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[Continued on next page]

(54) **Title:** TRANSMISSION STRUCTURE SUPPORTING MULTI-USER SCHEDULING AND MIMO TRANSMISSION

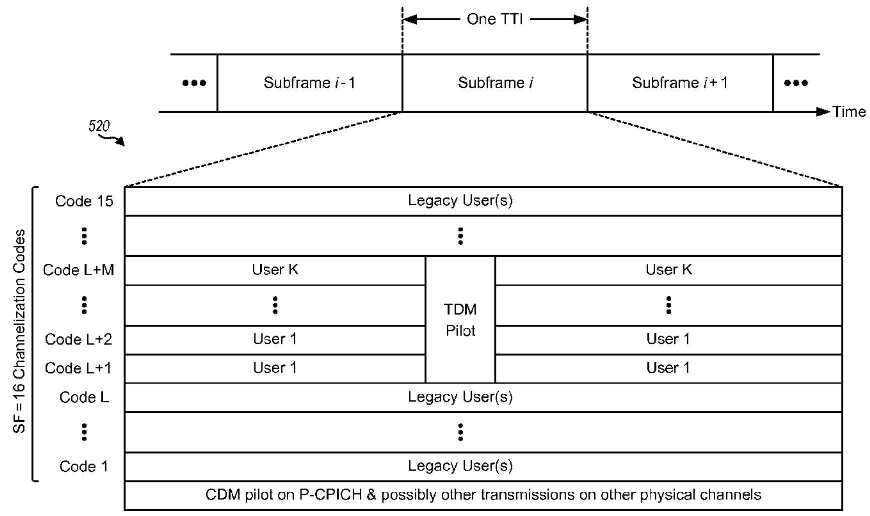

FIG. 5B

(57) **Abstract:** Techniques for transmitting data in a manner to support multi-user scheduling, multiple-input multiple-output (MIMO) transmission, and interference cancellation are described. A base station assigns multiple time segments of a transmission time interval (TTI) to at least one terminal, maps data for each terminal to at least one time segment assigned to the terminal, and spreads the data in each time segment with at least one channelization code used in the TTI. A terminal receives an assignment of at least one time segment from among multiple time segments of the TTI, obtains input samples for the at least one time segment, and despreads the input samples with the at least one channelization code used in the TTI.

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TRANSMISSION STRUCTURE SUPPORTING MULTI-USER SCHEDULING AND MIMO TRANSMISSION

I. Reference to Co-Pending Applications for Patent

[0001] The present Application for Patent is related to the following co-pending U.S. Patent Application:

Patent Application No. 11/502,882 entitled "TRANSMISSION STRUCTURE SUPPORTING MULTI-USER SCHEDULING AND MIMO TRANSMISSION" filed August 10, 2006, and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

I. Field

[0002] The present disclosure relates generally to communication, and more specifically to techniques for transmitting data in a wireless communication network.

II. Background

[0003] A wireless multiple-access communication network can concurrently communicate with multiple terminals on the downlink and uplink. The downlink (or forward link) refers to the communication link from the base stations to the terminals, and the uplink (or reverse link) refers to the communication link from the terminals to the base stations. Multiple terminals may simultaneously receive signaling and data on the downlink and/or transmit signaling and data on the uplink. This may be achieved by multiplexing the transmissions to be orthogonal to one another (e.g., on the downlink) and/or by controlling the transmit power of each transmission to achieve a desired received signal quality for the transmission while reducing interference to other transmissions (e.g., on the uplink).

[0004] A base station may transmit data to a number of terminals within its coverage area. To improve performance, it is desirable for the base station to be able to schedule a variable number of terminals in each transmission time interval (TTI). A TTI is the smallest unit of time over which a data packet can be scheduled for transmission to one or more terminals. To further improve performance, the base station may utilize multiple antennas to transmit multiple data streams simultaneously to the terminals.

These data streams are distorted by the radio environment and act as interference to one other at each recipient terminal. The interference hinders each terminal's ability to recover the data stream(s) sent for the terminal.

[0005] There is therefore a need in the art for techniques to efficiently transmit data to multiple terminals.

SUMMARY

[0006] Techniques for transmitting data in a manner to support multi-user scheduling, multiple-input multiple-output (MIMO) transmission, and interference cancellation are described herein. The techniques may improve performance.

[0007] According to an exemplary embodiment, an apparatus is described which includes at least one processor and a memory. The processor(s) assign multiple time segments of a TTI to at least one terminal, map data for each terminal to at least one time segment assigned to the terminal, and spread the data in each time segment with at least one channelization code used in the TTI.

[0008] According to another exemplary embodiment, an apparatus is described which includes at least one processor and a memory. The processor(s) receive an assignment of at least one time segment from among multiple time segments of a TTI, obtain input samples for the at least one time segment, and despread the input samples with at least one channelization code used in the TTI.

[0009] According to yet another exemplary embodiment, an apparatus is described which includes at least one processor and a memory. The processor(s) assign a first set of channelization codes to a first set of at least one terminal for a TTI, spread data for each terminal in the first set with at least one channelization code assigned to the terminal, generate a time division multiplex (TDM) pilot based on the channelization codes in the first set, map the TDM pilot to a time segment within the TTI, and map spread data for the first set of at least one terminal to remaining portion of the TTI.

[0010] According to yet another exemplary embodiment, an apparatus is described which includes at least one processor and a memory. The processor(s) receive an assignment of at least one channelization code for a terminal for a TTI, receive a TDM pilot from a time segment within the TTI, with the TDM pilot being generated based on a first set of channelization codes including the at least one channelization code assigned to the terminal, receive data from remaining portion of the TTI, and despread the received data with the at least one channelization code assigned to the terminal.

[0011] Various aspects and exemplary embodiments of the invention are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 shows a wireless communication network.

[0013] FIG. 2 shows a frame format in W-CDMA.

[0014] FIG. 3 shows a CDM format for the HS-PDSCH in HSDPA.

[0015] FIG. 4A shows a TDM format for the HS-PDSCH in HSDPA.

[0016] FIG. 4B shows a TDM format for the HS-PDSCH in HSDPA with MIMO.

[0017] FIG. 4C shows an exemplary transmission for HSDPA with the TDM format.

[0018] FIG. 4D shows assignment of time segments in a TTI to terminals.

[0019] FIG. 5A shows a CDM format with a TDM pilot for the HS-PDSCH in HSDPA.

[0020] FIG. 5B shows another CDM format with a TDM pilot for the HS-PDSCH.

[0021] FIG. 6 shows an exemplary transmission scheme for the TDM pilot.

[0022] FIG. 7 shows a block diagram of a base station and a terminal.

[0023] FIG. 8 shows a TX data processor and a TX spatial processor.

[0024] FIG. 9 shows an RX processor with successive interference cancellation.

[0025] FIG. 10 shows a process performed by the base station for downlink transmission.

[0026] FIG. 11 shows a process performed by the terminal for downlink data reception.

[0027] FIG. 12 shows another process for downlink data transmission.

[0028] FIG. 13 shows another process for downlink data reception.

DETAILED DESCRIPTION

[0029] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any exemplary embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other exemplary embodiments.

[0030] **FIG. 1** shows a wireless communication network 100 with multiple base stations 110 and multiple terminals 120. A base station is generally a fixed station that communicates with the terminals and may also be referred to as a Node B, an access point, a base transceiver subsystem (BTS), or some other terminology. Each base station 110 provides communication coverage for a particular geographic area and supports communication for the terminals located within the coverage area. A system controller 130 couples to base stations 110 and provides coordination and control for these base stations. System controller 130 may be a single network entity or a collection of network entities.

[0031] Terminals 120 may be dispersed throughout the system, and each terminal may be stationary or mobile. A terminal may also be referred to as a user equipment (UE), a mobile station (MS), an access terminal (AT), a subscriber unit, a station (STA), or some other terminology. A terminal may be a cellular phone, a wireless device, a personal digital assistant (PDA), a handheld device, a wireless modem, a laptop computer, and so on. A terminal may actively communicate with a base station (as shown by a solid line with double arrows) or may receive pilot and exchange signaling with a base station (as shown by a dashed line with double arrows). The terms "terminal" and "user" are used interchangeably herein.

[0032] The techniques described herein may be used for various wireless communication networks such as Code Division Multiple Access (CDMA) networks, Time Division Multiple Access (TDMA) networks, Frequency Division Multiple Access (FDMA) networks, and Orthogonal FDMA (OFDMA) networks. The terms "network" and "system" are often used interchangeably. A CDMA network may implement a radio technology such as Wideband-CDMA (W-CDMA, UMTS), cdma2000, and so on. cdma2000 covers IS-2000, IS-856 and IS-95 standards. A TDMA network may implement a radio technology such as Global System for Mobile Communications (GSM). These various radio technologies and standards are known in the art. W-CDMA and GSM are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). cdma2000 is described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). The techniques may be used for downlink transmissions as well as uplink transmissions. For clarity, the techniques are described below for downlink transmissions in a Universal Mobile Telecommunication System (UMTS) network that utilizes W-CDMA.

[0033] In UMTS, data for a terminal is processed as one or more transport channels at a higher layer. The transport channels may carry data for one or more services, e.g., voice, video, packet data, and so on. The transport channels are mapped to physical channels at a physical layer. The physical channels (except for a Synchronization Channel (SCH)) are channelized with different channelization codes and are orthogonal to one another in code domain. 3GPP Release 5 and later supports High-Speed Downlink Packet Access (HSDPA), which is a set of channels and procedures that enable high-speed packet data transmission on the downlink.

[0034] Table 1 lists downlink and uplink channels used for HSDPA and provides a short description for each channel. A radio link for a terminal may include zero, one, or multiple HS-SCCHs and zero, one, or multiple HS-PDSCHs.

Table 1

Link	Channel	Channel Name	Description
Downlink	HS-SCCH	Shared Control Channel for HS-DSCH	Carry signaling for HS-PDSCH.
Downlink	HS-PDSCH	High Speed Physical Downlink Shared Channel	Carry packets for different terminals.
Uplink	HS-DPCCH	Dedicated Physical Control Channel for HS-DSCH	Carry feedback for downlink transmission in HSDPA.

[0035] **FIG. 2** shows a frame format in W-CDMA. The timeline for transmission is divided into radio frames. The radio frames on the downlink are defined relative to the timing of a Common Pilot Channel (CPICH), which has the same timing as the SCH. Each radio frame has a duration of 10 milliseconds (ms) and is identified by a 12-bit system frame number (SFN). Each radio frame is further partitioned into 15 slots, which are labeled as slot 0 through slot 14. Each slot has a duration of 0.667 ms and includes 2560 chips at 3.84 Mcps. Each radio frame is also partitioned into five subframes 0 through 4. Each subframe has a duration of 2 ms and spans 3 slots. The subframes of the HS-SCCH are time aligned with the radio frames of the CPICH. The subframes of the HS-PDSCH are shifted to the right (or delayed) by two slots relative to the subframes of the HS-SCCH.

[0036] HSDPA uses a TTI of 2 ms, which is one subframe. The TTI governs the following operational aspects of HSDPA.

- Terminals are scheduled for transmission in each TTI.
- A packet transmission or retransmission for a terminal is sent in one TTI.
- Acknowledgement (ACK) or negative acknowledgement (NAK) is sent after each packet re/transmission.

- Channel quality indicator (CQI) is reported on a TTI by TTI basis, with possible reduction of reporting rate by skipping TTIs in a regular manner (for duty cycle less than 100%).

[0037] **FIG. 3** shows a code division multiplex (CDM) format/structure for the HS-PDSCH in HSDPA. The CDM format is used in 3GPP Release 5 and later. Up to 15 channelization codes with a spreading factor of 16 ($SF = 16$) may be used for HSDPA. The channelization codes are orthogonal variable spreading factor (OVSF) codes that are generated in a structured manner. The spreading factor is the length of a channelization code. A data symbol is spread with a channelization code to generate SF chips for the data symbol. The channelization codes for HSDPA may be assigned to terminals in each TTI based on various factors such as data rate requests of the terminals, the number of available channelization codes, the available transmit power for HSDPA, and so on. In the example shown in FIG. 3, 15 channelization codes are used for HSDPA, user 1 is assigned channelization codes 1, 2 and 3, user 2 is assigned channelization codes 4 and 5, user 3 is assigned channelization codes 6 and 7, and so on, and user K is assigned channelization code 15.

[0038] HSDPA may be considered as having up to 15 HS-PDSCHs, with each HS-PDSCH corresponding to a different $SF = 16$ channelization code. HSDPA may also be considered as having a single HS-PDSCH with up to 15 channelization codes. The following description assumes the former case, with up to 15 HS-PDSCHs being available for HSDPA.

[0039] FIG. 3 also shows a Primary Common Pilot Channel (P-CPICH) that carries a continuous CDM pilot that is spread with a fixed channelization code of $C_{ch,256,0}$. Pilot is data (e.g., a predefined bit sequence) that is known *a priori* by the base stations and the terminals. Pilot may also be referred to as reference, training signal, preamble, beacon, and so on. The channelization code for the P-CPICH has a spreading factor of 256 ($SF = 256$) and is a sequence of all zeros. The P-CPICH is sent in each slot. Other transmissions may also be sent on other physical channels (e.g., the HS-SCCH) with other channelization codes. One channelization code of $SF = 16$ ($C_{ch,16,0}$) is not used for HS-PDSCH transmission as this would collide with the transmission of the P-CPICH on $C_{ch,256,0}$, and other physical channels.

[0040] As shown in FIG. 3, multiple terminals may be assigned different channelization codes in a given TTI for HSDPA. Different sets of terminals may be assigned the channelization codes in different TTIs. A given terminal may be assigned any number of channelization codes in each TTI, and the assignment for the terminal may vary from TTI to TTI.

