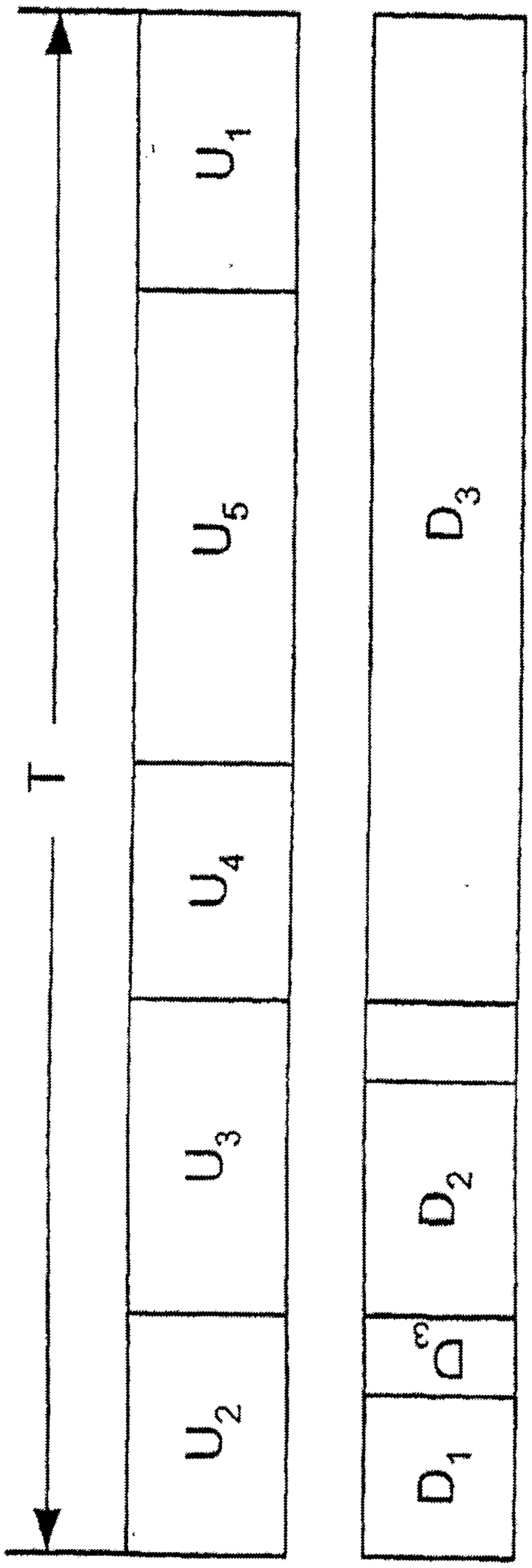


Figure 18:

$D_3 > U_4 + U_5 + U_1$

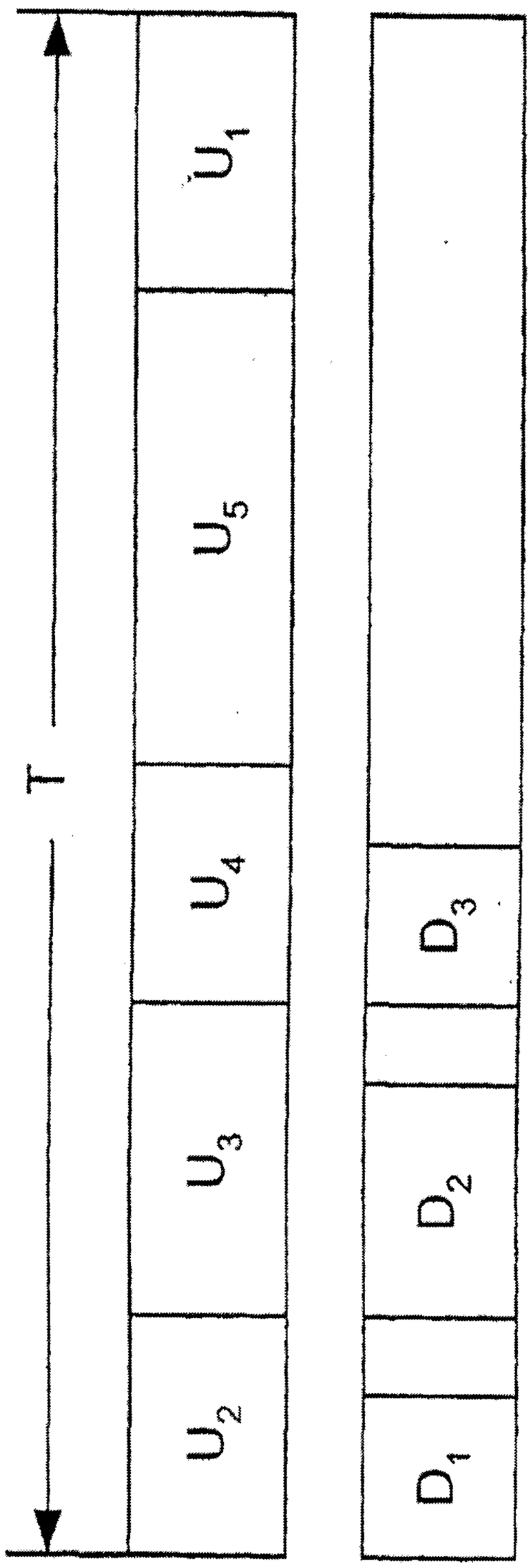


Figure 19: $D_3 < U_4$

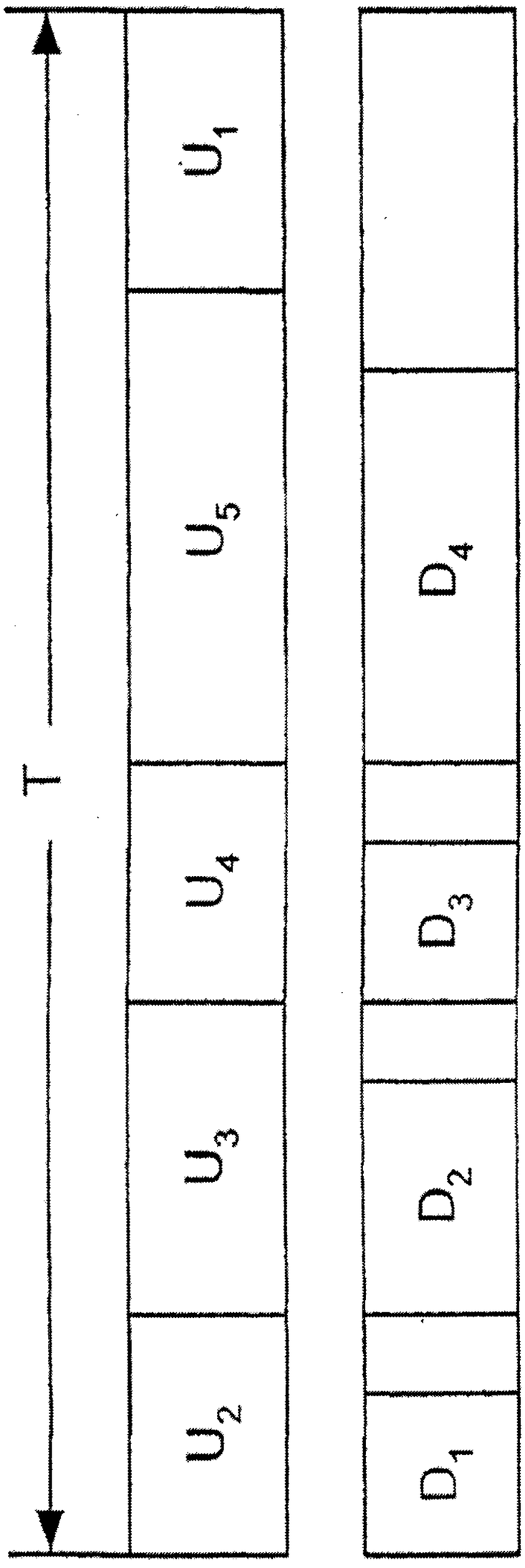


Figure 20: $D_4 < U_5$