[0041] As shown in FIG. 3, HSDPA utilizes CDM to simultaneously transmit packets to different terminals in a given TTI. The channelization codes and transmit power are used by the base station as assignable resources to simultaneously serve multiple terminals. HSDPA supports multi-user scheduling, which refers to the ability to schedule multiple terminals in a given TTI. Multi-user scheduling may provide certain advantages over single-user scheduling, which can schedule a single terminal in a TTI. For example, the ability to schedule many terminals with small payloads in the same TTI is beneficial for efficient handling of low bit-rate delay-sensitive applications such as voice-over-Internet Protocol (VoIP).

[0042] MIMO transmission may be used to further improve performance. MIMO utilizes multiple transmit antennas and multiple receive antennas to achieve increased dimensionality, which may provide higher spectral efficiencies and higher maximum data rates per terminal.

[0043] For MIMO transmission on the downlink, a base station may transmit multiple (M) data streams simultaneously from multiple (T) transmit antennas to multiple receive (R) antennas at a terminal, where $M \leq \min\{T, R\}$, while reusing all allocated channelization codes. The data streams interfere with one another at the terminal. The terminal may perform MIMO detection to separate out the data streams. To improve performance, the terminal may perform successive interference cancellation (SIC). With SIC, the terminal first recovers one data stream, then estimates and subtracts the interference caused by this data stream, then recovers the next data stream in similar manner. By subtracting out the interference from each data stream that is recovered, the signal-to-interference-and-noise ratio (SINR) of each remaining data stream improves. It can be shown that minimum mean square error (MMSE) detection in combination with SIC (MMSE-SIC) can theoretically achieve optimal performance.

[0044] It is desirable to support both multi-user scheduling and SIC. However, the use of CDM for HSDPA may limit the benefits achievable for SIC. The complete benefits of SIC may be obtained when all available channelization codes are allocated to one terminal and by canceling the contributions of all channelization codes in a recovered data stream from the remaining data streams. If multiple terminals are scheduled in a given TTI with separate data streams that are multiplexed by CDM, then each terminal would need to demodulate and decode the transmission for that terminal as well as the other transmissions for other terminals in order to estimate and cancel the interference from all channelization codes. It may be impractical or even impossible to require a terminal to recover the transmissions for other terminals. Hence, the amount of interference that can be canceled may be limited by using the CDM format shown in FIG. 3.

[0045] **FIG. 4A** shows an exemplary embodiment of a time division multiplex (TDM) format/structure 400 for the HS-PDSCH in HSDPA. In this exemplary embodiment, a TTI is partitioned into multiple (S) time segments 1 through S, where in general S may be any value. In an exemplary embodiment, S is equal to 16, and each time segment includes 480 chips per channelization code at 3.84 Mcps or 30 symbols for $SF = 16$. This exemplary embodiment of $S = 16$, with 15 time segments being usable for data, preserves the existing rate matching table, which may simplify coding and decoding. In another exemplary embodiment, S is equal to 15, and each time segment includes 512 chips or 32 symbols for $SF = 16$. Other values may also be used for S. The P-CPICH may also be sent in each slot to retain backward compatibility with the CDM format shown in FIG. 3.

[0046] In an exemplary embodiment, which is referred to as full assignment, each time segment is assigned to only one terminal. The S time segments of a TTI may be assigned to one or multiple terminals. All of the channelization codes for HSDPA may be used in each of the S time segments. A terminal assigned with a given time segment is allocated all channelization codes for HSDPA in that time segment. In the example shown in FIG. 4A, user 1 is assigned time segments 1, 2 and 3, user 2 is assigned time segments 4 and 5, user 3 is assigned time segments 6 and 7, and so on, and user K is assigned time segment S. In general, each terminal may be assigned any number of time segments in a given TTI, up to the number of time segments available for data transmission.

[0047] **FIG. 4B** shows an exemplary embodiment of a TDM format 410 for the HS-PDSCH in HSDPA with MIMO. Multiple (M) data streams may be sent simultaneously in a TTI to one or multiple terminals. Resources such as time segments, channelization codes, and transmit power may be assigned for each data stream. In the full assignment embodiment, a terminal may be assigned the same time segment across all of the data streams. This exemplary embodiment allows the base station to schedule up to S terminals in a TTI while enabling each terminal to perform SIC over all channelization codes for HSDPA plus the known pilot channel and other physical channels that can be decoded by the terminal. In the example shown in FIG. 4B, user 1 is assigned time segments 1, 2 and 3 across all M data streams, user 2 is assigned time segments 4 and 5 across all M data streams, user 3 is assigned time segments 6 and 7 across all M data streams, and so on, and user K is assigned time segment S across all M data streams.

[0048] In another exemplary embodiment, which is referred to as partial assignment, a given time segment may be assigned to multiple terminals. The partial assignment may be performed in various manners. In one embodiment, each terminal may be assigned a subset of the channelization codes for HSDPA across the M data streams. In another embodiment, each terminal may be assigned all channelization codes for HSDPA for a subset (e.g., one) of the M data streams. In yet another embodiment, each terminal may be assigned a subset of the channelization codes for HSDPA for a subset of the data streams. In general, a terminal may be assigned any number of channelization codes in each of the M data streams within any time segment. Partial assignment allows the base station to schedule terminals with finer granularly in a TTI. Partial assignment may be used when scheduling more terminals with smaller payloads is preferred over scheduling fewer terminals with higher data rates, e.g., when VoIP is used by many terminals.

[0049] In yet another exemplary embodiment, a combination of full and partial assignments may be used for a given TTI. For example, full assignment may be used for some time segments (e.g., for terminals with SIC capability and/or larger data payload) and partial assignment may be used for other time segments (e.g., for terminals without SIC capability and/or with smaller data payload).

[0050] In an exemplary embodiment, one or more time segments are used to send a TDM pilot. A TDM pilot is a pilot transmitted in a portion of a TTI with a set of one or more channelization codes. Data may be transmitted with the same channelization code set in the remaining portion of the TTI. The data and TDM pilot thus share the TTI, time-wise, and use the same channelization code set. A time segment used for TDM pilot is referred to as a pilot segment. The TDM pilot may be sent on the HS-PDSCH among with the CDM pilot on the P-CPICH. The TDM pilot may be transmitted in various manners, as described below. In an exemplary embodiment, the TDM pilot is transmitted with all channelization codes used for HSDPA. The TDM pilot may be transmitted with the same transmit power per channelization code as the HSDPA data carried on HS-PDSCH, and the total transmit power for the TDM pilot would then be equal to the total transmit power for HSDPA data. The number of time segments to use for the TDM pilot may be selected based on a tradeoff between the benefits (e.g., improvement in throughput) achievable with the TDM pilot versus the overhead to send the TDM pilot.

[0051] In general, any of the S time segments may be used as a pilot segment. The TDM pilot may be sent in the first time segment of a TTI to allow all terminals to use the TDM pilot to recover the HSDPA data sent in subsequent time segments of the TTI. The TDM pilot may also be sent in a middle time segment of a TTI to be approximately equal distances over time to the two end time segments of the TTI. The TDM pilot may also be sent in other time segments.

[0052] In the exemplary embodiments shown in FIGS. 4A and 4B, the TDM pilot is transmitted in one time segment. If $S = 16$, then the overhead for the TDM pilot is $1/16 = 6.25\%$. In an exemplary embodiment, the TDM pilot is fixed and transmitted in one or more designated time segments of each TTI. In another exemplary embodiment, the TDM pilot is configurable and (1) may or may not be transmitted in a given TTI, (2) may be transmitted in a selectable number of time segments of a TTI, and/or (3) may be transmitted with different number of channelization codes. The configuration of the TDM pilot may be varied from TTI to TTI, from radio frame to radio frame, or more slowly.

[0053] The terminals may use the TDM pilot for various purposes such as channel estimation, channel quality measurement, and so on. A terminal may derive channel gain estimates for all data streams at all receive antennas (or between all transmit antennas and all receive antennas) based on the TDM pilot. The terminal may use the channel gain estimates to derive equalizer taps, spatial filter matrices, and so on. The terminal may then process the received signals with the equalizer taps and/or spatial filter matrices to recover the transmitted data streams.

[0054] The terminal may also measure the received SINR based on the TDM pilot, compute CQI (Channel Quality Indicator) based on the SINR estimate, and send the CQI to the base station. The terminals may also measure the received SINR based on the CDM pilot sent on the P-CPICH. However, the CQI computed based on the SINR achieved over the TDM pilot (or the pilot SINR) may be a better reflection of the SINR achieved over the HSDPA data (or the data SINR) since the TDM pilot is sent with the same channelization codes used for the HSDPA data and at the same power level as the HSDPA data. The base station knows the amount of transmit power used for HSDPA in each TTI and can approximately adjust the reported CQI to account for any changes in transmit power and/or code assignment from the time the terminal computes the pilot SINR to the time the base station sends HSDPA data using the reported CQI. A more accurate reported CQI, which may be obtained through the TDM pilot, may enable more accurate rate selection, which may improve performance of delay sensitive traffic as well as other traffic. The more accurate reported CQI may also support use of higher order modulation schemes such as, e.g., 64-QAM and 256-QAM.

[0055] The terminal may also determine a traffic-to-pilot ratio, which is a ratio of traffic power to pilot power, based on the TDM pilot. The terminal may derive a scalar based on, e.g., as a square root of, the traffic-to-pilot ratio. The terminal may multiply symbol estimates with the scalar to achieve proper scaling for the symbol estimates for subsequent decoding.

[0056] The terminal may use the SINR estimate for MIMO detection and/or demodulation. For example, the terminal may compute log likelihood ratios (LLRs) for code bits using the SINR estimate and may then decode the LLRs to obtain decoded data. A more accurate SINR estimate, which may be obtained through the TDM pilot, may result in more accurate LLR computation and improved demodulation and decoding performance, especially for modulation schemes with non-constant power constellations such as 16-QAM and 64-QAM.

[0057] The TDM pilot for HSDPA may be transmitted concurrently with other data and/or control channels, e.g., the HS-SCCH. The TDM pilot resembles a pure TDM pilot burst, which has been shown to provide improved training quality over a CDM pilot. The possible performance improvement provided by the TDM pilot may justify transmission of the TDM pilot despite the overhead penalty.

[0058] **FIG. 4C** shows an exemplary transmission for HSDPA with TDM format 400 in FIG. 4A. The base station schedules terminals for data transmission on the HS-PDSCH in a TTI. The base station sends signaling/control information for each scheduled terminal on the HS-SCCH. The signaling for each scheduled terminal indicates the specific time segment(s) assigned to that terminal in the TTI. The base station sends HSDPA data for the scheduled terminals in their assigned time segments on the HS-

PDSCH. The data transmission on the HS-PDSCH is delayed by $\tau_{\text{HS-PDSCH}} = 2$ slots from the corresponding signaling transmission on the HS-SCCH.

[0059] Each terminal that might receive data on the HS-PDSCH in the TTI processes the HS-SCCH to determine whether signaling has been sent for that terminal. Each scheduled terminal processes the TDM pilot (if sent) and further processes the assigned time segment(s) to recover the HSDPA data sent for the terminal. Each scheduled terminal sends an ACK if a packet sent in the current TTI is decoded correctly and sends a NAK otherwise. Each terminal may also estimate the pilot SINR based on the TDM pilot (if sent) and/or the CDM pilot, computes the CQI based on the SINR estimate, and sends the CQI along with the ACK/NAK on the HS-DPCCH. The feedback transmission on the HS-DPCCH is delayed by approximately 7.5 slots from the end of the corresponding data transmission on the HS-PDSCH, as received at the terminal. Terminals 1 through K have propagation delays of $\tau_{\text{PD},1}$ through $\tau_{\text{PD},\text{K}}$, respectively, to the base station. The HS-DPCCHs for terminals 1 through K are thus delayed by approximately $7.5 \text{ slots} + \tau_{\text{PD},1}$ through $7.5 \text{ slots} + \tau_{\text{PD},\text{K}}$, respectively, relative to the HS-PDSCH at the base station. Terminals that are not scheduled in the current TTI may also send ACK/NAK for a prior packet transmission and CQI for the current TTI on the HS-DPCCHs.

[0060] The base station may support both the TDM format shown in FIG. 4A and the CDM format shown in FIG. 3. The base station may select either the TDM or CDM format in each TTI and may send signaling for the scheduled terminals on the HS-SCCH. Each scheduled terminal may know whether the TDM or CDM format is being used based on the capability of the terminal, configuration information exchanged earlier (e.g., during call setup), signaling sent on the HS-SCCH, and so on. For example, legacy terminals that do not support the TDM format may assume that HSDPA data is sent using the CDM format. New terminals that support both the TDM and CDM formats may be informed (e.g., by higher layer signaling) which format will be used for the current TTI, the current radio frame, or the entire call.

[0061] It is desirable to use the same signaling format on the HS-SCCH for both the TDM and CDM formats. The signaling on the HS-SCCH includes a number of parameters, one of which is a 7-bit channelization-code-set (CCS) parameter. For the CDM format, the CCS parameter indicates the starting channelization code and the number of consecutive channelization codes assigned to a terminal in the current TTI. In an exemplary embodiment, the CCS parameter is also used to convey the assignment of time segments for the TDM format. The interpretation of the CCS bits would be different depending on whether the TDM or CDM format is used for the HS-PDSCH.

[0062] **FIG. 4D** shows an exemplary embodiment of assigning time segments in a TTI to terminals. A terminal may be assigned one or more consecutive time segments in the TTI. In an exemplary embodiment, to reduce signaling, the terminals may be assigned time segments in a sequential order based on the number of assigned time segments. For example, the terminal with the most number of time segments may be assigned first in the TTI, the terminal with the second most number of time segments may be assigned next, and so on, and the terminal with the least number of time segments may be assigned last in the TTI. In the example shown in FIG. 4D, user 1 is assigned the first L_1 time segments, user 2 is assigned the next L_2 time segments, where $L_2 \leq L_1$, user 3 is assigned the next L_3 time segments, where $L_3 \leq L_2$, and so on, and user K is assigned the last L_K time segments, where $L_K \leq L_{K-1}$.

[0063] In the exemplary embodiment shown in FIG. 4D, the maximum of time segments that can be assigned to a terminal is dependent on the starting time segment for the terminal.

- If the starting time segment is the first time segment of the TTI, then the terminal may be assigned 1 to S time segments.
- If the starting time segment is the second time segment, then the terminal may be assigned one time segment since another terminal with its starting point at the first time segment was assigned only one time segment.
- If the starting time segment is the third time segment, then the terminal may be assigned either one or two time segments.
- If the starting time segment is the N-th time segment, where $1 < N \leq S$, then the terminal may be assigned from one to $\min\{N-1, S-N\}$ time segments. The limitation of $N-1$ is due to the sequential order of assigning time segments. The limitation of $S-N$ is due to the finite length of the TTI. For a terminal starting in the second half of the TTI, the limitation of $S-N$ is more restrictive than the limitation of N.

[0064] A total of 15 time segments in a TTI may be assignable to the terminals for HSDPA if (a) $S = 16$ and the TDM pilot is sent in one time segment or (b) $S = 15$ and the TDM pilot is not sent. For the assignment embodiment shown in FIG. 4D, if 15 time segments are assignable in a TTI, then there are 71 possible assignments of time segments. The time segment assignment for a terminal may be conveyed with the 7-bit CCS parameter. In this case, 71 out of 128 possible values for the CCS parameter may be used to convey the time segment assignment. The $128 - 71 = 57$ remaining values may be used for other signaling.

[0065] In another exemplary embodiment, the terminals may be assigned one or more consecutive time segments in the reverse order shown in FIG. 4D. For example, the terminal with the least number of time segments may be assigned first in the TTI, the terminal with the second least number of time segments may be assigned next, and so on, and the terminal with the most number of time segments may be assigned last in the TTI. In yet another exemplary embodiment, a terminal may be assigned one or more consecutive time segments anywhere in a TTI. This exemplary embodiment is similar to the manner in which one or more consecutive channelization codes in a code tree may be assigned to a terminal for the CDM format shown in FIG. 3. The signaling for a terminal may then indicate the starting time segment and the number of consecutive time segments assigned to the terminal. If a total of 15 time segments are assignable in a TTI, then there are 120 possible assignments of time segments. The time segment assignment for a terminal may be conveyed with the 7-bit CCS parameter. In this case, $128 - 120 = 8$ remaining values may be used for other signaling.

[0066] As noted above, a combination of full and partial assignments may be used for a given TTI. To reduce signaling, some commonly used partial assignments may be defined for the (e.g., 57) remaining values of the 7-bit CCS parameter. Additional partial assignments may also be defined by using more signaling bits. In the extreme, the channelization codes in each time segment may be assigned to the terminals, e.g., in the same manner as the channelization codes are assigned to the terminals in each TTI for the CDM format.

[0067] One or more HS-SCCHs are sent simultaneously from a base station using channelization codes with a spreading factor of 128. The signaling for each terminal is scrambled with a UE identity for that terminal and sent on one of the HS-SCCHs using one of the $SF = 128$ channelization codes allocated to the set of HS-SCCHs. In an exemplary embodiment, to reduce the channelization code space used for the set of HS-SCCHs, the signaling for terminals observing good channel conditions may be sent using channelization codes with a spreading factor of 256 instead of 128. These terminals may be terminals employing MIMO, which typically relies on higher SINR to achieve good performance. A higher code rate and/or a higher order modulation scheme may be used in combination with the larger spreading factor.

[0068] **FIG. 5A** shows an embodiment of a CDM format 510 with a TDM pilot, which may be used for the HS-PDSCH in HSDPA. In this embodiment, up to 15 channelization codes with a spreading factor of 16 $(\mathrm{SF}=16)$ may be used for HSDPA in a given TTI, and each channelization code may be assigned to a terminal for the entire TTI. In the example shown in FIG. 5A, all 15 channelization codes are used for HSDPA, user 1 is assigned channelization codes 1, 2 and 3, user 2 is assigned channelization codes 4 and 5, user 3 is assigned channelization codes 6 and 7, and so on, and user K is assigned channelization code 15.

[0069] In the embodiment shown in FIG. 5A, the TDM pilot is transmitted in a time segment that occupies a fraction of the TTI and with all channelization codes used for HSDPA. In one embodiment, the time segment is $1/16$ of the TTI, which is 480 chips for HSDPA. In general, the TDM pilot may be transmitted in a time segment of any duration and located in any part of the TTI. The terminals may know the presence as well as the location of the TDM pilot. Each terminal may then use the TDM pilot for various purposes such as channel estimation, channel quality measurement, and so on.

[0070] **FIG. 5B** shows an embodiment of a CDM format 520 with a TDM pilot, which may also be used for the HS-PDSCH in HSDPA. In this embodiment, up to 15 channelization codes with a spreading factor of 16 $(\mathrm{SF}=16)$ may be used for HSDPA in a given TTI, and each channelization code may be assigned to a terminal for the entire TTI. Any $\mathrm{SF}=16$ channelization code not used for HSDPA may be used for transmissions other than HSDPA. As an example, for one $\mathrm{SF}=16$ channelization code not used for HSDPA, non-HSDPA data may be transmitted to one or more users with (i) two $\mathrm{SF}=32$ channelization codes, (ii) four $\mathrm{SF}=64$ channelization codes, (iii) one $\mathrm{SF}=32$ channelization code and two $\mathrm{SF}=64$ channelization codes, (iv) eight $\mathrm{SF}=128$ channelization codes, and so on. In the example shown in FIG. 5B, L $\mathrm{SF}=16$ channelization codes 1 through L may or may not be used for HSDPA, M channelization codes $\mathrm{L}+1$ through $\mathrm{L}+\mathrm{M}$ are used for HSDPA, and the remaining channelization codes $\mathrm{L}+\mathrm{M}+1$ through 15 may or may not be used for HSDPA. User 1 is assigned channelization codes $\mathrm{L}+1$ and $\mathrm{L}+2$, and so on, and user K is assigned channelization code $L+M$. In general, any suitable set of $SF=16$ channelization codes may be used for HSDPA.

[0071] In the embodiment shown in FIG. 5B, the TDM pilot is transmitted in a time segment with a subset of the 15 channelization codes that may be used for HSDPA. The time segment may be $1/16$ of the TTI or some other duration. The number of channelization codes and which channelization codes to use for the TDM pilot may be determined in various manners, as described below. Terminals that know the presence and location of the TDM pilot may use the TDM pilot for various purposes such as channel estimation, channel quality measurement, and so on.

[0072] The system may support "legacy" users as well as "new" users for HSDPA. A new user may support HSDPA and may also be capable of processing the TDM pilot. A legacy user may support HSDPA (e.g., as defined in 3GPP Release 5 or 6) but may not be capable of processing the TDM pilot (e.g., because the legacy user does not know the existence of the TDM pilot). A legacy user may use the CDM pilot transmitted on the P-CPICH for channel estimation, channel quality measurement, and so on.

[0073] The system may transmit the TDM pilot in various manners in order to support both legacy and new users. In a given TTI, HSDPA data may be sent to only legacy user(s), or only new user(s), or both legacy and new users, or no users. The TDM pilot may be transmitted as follows.

[0074] If HSDPA data is not transmitted to any new user in the TTI (i.e., HSDPA data is transmitted to only legacy user(s) or is not transmitted to any user in the TTI), then the TDM pilot may be omitted since it may not benefit any of the users receiving data in the TTI. Omitting the TDM pilot may also avoid degradation to the users receiving data in the TTI.

[0075] If HSDPA data is transmitted to only new user(s) on all 15 $SF=16$ channelization codes in the TTI, then the TDM pilot may be transmitted with all 15 channelization codes, as shown in FIG. 5A. The new user(s) would know the presence and location of the TDM pilot and may use the TDM pilot to demodulate the HSDPA data sent in the TTI.

[0076] If HSDPA data is transmitted to new user(s) on a subset of the 15 $SF=16$ channelization codes in the TTI, then the TDM pilot may be transmitted in various manners. In a first embodiment, the TDM pilot is transmitted with only the channelization codes assigned to the new user(s) for HSDPA. In the example shown in

FIG. 5B, the new user(s) may be assigned channelization codes $L+1$ through $L+M$ for HSDPA. Channelization codes 1 through L and channelization codes $L+M+1$ through 15 may be assigned to legacy user(s) for HSDPA (as shown in FIG. 5B) or may be used for non-HSDPA data sent to other users (not shown in FIG. 5B). The TDM pilot may then be transmitted with only channelization codes $L+1$ through $L+M$. This embodiment avoids degradation to other users not be capable of processing the TDM pilot.

[0077] In a second embodiment, the TDM pilot is transmitted with all channelization codes used for HSDPA for new and legacy users. In the example shown in FIG. 5B, the new and legacy users may be assigned channelization codes $L+1$ through $L+M$ for HSDPA. Channelization codes 1 through L and channelization codes $L+M+1$ through 15 may be used for non-HSDPA data sent to other users. The TDM pilot may then be transmitted with only channelization codes $L+1$ through $L+M$. In this embodiment, the new user(s) may be able to use the TDM pilot sent in the TTI. The legacy user(s) may not know the existence of the TDM pilot and may process the portion of the TDM pilot sent with their assigned channelization code(s) as if it is HSDPA data. The TDM pilot may thus act as noise to the legacy user(s). The channelization codes used for non-HSDPA data sent to other users are not affected by the TDM pilot.

[0078] In a third embodiment, the TDM pilot is transmitted with all or a predetermined number of $SF=16$ channelization codes. In this embodiment, the TDM pilot may puncture (or replace) the HSDPA data of legacy user(s) and/or the non-HSDPA data of other users. Each user whose channelization code is punctured by the TDM pilot may observe noise from the portion of the TDM pilot sent with that channelization code. The number of channelization codes to use for the TDM pilot may be selected based on a tradeoff between the performance of the new user(s) and the performance of the remaining users. The number of channelization codes to puncture and which channelization codes to puncture may be determined based on various factors, which may relate to the performance of the affected users.

[0079] Table 2 summarizes the transmission of the TDM pilot for the various scenarios described above.

Table 2

HSDPA data sent to ...	TDM pilot transmission
No users	Do not transmit TDM pilot
Only legacy user(s)	Do not transmit TDM pilot
New user(s) on all 15 SF = 16 channelization codes	Transmit TDM pilot with all 15 channelization codes
New user(s) on some of the 15 SF = 16 channelization codes	Option 1. Transmit TDM pilot with only channelization code(s) used for HSDPA for the new user(s) 2. Transmit TDM pilot with all channelization codes used for HSDPA for the new and legacy users 3. Transmit TDM pilot with all or a predetermined number of channelization codes available for HSDPA

[0080] **FIG. 6** shows an exemplary transmission scheme 610 for the TDM pilot, which may be used for any of the TDM and CDM formats shown in FIGS. 4A, 4B, 5A and 5B. In each TTI for the HS-PDSCH, signaling/control information for the scheduled terminal(s) may be sent on the HS-SCCH two slots prior to the data transmission on the HS-PDSCH. A terminal may be assigned certain TTIs in which the terminal might receive data. The terminal may then wake up prior to each assigned TTI to receive any data sent to the terminal and may go to sleep in the time period between the assigned TTIs in order to conserve battery power. It may be desirable to transmit the TDM pilot such that the terminal can receive the TDM pilot near the start of the HS-SCCH for each assigned TTI.

[0081] In the embodiment shown in FIG. 6, the start of the HS-SCCH for an assigned TTI is at time T_1, and the start of the HS-PDSCH for the assigned TTI is at time T_3. If a TDM pilot 612 is transmitted on the HS-PDSCH starting at time T_2, which is shortly after the start of the second slot of a prior TTI for the HS-PDSCH, then the terminal can receive TDM pilot 612 near the start of the HS-SCCH. A primary SCH and a secondary SCH may be sent in the first 256 chips of each slot and may not be orthogonal to other transmissions on the downlink. The start of the TDM pilot at time T_2 may be selected to be after the end of the primary and secondary SCH in order to avoid collision between the TDM pilot and the SCH. The terminal may be able to derive a channel estimate based on TDM pilot 612, use this channel estimate to demodulate the HS-SCCH, and receive the signaling/control information sent on the HS-SCCH. If the terminal is scheduled for data transmission in the assigned TTI, then the terminal may also use the channel estimate derived from TDM pilot 612 to demodulate the HS-PDSCH. Alternatively, the terminal may derive a new channel estimate based on (i) only TDM pilot 614 sent in the assigned TTI or (ii) both TDM pilots 612 and 614 sent in the prior and assigned TTIs. The terminal may then demodulate the HS-PDSCH in the assigned TTI based on the new channel estimate.

[0082] The TDM pilot may also be sent at the end of the first slot, at the middle or the end of the second slot, or at some other location of a TTI for the HS-PDSCH. Transmitting the TDM pilot near the start of the HS-SCCH may allow terminals to more quickly demodulate the HS-SCCH, which may reduce buffering requirements and/or provide other benefits.

[0083] **FIG. 7** shows a block diagram of an exemplary embodiment of base station 110 and terminal 120. Base station 110 may be one of the base stations in FIG. 1. Terminal 120 may be one of the terminals in FIG. 1. In this exemplary embodiment, base station 110 is equipped with multiple (T) antennas 718a through 718t that may be used for data transmission and reception. Terminal 120 is equipped with multiple (R) antennas 752a through 752r that may be used for data reception and one antenna 752a that may be used for data transmission. Each antenna may be a physical antenna, a virtual antenna comprising an antenna array and an appropriate beam forming device or an antenna array with a fixed weighting network, etc.

[0084] At base station 110, a transmit (TX) data processor 712 receives and processes traffic data from a data source 710 and generates data symbols. TX data processor 712 also processes signaling from a controller 730 and generates signaling symbols. As used herein, a data symbol is a symbol for data, a signaling symbol is a symbol for signaling/control information, a pilot symbol is a symbol for pilot, and a symbol is typically a complex value. The data, signaling and pilot symbols may be modulation symbols from a modulation scheme such as PSK or QAM. For MIMO, TX data processor 712 may demultiplex the data, signaling and pilot symbols into multiple streams. TX data processor 712 may then perform CDMA modulation on each data symbol stream to generate a corresponding chip stream. A TX spatial processor 714 receives the chip streams from processor 712, performs spatial mapping on the chip streams, and provides T output streams to T transmitters (TMTR) 716a through 716t. Each transmitter 716 processes (e.g., converts to analog, filters, amplifies, and upconverts) its output stream and generates a downlink signal. T downlink signals from transmitters 716a through 716t are transmitted from antennas 718a through 718t, respectively.