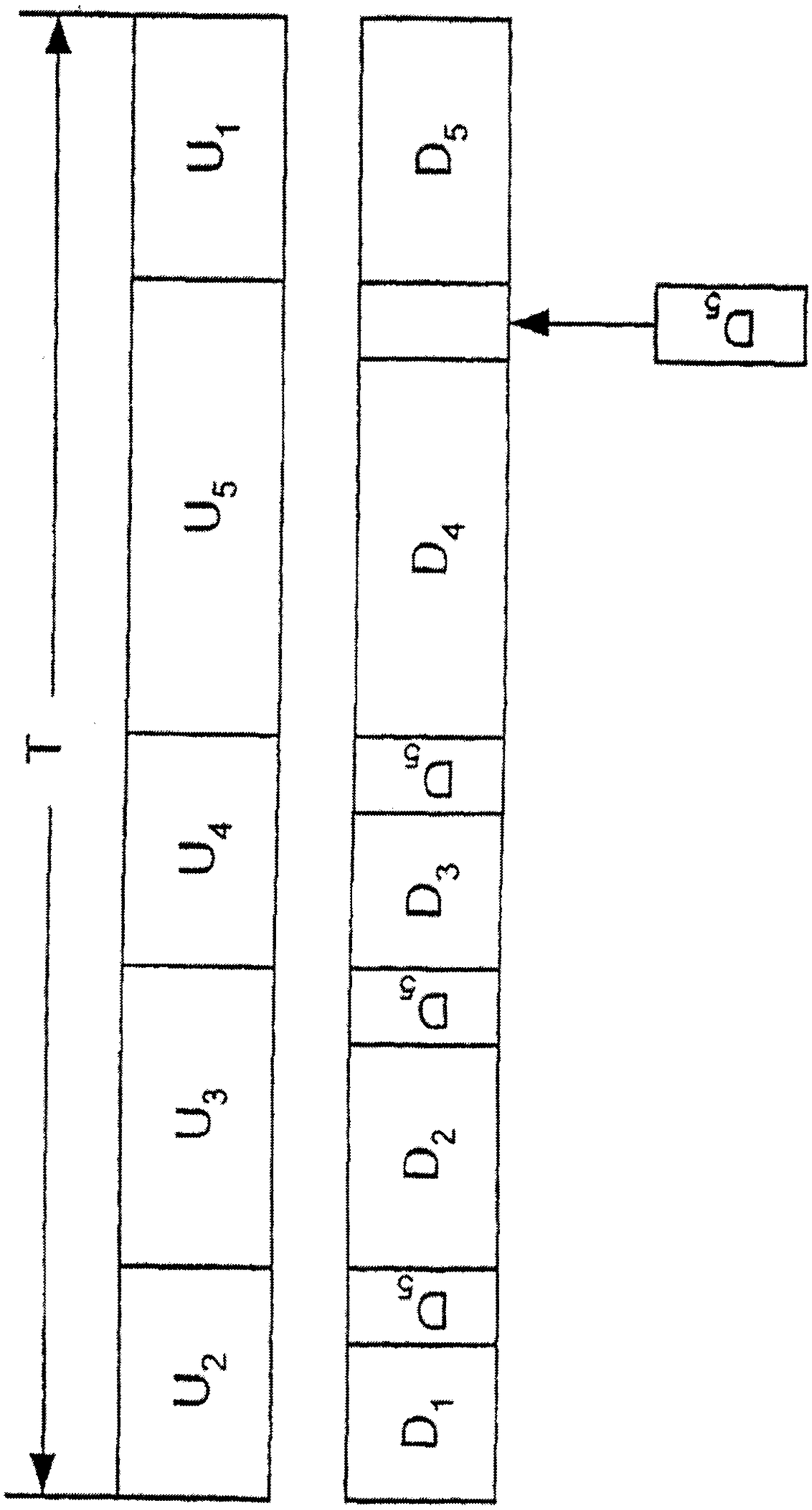


Figure 21

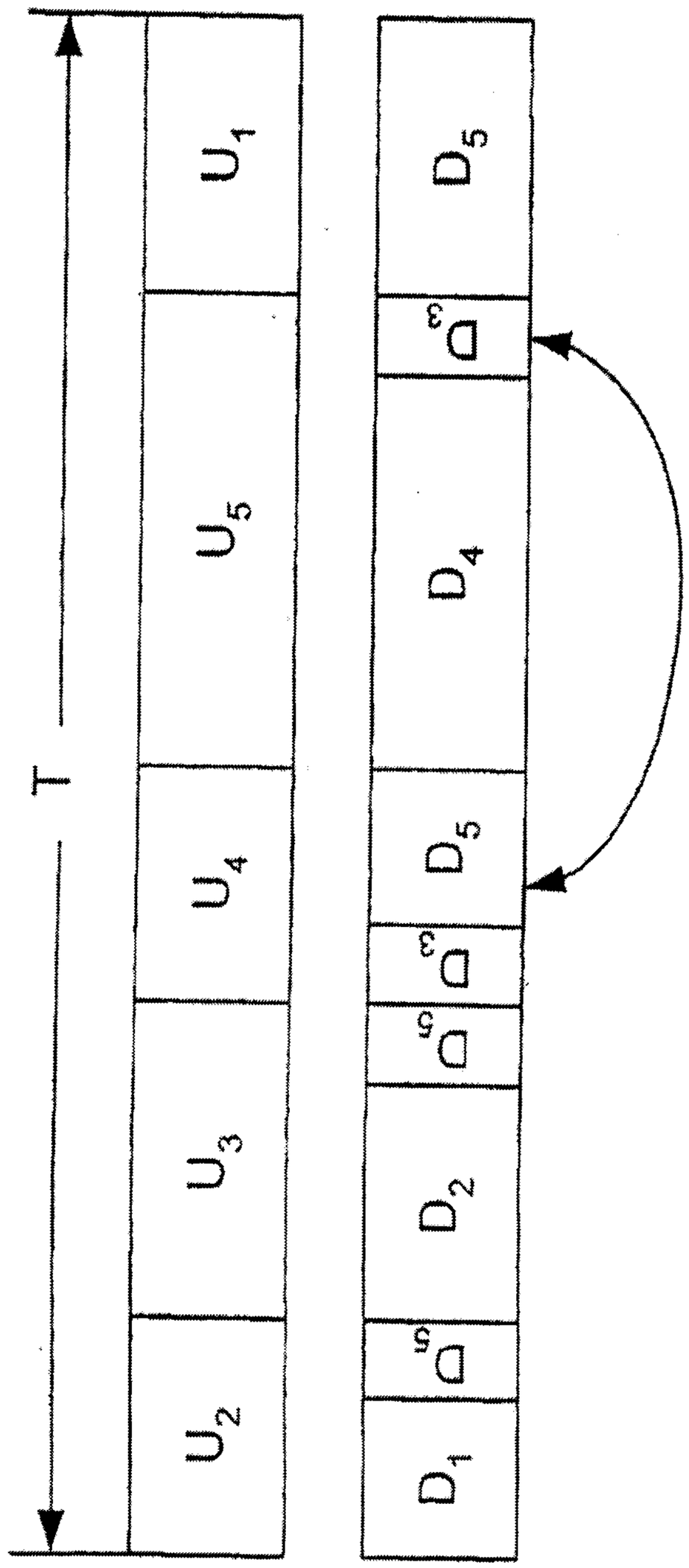
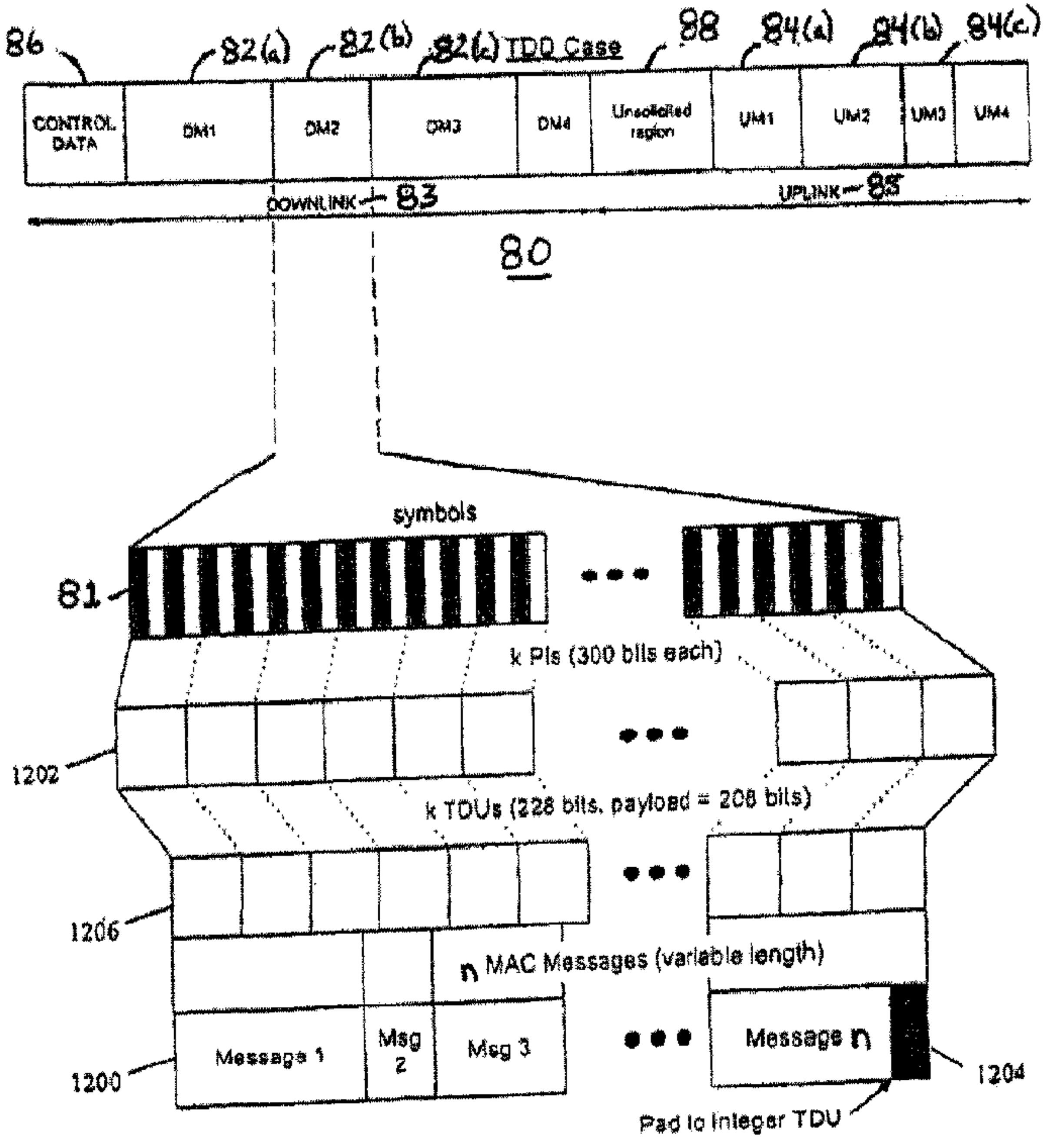


Figure 22


86
82(a)
82(b)
82(c) TDD Case
88
84(a)
84(b)
84(c)
CONTROL DATA
DM1
DM2
DM3
DM4
Unsolicited region
UM1
UM2
UM3
UM4
DOWNLINK 83
UPLINK 85
80
symbols
81
k Pls (300 bits each)
1202
k TDUs (228 bits, payload = 208 bits)
1206
n MAC Messages (variable length)
Message 1
Msg 2
Msg 3
Message n
1200
1204
Pad to Integer TDU