[0085] At terminal 120, R antennas 752a through 752r receive the T downlink signals, and each antenna 752 provides a received signal to a respective receiver (RCVR) 754. Each receiver 754 processes (e.g., filters, amplifies, downconverts, digitizes, and demodulates) its received signal and provides input samples to a receive (RX) spatial processor 756 and a channel processor 774. Channel processor 774 estimates the channel response based on the received pilot (e.g., the TDM pilot) and provides a channel estimate. A MIMO detector 756 performs MIMO detection on the input samples with the channel estimate and provides detected samples. An RX data processor 758 further processes (e.g., descrambles, despreads, symbol demaps, deinterleaves and decodes) the detected samples and provides decoded data to a data sink 760. CDMA demodulation (e.g., descrambling and despreading) may be performed either after detection (e.g., for a MIMO transmission) or prior to detection (e.g., for a single-stream transmission).

[0086] Terminal 120 may send feedback information (e.g., ACKs/NAKs for received packets, CQIs, and so on) to base station 110. The feedback information and traffic data from a data source 762 are processed by a TX data processor 764, and further processed by a transmitter 754a to generate an uplink signal, which is transmitted via antenna 752a. At base station 110, the uplink signal is received by T antennas 718a through 718t, processed by receivers 716a through 716t, processed by a single-input multiple-output (SIMO) detector 720, and further processed by an RX data processor 722 to recover the feedback information and traffic data sent by terminal 120.

[0087] Controllers/processors 730 and 770 control the operation at base station 110 and terminal 120, respectively. Memories 732 and 772 store data and program codes for base station 110 and terminal 120, respectively.

[0088] **FIG. 8** shows a block diagram of an exemplary embodiment of TX data processor 712 and TX spatial processor 714 at base station 110 in FIG. 7. In this exemplary embodiment, TX data processor 712 includes a data processor 810 for the HS-PDSCH, a data processor 812 for the HS-SCCH, and a data processor 814 for other physical channels.

[0089] Within data processor 810 for the HS-PDSCH, an encoder/symbol mapper 820 receives traffic data for the terminals scheduled in the current TTI, processes (e.g., formats, encodes, interleaves, and symbol maps) each packet for each terminal to generate data symbols, and demultiplexes the data symbols for all terminals into M streams to be sent simultaneously. M packets may be sent on M streams, one packet on each stream, to facilitate successive interference cancellation. Alternatively, a packet may be demultiplexed and sent across multiple streams. A CDMA modulator 822 receives the M data symbol streams, maps the data symbols for each terminal to the time segment(s) assigned to that terminal, and multiplexes in pilot symbols. For each stream, CDMA modulator 822 spreads the data and pilot symbols with the channelization codes for HSDPA, scales the chips for each channelization code with a gain factor for that code, combines the scaled chips for all channelization codes, and scrambles the combined chips to generate a scrambled chip stream. Data processor 810 provides M chip streams for the HS-PDSCH. Data processor 812 processes the signaling for the HS-SCCH and provides M chip streams for the HS-SCCH. Data processor 814 processes traffic data and signaling for other physical channels and provides M chip streams for these physical channels.

[0090] TX spatial processor 714 includes a spatial mapper 830 for the HS-PDSCH, a spatial mapper 832 for the HS-SCCH, and a spatial mapper 834 for other physical channels. Spatial mapper 830 may perform matrix multiplication of the M chip streams for the HS-PDSCH with one or more spatial mapping matrices and provides T mapped chip streams. Spatial mapper 832 spatially maps the M chip streams for the HS-SCCH and provides T mapped chip streams, where $M \leq T$. Spatial mapper 834 spatially maps the M chip streams for the other physical channels and provides T mapped chip streams. A combiner 840 combines the mapped chips for all physical channels and provides T output streams for T antennas. The combining may also be performed prior to the spatial mapping.

[0091] A spatial mapping matrix may be an orthonormal matrix (e.g., a Walsh matrix or a Fourier matrix), an identity matrix, or some other matrix. An orthonormal matrix can map a chip from one stream to all T antennas, which may provide spatial diversity. The identity matrix simply passes the chips. A single spatial mapping matrix may be used for all terminals and may be signaled or known *a priori*. A different spatial mapping matrix may also be used for each terminal for its assigned time segment(s), may be selected by the terminal or the base station to achieve good performance, and may be signaled (e.g., using the remaining values of the CCS parameter or some other signaling bits) or known *a priori*. The spatial mapping may be performed for all physical channels or for only some physical channels, e.g., the HS-PDSCH and/or HS-SCCH.

[0092] **FIG. 9** shows a block diagram of an RX processor 900 that performs successive interference cancellation (SIC). RX processor 900 is an exemplary embodiment of MIMO detector 756 and RX data processor 768 at terminal 120 in FIG. 7.

[0093] For the first stage 910a, a MIMO detector 912a receives R streams of input samples from receivers 754a through 754r for all time segment(s) assigned to terminal 120 in a TTI, performs MIMO detection on the input samples with the channel estimate, and provides detected samples for the first stream being recovered. MIMO detector 912a may implement MMSE, zero-forcing (ZF), or some other MIMO detection scheme, which may be able to perform detection without using a channel estimate. For example, a least mean square (LMS) scheme or some other scheme may be used to adapt the weights of an equalizer without using a channel estimate. A CDMA demodulator 914a performs descrambling and despreading on the detected samples with the channelization (Ch) codes assigned to terminal 120 for HSDPA and provides despread symbols. A symbol demapper/decoder 916a processes (e.g., computes LLRs, deinterleaves, and decodes) the despread symbols and provides a decoded packet for the first stream.

[0094] If the packet is decoded correctly, then an encoder/symbol mapper 918a encodes, interleaves and symbol maps the packet to regenerate the data symbols for the packet. A CDMA modulator 920a spreads the regenerated symbols with the channelization codes assigned to terminal 120 for HSDPA, scrambles the spread symbols, and provides regenerated chips for the first stream. A spatial mapper 922a maps the regenerated chips in the same manner performed by base station 110 and provides mapped chips. An interference estimator 924a estimates the interference due to the first stream based on the mapped chips and the channel estimate. An interference subtraction unit 926a subtracts the interference estimate from the input samples and provides input samples for the next stage.

[0095] Each subsequent stage receives the input samples from a preceding stage, processes the input samples in similar manner as the first stage, and provides a decoded packet for the stream being recovered by that stage. If the packet is decoded correctly, then the interference from the decoded packet is estimated and subtracted from the input samples for that stage to obtain input samples for the next stage.

[0096] As shown in FIG. 9, the amount of interference that can be estimated and canceled for each stream is determined by the channelization codes assigned to the terminal versus the channelization codes used for HSDPA. If the terminal is assigned all channelization codes for HSDPA, e.g., as shown in FIG. 4B, then the total interference for HSDPA may be estimated and canceled. The SINRs of subsequent streams may improve due to the canceled interference from prior streams.

[0097] As also shown in FIG. 9, the channel estimate is used for both MIMO detection and interference estimation. A higher quality channel estimate may be obtained based on the TDM pilot shown in FIG. 4B. In another exemplary embodiment, if a packet is decoded correctly for a given stream, then a data-based channel estimate may be derived for that stream based on the despread symbols from CDMA demodulator 914 and the regenerated symbols from encoder/symbol mapper 918. The data-based channel estimate may have higher quality than the pilot-based channel estimate and may be used in block 924 to derive a more accurate interference estimate.

[0098] **FIG. 10** shows an exemplary embodiment of a process 1000 performed by base station 110 for downlink transmission. Multiple time segments of a TTI are assigned to at least one terminal (block 1012). For full assignment, each time segment is assigned to one terminal, and each terminal is assigned at least one consecutive time segment in the TTI. For partial assignment, a time segment may be assigned to, and shared by, multiple terminals. A combination of full and partial assignments may also be used. The multiple time segments may be assigned to the at least one terminal in a sequential order determined by the number of time segments being assigned to each terminal. For example, the terminal with most number of time segments may be assigned first in the TTI, and the terminal with least number of time segments may be assigned last in the TTI. If MIMO is employed, then the multiple time segments may be assigned to the at least one terminal for each of multiple streams being sent simultaneously. Each terminal may be assigned at least one time segment across the multiple streams. Different terminals may also be assigned across streams, across channelization codes, or across both streams and channelization codes in a given time segment.

[0099] Data for each terminal is processed (e.g., encoded and symbol mapped) and then mapped to the at least one time segment assigned to the terminal (block 1014). The data in each time segment is spread with at least one channelization code used in the TTI (block 1016). Pilot may be mapped to at least one time segment designated for pilot transmission (block 1018) and spread with the at least one channelization code used in the TTI (block 1020). The pilot may be scaled to achieve equal transmit power for the pilot and the data for the at least one terminal. Signaling is generated for each terminal to convey, e.g., a starting time segment and the number of time segments assigned to the terminal (block 1022). The spread data for the at least one terminal and the pilot may be sent, e.g., on the HS-PDSCH. The signaling for each terminal may be sent, e.g., on the HS-SCCH.

[00100] **FIG. 11** shows an exemplary embodiment of a process 1100 performed by terminal 120 to receive downlink transmission. An assignment of at least one time segment from among multiple time segments of a TTI is received (block 1112). The assignment may be conveyed via signaling that indicates a starting time segment and the number of time segments in the assignment. Input samples for the at least one time segment are obtained (block 1114). The input samples are despread with at least one channelization code used in the TTI to obtain despread symbols (block 1116). Pilot sent with the at least one channelization code may be received from at least one time segment designated for pilot transmission (block 1118). A channel estimate and/or CQI may be derived based on the received pilot (block 1120). Detection may be performed on the despread symbols with the channel estimate to obtain detected symbols (block 1122).

[00101] If MIMO is employed, then the assignment of the at least one time segment may be for multiple streams sent simultaneously from multiple transmit antennas. Input samples for the at least one time segment may be obtained from multiple receive antennas. MIMO detection may be performed on the input samples to obtain detected samples for each of the multiple streams. The detected samples for each stream may be despread with the at least one channelization code to obtain despread symbols for the stream. The despread symbols for each stream may be decoded. Interference due to each stream may be estimated and canceled after successfully decoding the stream.

[00102] **FIG. 12** shows an embodiment of a process 1200 performed by base station 110 for downlink transmission. A first set of channelization codes may be assigned to a first set of at least one terminal for a TTI (block 1212). Each terminal in the first set may be assigned at least one channelization code in the first set for the entire TTI. Data for each terminal in the first set may be spread with at least one channelization code assigned to the terminal (block 1214). A TDM pilot may be generated based on the channelization codes in the first set (block 1216). The TDM pilot may be mapped to a time segment

within the TTI (block 1218). The spread data for the first set of at least one terminal may be mapped to remaining portion of the TTI (block 1220).

[00103] In a first embodiment, the TDM pilot does not puncture the data of legacy and non-HSDPA users. A second set of channelization codes may be assigned to a second set of at least one terminal for the TTI (block 1222). Data for each terminal in the second set may be spread with at least one channelization code assigned to the terminal (block 1224). The spread data for the second set of at least one terminal may be mapped across the entire TTI (block 1226). The channelization codes in the first and second sets may have the same spreading factor (e.g., $SF = 16$), the first set of terminal(s) may be for new user(s), and the second set of terminal(s) may be for legacy user(s). Alternatively, the channelization codes in the second set may have larger spreading factor than the channelization codes in the first set, the first set of terminal(s) may be for new user(s), and the second set of terminal(s) may be for non-HSDPA user(s).

[00104] In a second embodiment, the TDM pilot punctures the data of legacy and/or non-HSDPA users. In this case, blocks 1222, 1224 and 1226 may be replaced as follows. A second set of channelization codes may be assigned to a second set of at least one terminal for the TTI. The at least one terminal in the second set may be for legacy and/or non-HSDPA users and may not be capable of processing the TDM pilot. Data for each terminal in the second set may be spread with at least one channelization code assigned to the terminal. The spread data for the second set of at least one terminal may be mapped to the remaining portion of the TTI. The TDM pilot may be generated further based on the channelization codes in the second set.

[00105] In a third embodiment, the TDM pilot punctures the data of legacy users but not the data of non-HSDPA users. In this case, the second set of at least one terminal described above for the second embodiment may be for legacy users. A third set of channelization codes may be assigned to a third set of at least one terminal for the TTI. The at least one terminal in the third set may also not be capable of processing the TDM pilot. Data for each terminal in the third set may be spread with at least one channelization code assigned to the terminal. The spread data for the third set of at least one terminal may be mapped across the entire TTI.

[00106] The TTI may occupy three slots, and the time segment for the TDM pilot may be located within a middle slot of the TTI or at some other location within the TTI. The spread data for the first set of at least one terminal and the TDM pilot may be sent, e.g., on the HS-PDSCH. Signaling for each terminal in the first set may be sent, e.g., on the HS-SCCH.

[00107] **FIG. 13** shows an embodiment of a process 1300 performed by terminal 120 to receive downlink transmission. An assignment of at least one channelization code for a terminal for a TTI may be received (block 1312). A TDM pilot may be received from a time segment within the TTI, with the TDM pilot being generated based on a first set of channelization codes including the at least one channelization code assigned to the terminal (block 1314). Data may be received from remaining portion of the TTI (block 1316). The received data may be despread based on the at least one channelization code assigned to the terminal (block 1318).

[00108] A channel estimate may be derived based on the TDM pilot, and a data channel (e.g., the HS-PDSCH) may be processed based on the channel estimate to obtain the received data. A TDM pilot may also be received from a prior TTI, a channel estimate may be derived based on this TDM pilot, and a signaling channel (e.g., the HS-SCCH) may be processed based on this channel estimate to obtain the assignment of at least one channelization code for the terminal.

[00109] The channelization codes in the first set may be assigned to terminals capable of processing the TDM pilot, in which case the TDM pilot does not puncture the data of any terminal. Alternatively, at least one channelization code in the first set may be assigned to a terminal not capable of processing the TDM pilot, and the TDM pilot would then puncture the data of this terminal.

[00110] For clarity, the techniques have been described specifically for HSDPA in 3GPP. The techniques may also be used for other wireless communication networks that may implement other radio technologies. For example, the techniques may be used for a CDMA2000 1X network that implements IS-2000 Releases 0 and A, a CDMA2000 1xEV-DV network that implements IS-2000 Release C, a CDMA2000 1xEV-DO network that implements IS-856, and so on. cdma2000 uses a Forward Packet Data Channel (F-PDCH) and a Forward Packet Data Control Channel (F-PDCCH) that correspond to the HS-PDSCH and HS-SCCH, respectively. The format/ structure of the F-PDCH may be implemented, e.g., as shown in FIGS. 4A and 4B.

[00111] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be

referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[00112] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the exemplary embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[00113] The various illustrative logical blocks, modules, and circuits described in connection with the exemplary embodiments disclosed herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[00114] The steps of a method or algorithm described in connection with the exemplary embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the

processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[00115] The previous description of the disclosed exemplary embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these exemplary embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other exemplary embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the exemplary embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

CLAIMS

What is claimed is:

1. An apparatus for wireless communication, comprising:

at least one processor to assign a first set of channelization codes to a first set of at least one terminal for a transmission time interval (TTI), to spread data for each terminal in the first set with at least one channelization code assigned to the terminal, to generate a time division multiplex (TDM) pilot based on the channelization codes in the first set, to map the TDM pilot to a time segment within the TTI, and to map spread data for the first set of at least one terminal to remaining portion of the TTI; and

a memory coupled to the at least one processor.

2. The apparatus of claim 1, wherein the at least one processor assigns at least one channelization code to each terminal in the first set for the entire TTI.

3. The apparatus of claim 1, wherein the at least one processor assigns a second set of channelization codes to a second set of at least one terminal for the TTI, spreads data for each terminal in the second set with at least one channelization code assigned to the terminal, and maps spread data for the second set of at least one terminal across the entire TTI.

4. The apparatus of claim 3, wherein the channelization codes in the first set and the channelization codes in the second set have the same spreading factor.

5. The apparatus of claim 3, wherein the channelization codes in the second set have larger spreading factor than the channelization codes in the first set.

6. The apparatus of claim 1, wherein the at least one processor assigns a second set of channelization codes to a second set of at least one terminal for the TTI, spreads data for each terminal in the second set with at least one channelization code assigned to the terminal, maps spread data for the second set of at least one terminal to the remaining portion of the TTI, and generates the TDM pilot further based on the

channelization codes in the second set, the at least one terminal in the second set not being capable of processing the TDM pilot.

7. The apparatus of claim 6, wherein the channelization codes in the first set and the channelization codes in the second set have equal spreading factor.

8. The apparatus of claim 7, wherein the at least one processor assigns a third set of channelization codes to a third set of at least one terminal for the TTI, spreads data for each terminal in the third set with at least one channelization code assigned to the terminal, and maps spread data for the third set of at least one terminal across the entire TTI, the at least one terminal in the third set not being capable of processing the TDM pilot.

9. The apparatus of claim 1, wherein the TTI comprises three slots and the time segment for the TDM pilot is located within a middle slot of the TTI.

10. The apparatus of claim 1, wherein the at least one processor sends the spread data for the first set of at least one terminal and the TDM pilot on a High Speed Physical Downlink Shared Channel (HS-PDSCH), and sends signaling for each terminal in the first set on a Shared Control Channel for HS-PDSCH (HS-SCCH).

11. A method for wireless communication, comprising:

assigning a first set of channelization codes to a first set of at least one terminal for a transmission time interval (TTI);

spreading data for each terminal in the first set with at least one channelization code assigned to the terminal;

generating a time division multiplex (TDM) pilot based on the channelization codes in the first set;

mapping the TDM pilot to a time segment within the TTI; and

mapping spread data for the first set of at least one terminal to remaining portion of the TTI.

12. The method of claim 11, wherein the assigning the first set of channelization codes comprises assigning at least one channelization code to each terminal in the first set for the entire TTI.

13. The method of claim 11, further comprising:

assigning a second set of channelization codes to a second set of at least one terminal for the TTI;

spreading data for each terminal in the second set with at least one channelization code assigned to the terminal; and

mapping spread data for the second set of at least one terminal across the entire TTI.

14. The method of claim 11, further comprising:

assigning a second set of channelization codes to a second set of at least one terminal for the TTI, the at least one terminal in the second set not being capable of processing the TDM pilot;

spreading data for each terminal in the second set with at least one channelization code assigned to the terminal;

mapping spread data for the second set of at least one terminal to the remaining portion of the TTI; and

generating the TDM pilot further based on the channelization codes in the second set.

15. An apparatus for wireless communication, comprising:

means for assigning a first set of channelization codes to a first set of at least one terminal for a transmission time interval (TTI);

means for spreading data for each terminal in the first set with at least one channelization code assigned to the terminal;

means for generating a time division multiplex (TDM) pilot based on the channelization codes in the first set;

means for mapping the TDM pilot to a time segment within the TTI; and

means for mapping spread data for the first set of at least one terminal to remaining portion of the TTI.

16. The apparatus of claim 15, further comprising:

means for assigning a second set of channelization codes to a second set of at least one terminal for the TTI;

means for spreading data for each terminal in the second set with at least one channelization code assigned to the terminal; and

means for mapping spread data for the second set of at least one terminal across the entire TTI.

17. The apparatus of claim 15, further comprising:

means for assigning a second set of channelization codes to a second set of at least one terminal for the TTI, the at least one terminal in the second set not being capable of processing the TDM pilot;

means for spreading data for each terminal in the second set with at least one channelization code assigned to the terminal;

means for mapping spread data for the second set of at least one terminal to the remaining portion of the TTI; and

means for generating the TDM pilot further based on the channelization codes in the second set.

18. An apparatus for wireless communication, comprising:

at least one processor to receive an assignment of at least one channelization code for a terminal for a transmission time interval (TTI), to receive a time division multiplex (TDM) pilot from a time segment within the TTI, to receive data from remaining portion of the TTI, and to despread the received data with the at least one channelization code assigned to the terminal, the TDM pilot being generated based on a first set of channelization codes including the at least one channelization code assigned to the terminal; and

a memory coupled to the at least one processor.

19. The apparatus of claim 18, wherein the at least one processor derives a channel estimate based on the TDM pilot and processes a data channel based on the channel estimate to obtain the received data.

20. The apparatus of claim 18, wherein the at least one processor receives a TDM pilot from a prior TTI, derives a channel estimate based on the TDM pilot from the prior TTI, and processes a signaling channel based on the channel estimate to obtain the assignment of at least one channelization code for the terminal.

21. The apparatus of claim 18, wherein the channelization codes in the first set is assigned to terminals capable of processing the TDM pilot.

22. The apparatus of claim 18, wherein at least one channelization code in the first set is assigned to a terminal not capable of processing the TDM pilot.

23. A method for wireless communication, comprising:

receiving an assignment of at least one channelization code for a terminal for a transmission time interval (TTI);

receiving a time division multiplex (TDM) pilot from a time segment within the TTI, the TDM pilot being generated based on a first set of channelization codes including the at least one channelization code assigned to the terminal;

receiving data from remaining portion of the TTI; and

despreading the received data with the at least one channelization code assigned to the terminal.

24. The method of claim 23, further comprising:

deriving a channel estimate based on the TDM pilot; and

processing a data channel based on the channel estimate to obtain the received data.

25. The method of claim 23, further comprising:

receiving a TDM pilot from a prior TTI;

deriving a channel estimate based on the TDM pilot from the prior TTI; and

processing a signaling channel based on the channel estimate to obtain the assignment of at least one channelization code for the terminal.

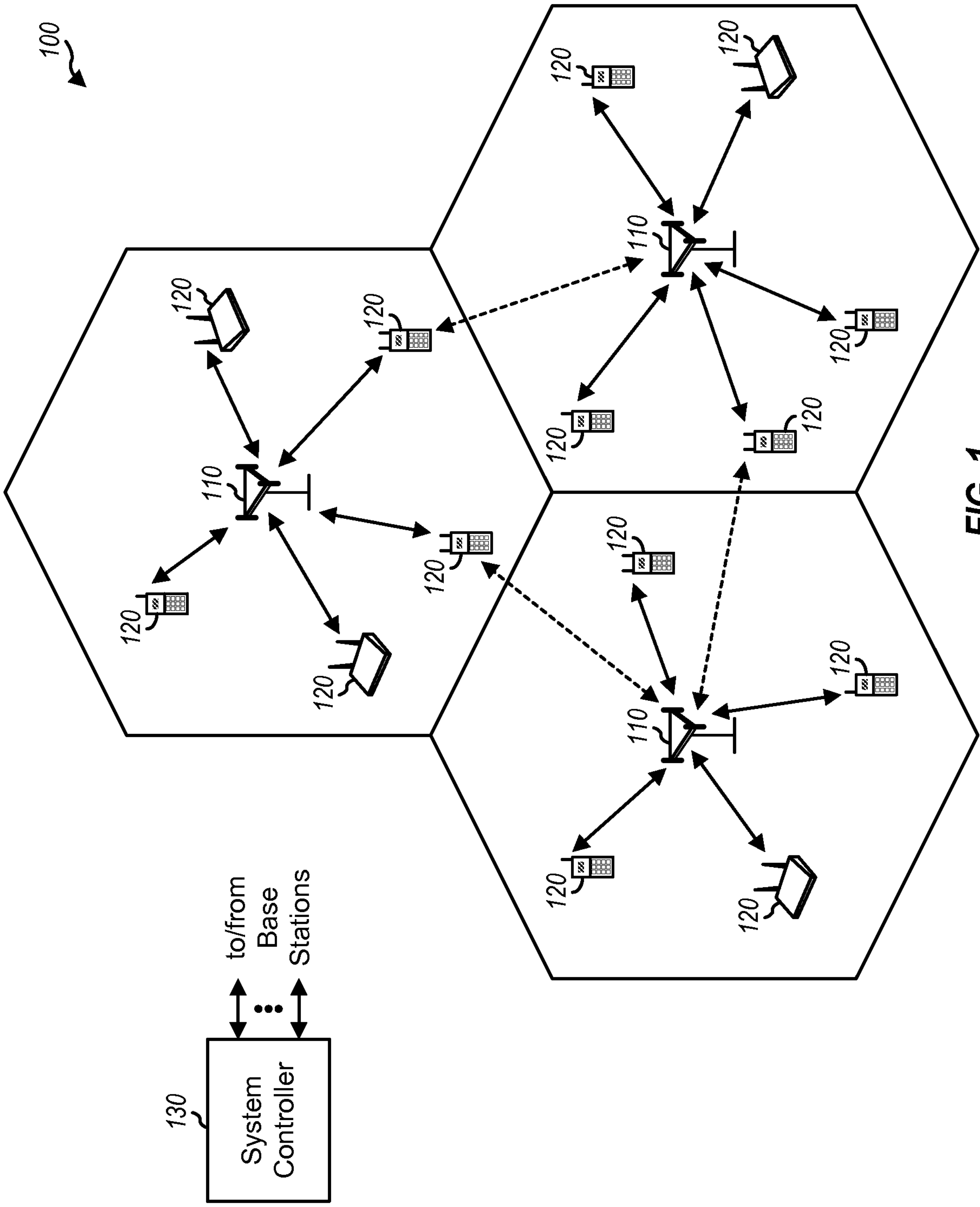
100
110
110
110
120
130
System Controller
to/from Base Stations

FIG. 1

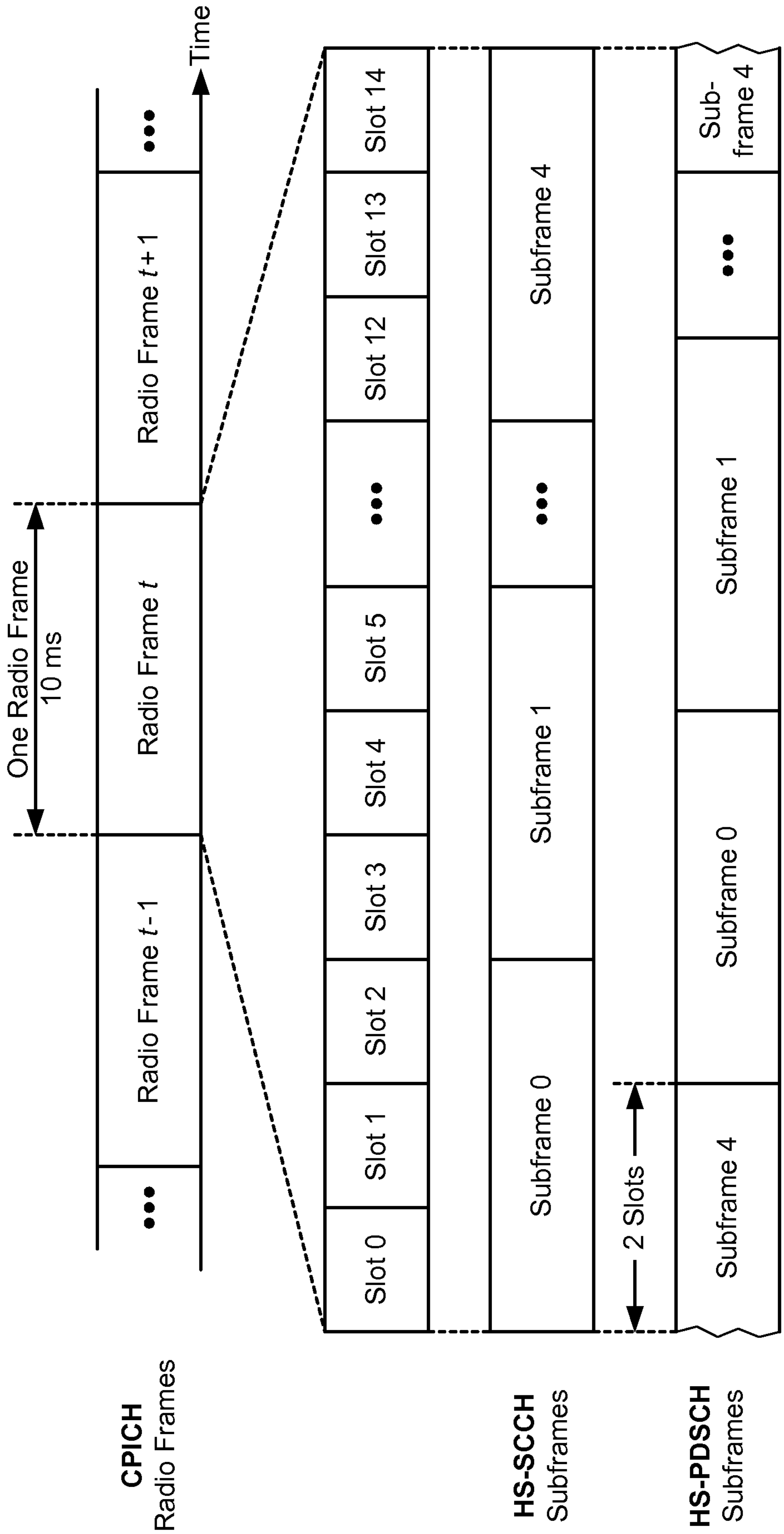
Time
One Radio Frame
10 ms
CPICH
Radio Frames
Radio Frame t - 1
Radio Frame t
Radio Frame t + 1
Slot 0
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Slot 12
Slot 13
Slot 14
HS-SCCH
Subframes
Subframe 0
Subframe 1
Subframe 4
2 Slots
HS-PDSCH
Subframes
Subframe 4
Subframe 0
Subframe 1
Sub-
frame 4

FIG. 2

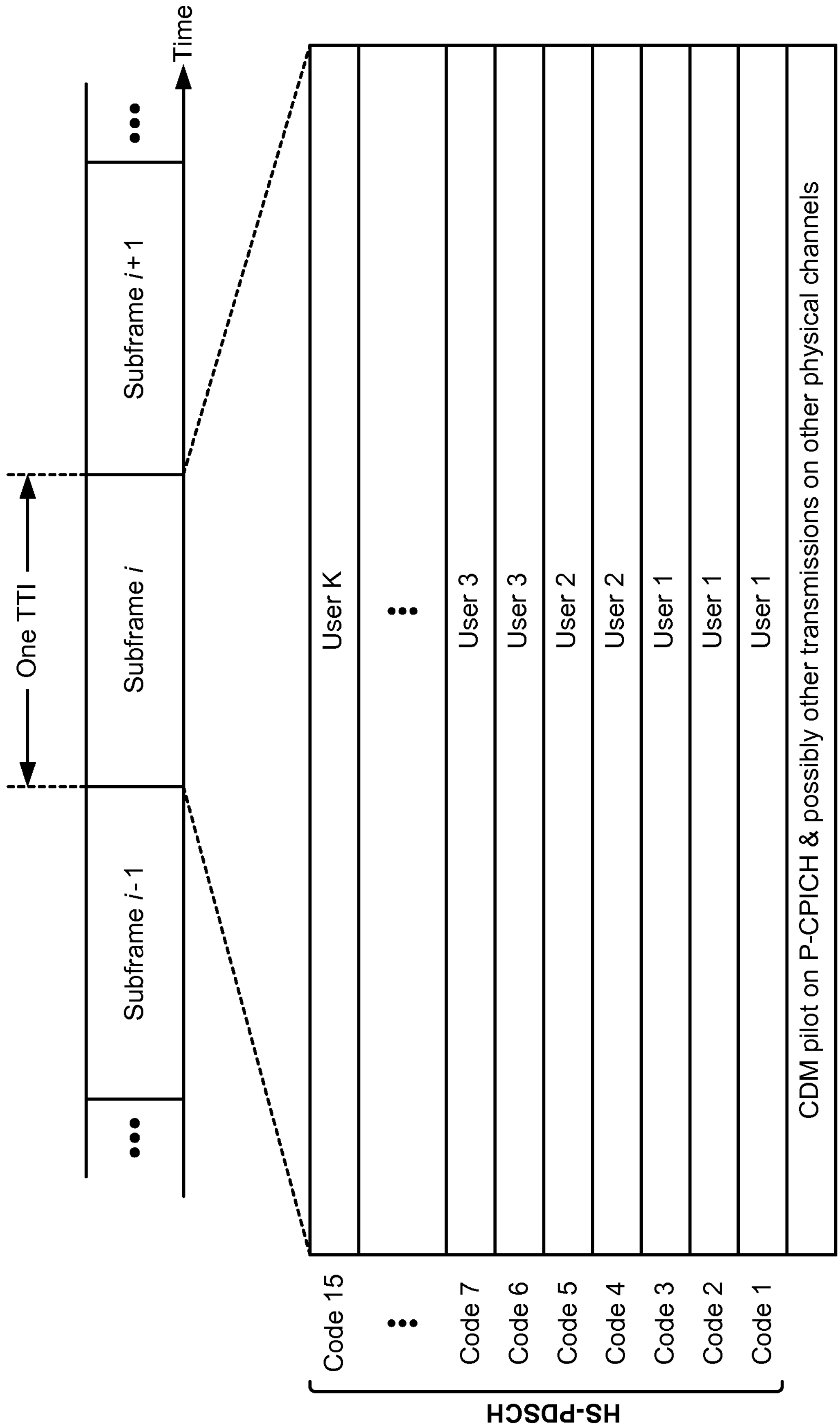
Time
One TTI
Subframe i-1
Subframe i
Subframe i+1
User K
User 3
User 3
User 2
User 2
User 1
User 1
User 1
CDM pilot on P-CPICH & possibly other transmissions on other physical channels
Code 15
Code 7
Code 6
Code 5
Code 4
Code 3
Code 2
Code 1
HS-PDSCH

FIG. 3

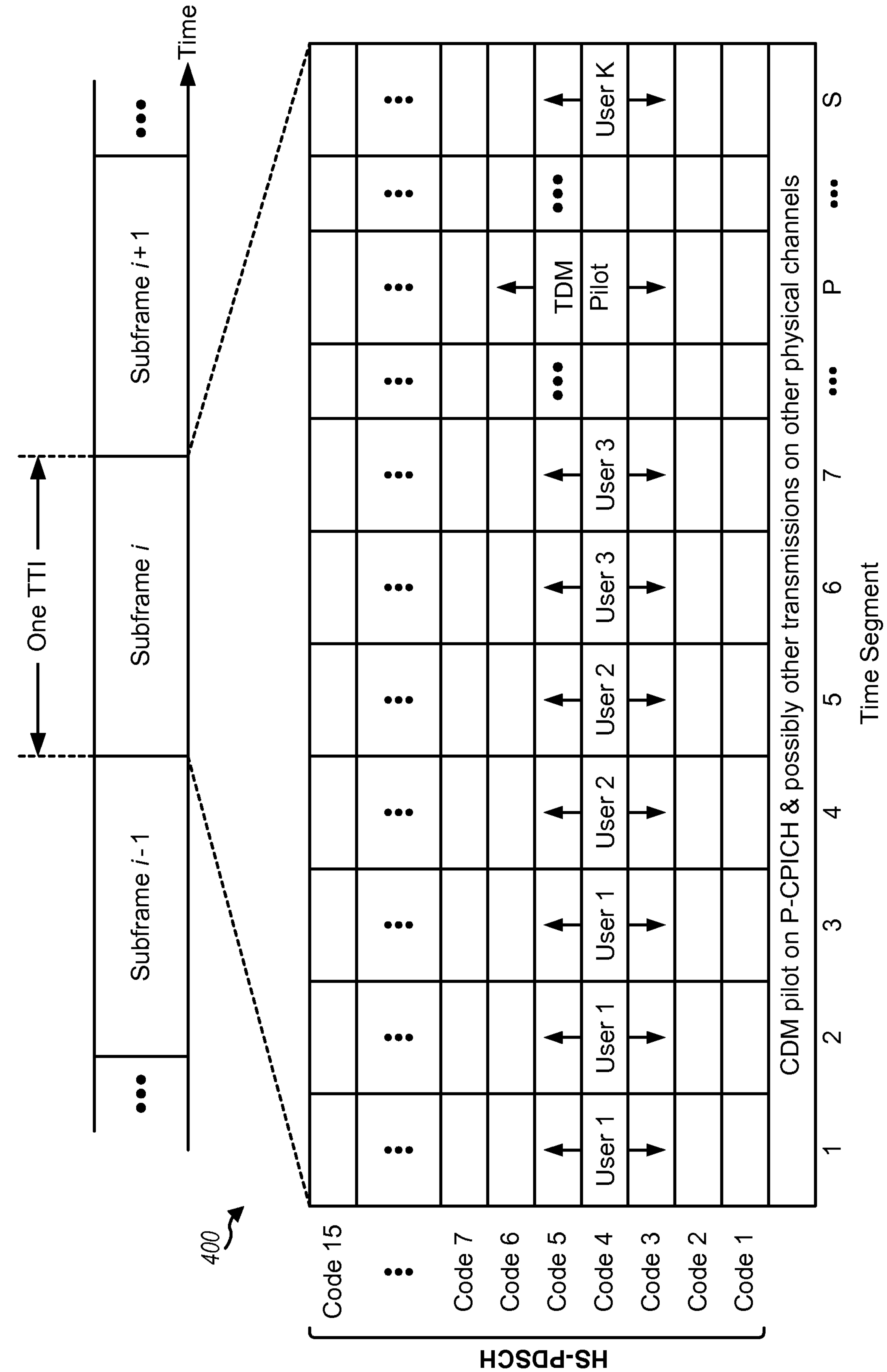
Time
One TTI
Subframe i-1
Subframe i
Subframe i+1
400
Code 15
Code 7
Code 6
Code 5
Code 4
Code 3
Code 2
Code 1
HS-PDSCH
User 1
User 1
User 1
User 2
User 2
User 3
User 3
TDM Pilot
User K
CDM pilot on P-CPICH & possibly other transmissions on other physical channels
1
2
3
4
5
6
7
P
S
Time Segment

FIG. 4A

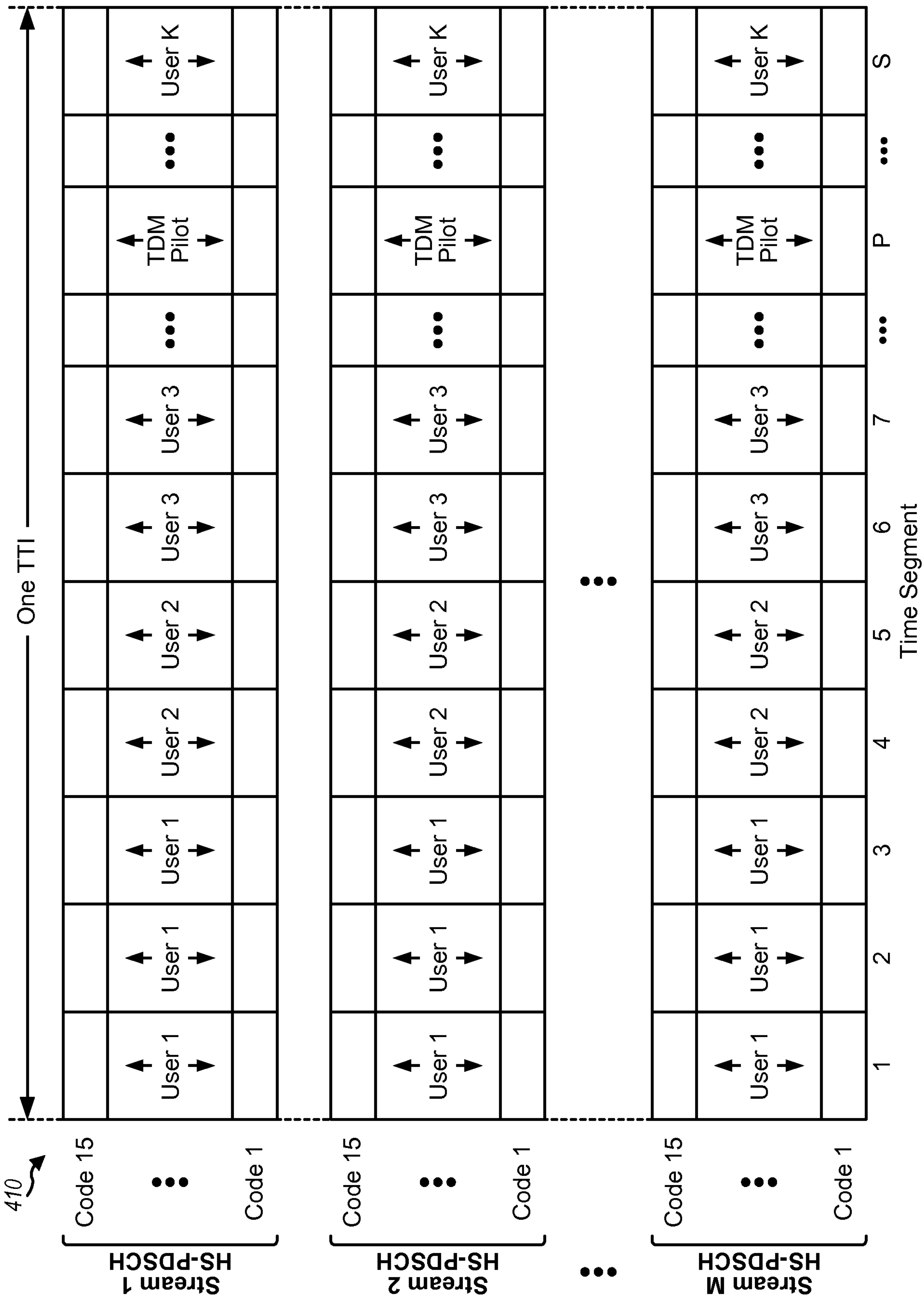
410
One TTI
Stream 1 HS-PDSCH
Stream 2 HS-PDSCH
Stream M HS-PDSCH
Code 15
Code 1
User 1
User 2
User 3
TDM Pilot
User K
1
2
3
4
5
6
7
P
S
Time Segment

FIG. 4B

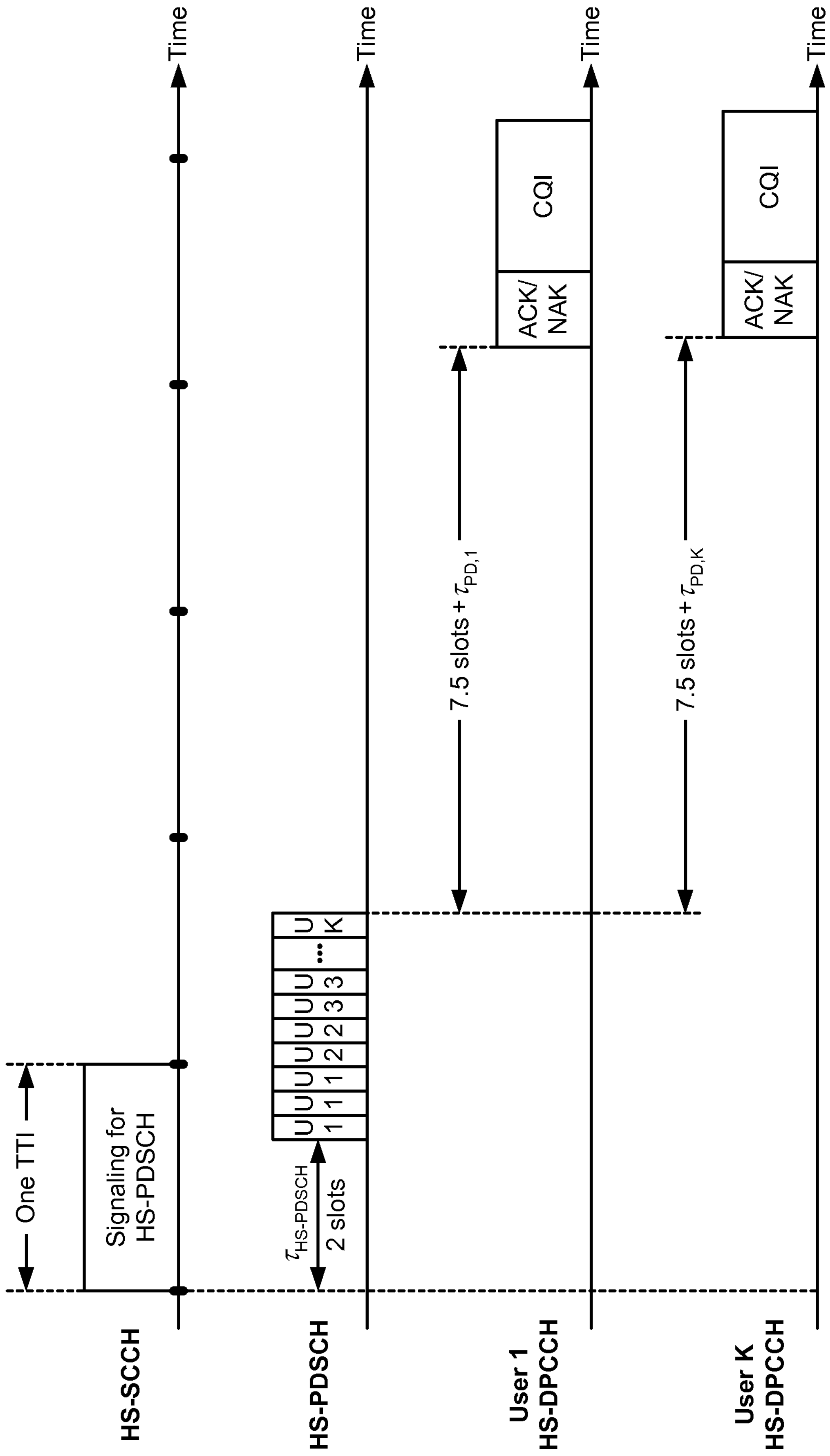
HS-SCCH
HS-PDSCH
User 1
HS-DPCCH
User K
HS-DPCCH
Time
Time
Time
Time
One TTI
Signaling for
HS-PDSCH
$\tau_{HS\text{-}PDSCH}$
2 slots
U 1
U 1
U 1
U 2
U 2
U 3
U 3
...
U K
ACK/
NAK
CQI
ACK/
NAK
CQI
7.5 slots + $\tau_{PD,1}$
7.5 slots + $\tau_{PD,K}$

FIG. 4C

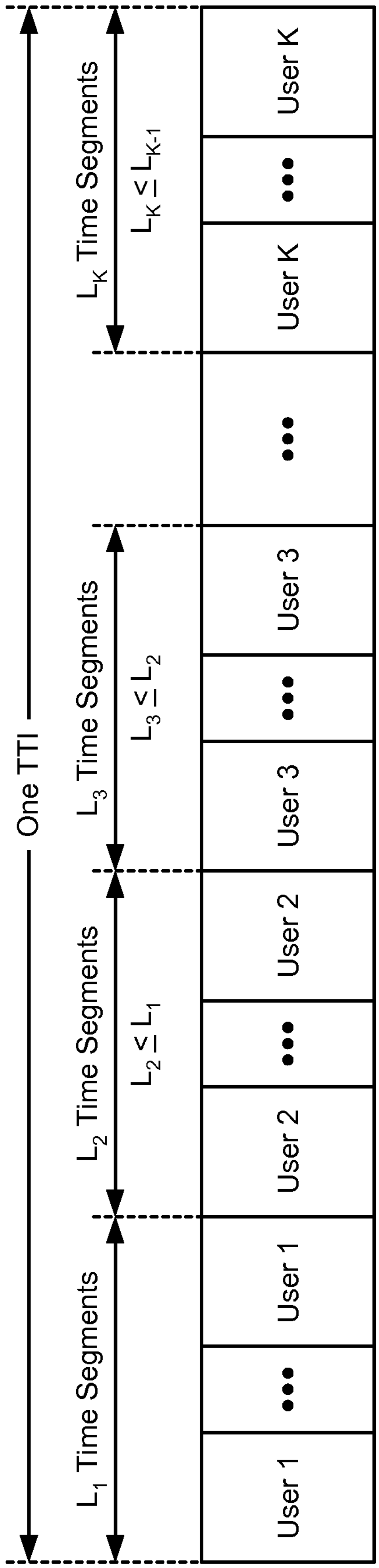
One TTI
L_1 Time Segments
L_2 Time Segments
$L_2 \leq L_1$
L_3 Time Segments
$L_3 \leq L_2$
L_K Time Segments
$L_K \leq L_{K-1}$
User 1
User 1
User 2
User 2
User 3
User 3
User K
User K

FIG. 4D

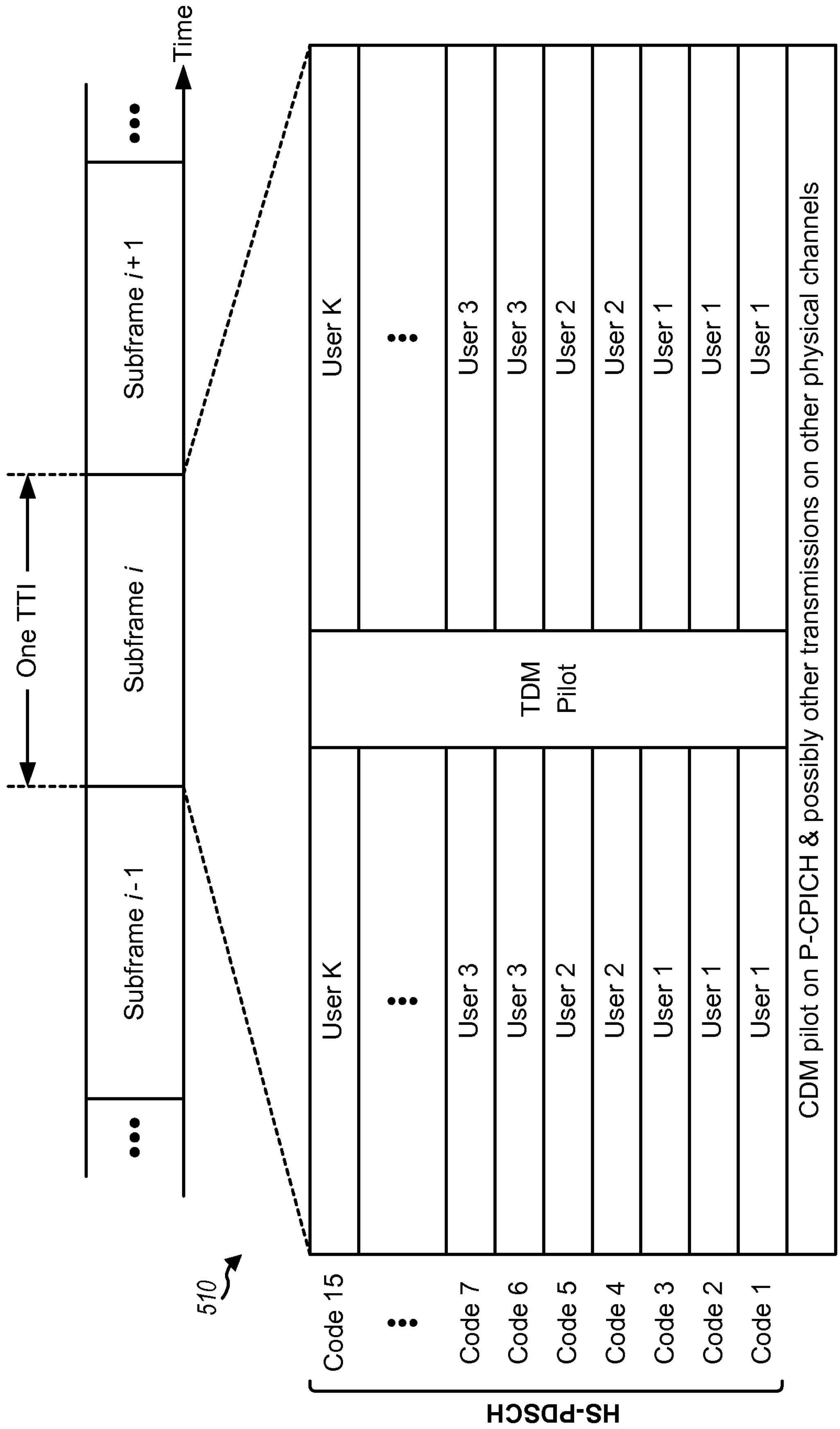
Time
Subframe i-1
Subframe i
Subframe i+1
One TTI
510
Code 15
Code 7
Code 6
Code 5
Code 4
Code 3
Code 2
Code 1
HS-PDSCH
User K
User 3
User 3
User 2
User 2
User 1
User 1
User 1
TDM Pilot
CDM pilot on P-CPICH & possibly other transmissions on other physical channels

FIG. 5A

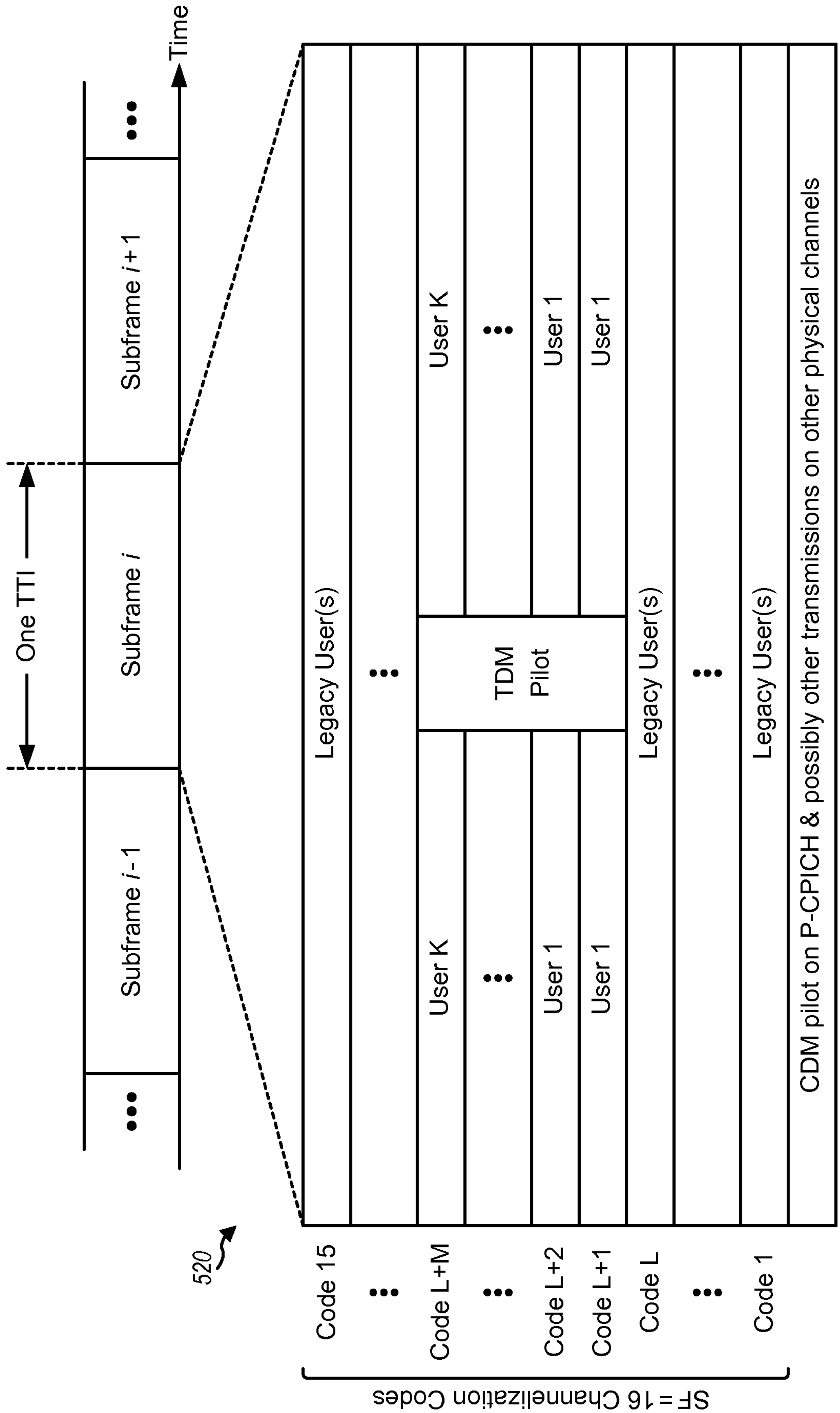
Time
One TTI
Subframe i-1
Subframe i
Subframe i+1
520
Code 15
Code L+M
Code L+2
Code L+1
Code L
Code 1
SF = 16 Channelization Codes
Legacy User(s)
User K
User 1
User 1
TDM Pilot
Legacy User(s)
Legacy User(s)
CDM pilot on P-CPICH & possibly other transmissions on other physical channels

FIG. 5B

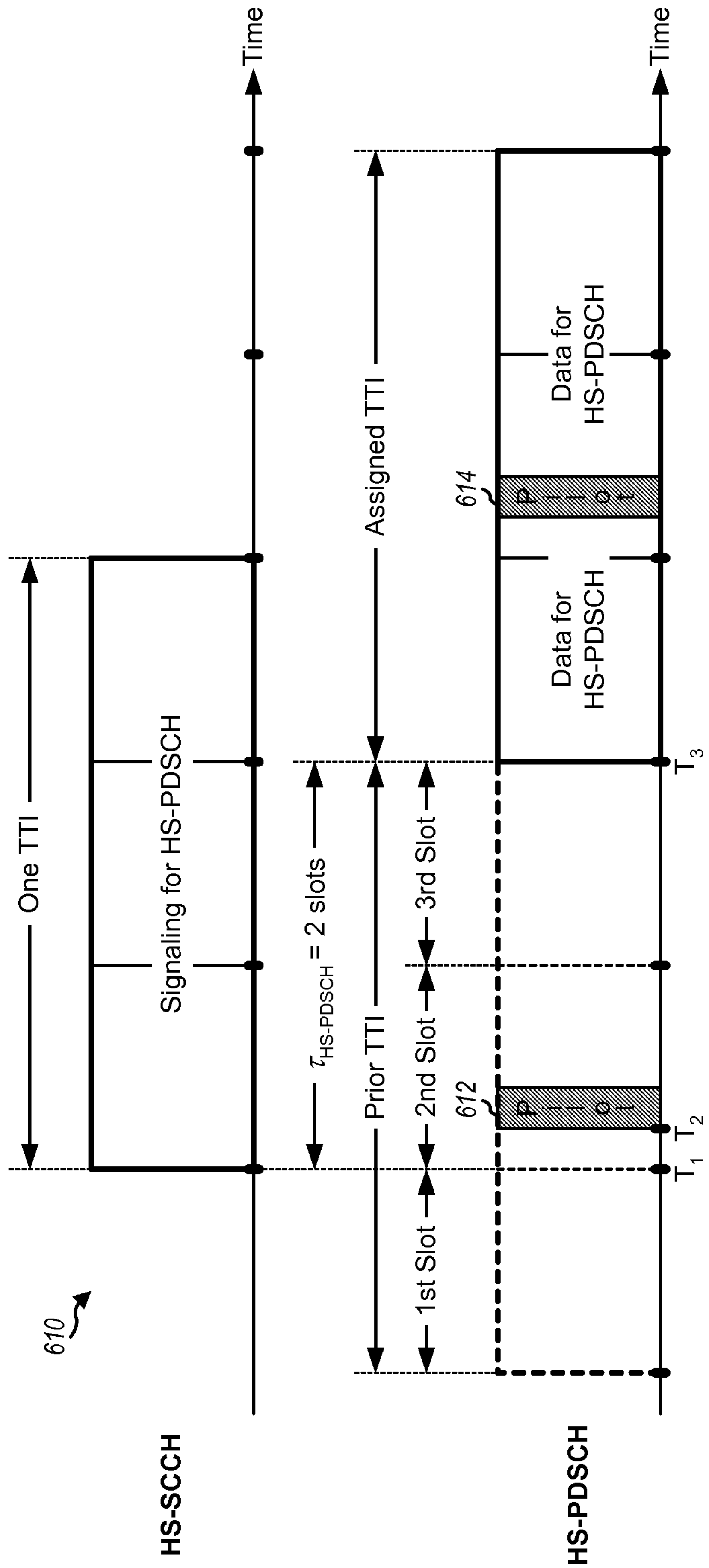
Time
Time
HS-SCCH
HS-PDSCH
610
One TTI
Signaling for HS-PDSCH
$\tau_{HS\text{-}PDSCH}$ = 2 slots
Prior TTI
Assigned TTI
1st Slot
2nd Slot
3rd Slot
612
614
Pilot
Pilot
Data for HS-PDSCH
Data for HS-PDSCH
T_1
T_2
T_3

FIG. 6

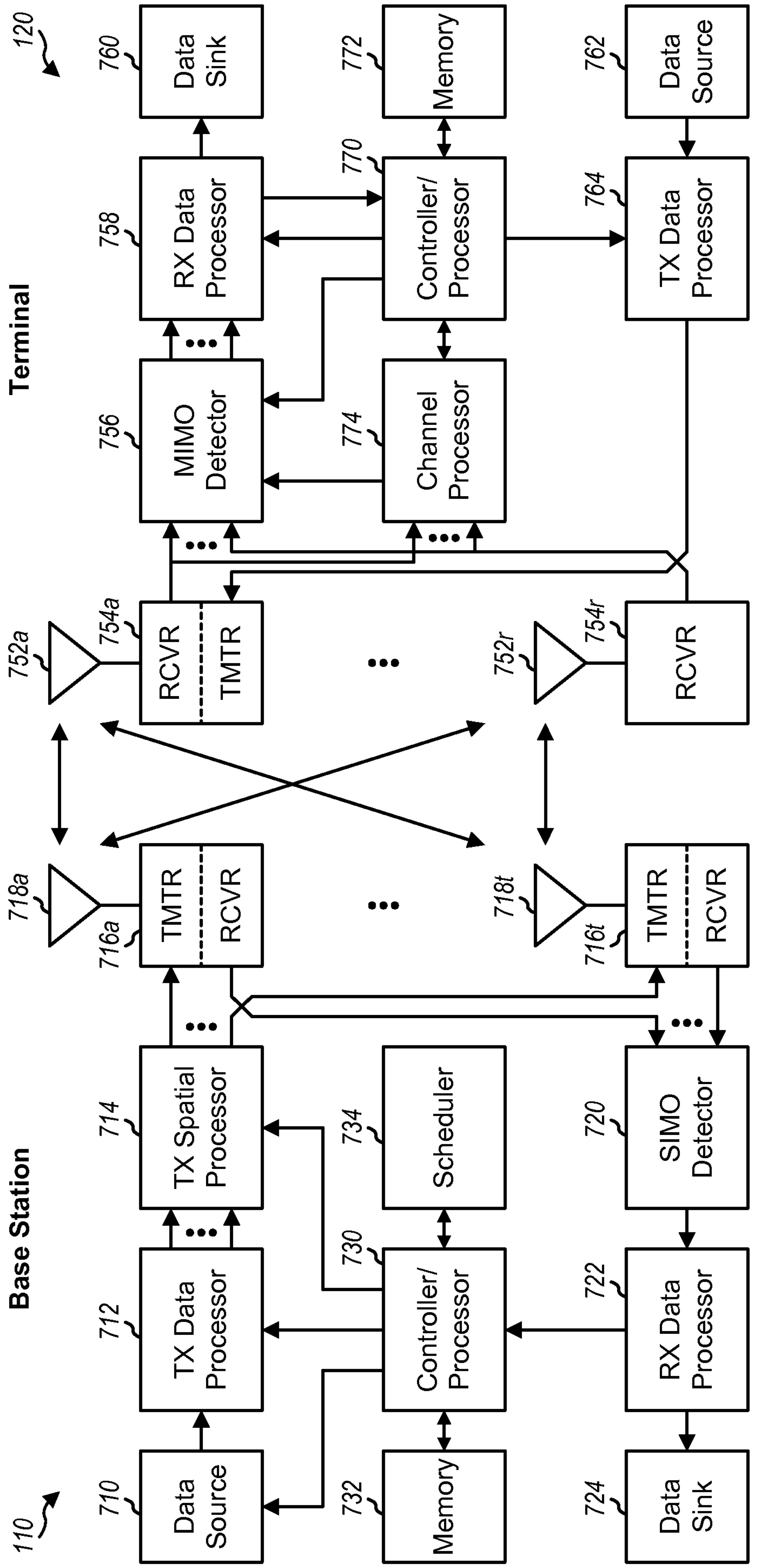
Base Station
Terminal
110
120
710
Data Source
712
TX Data Processor
714
TX Spatial Processor
716a
TMTR
RCVR
718a
716t
718t
720
SIMO Detector
722
RX Data Processor
724
Data Sink
730
Controller/ Processor
732
Memory
734
Scheduler
752a
754a
752r
754r
756
MIMO Detector
758
RX Data Processor
760
Data Sink
762
Data Source
764
TX Data Processor
770
Controller/ Processor
772
Memory
774
Channel Processor

FIG. 7

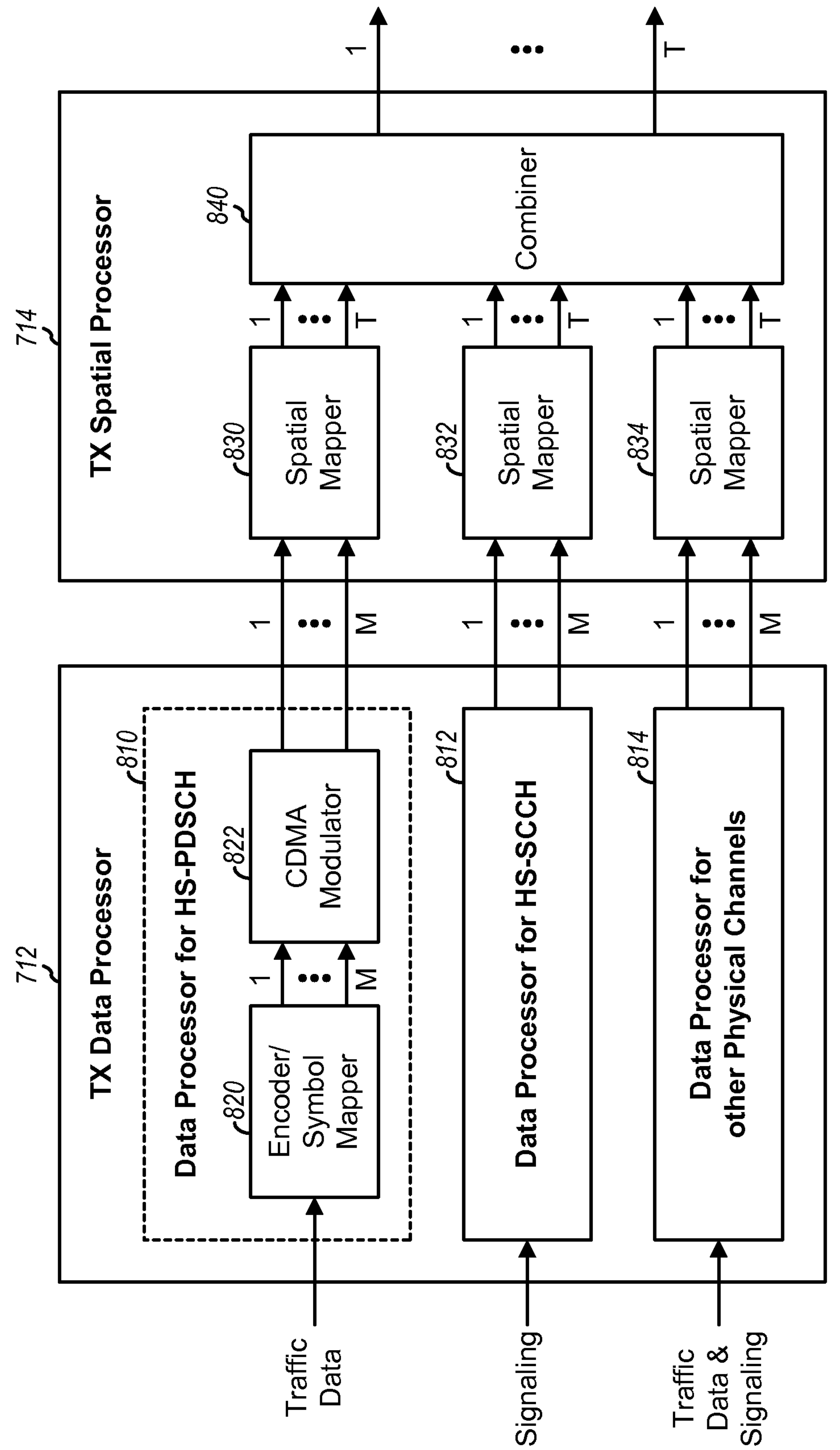
714
TX Spatial Processor
840
Combiner
1
T
830
Spatial Mapper
832
Spatial Mapper
834
Spatial Mapper
1
M
712
TX Data Processor
810
Data Processor for HS-PDSCH
820
Encoder/ Symbol Mapper
822
CDMA Modulator
812
Data Processor for HS-SCCH
814
Data Processor for other Physical Channels
Traffic Data
Signaling
Traffic Data & Signaling

FIG. 8

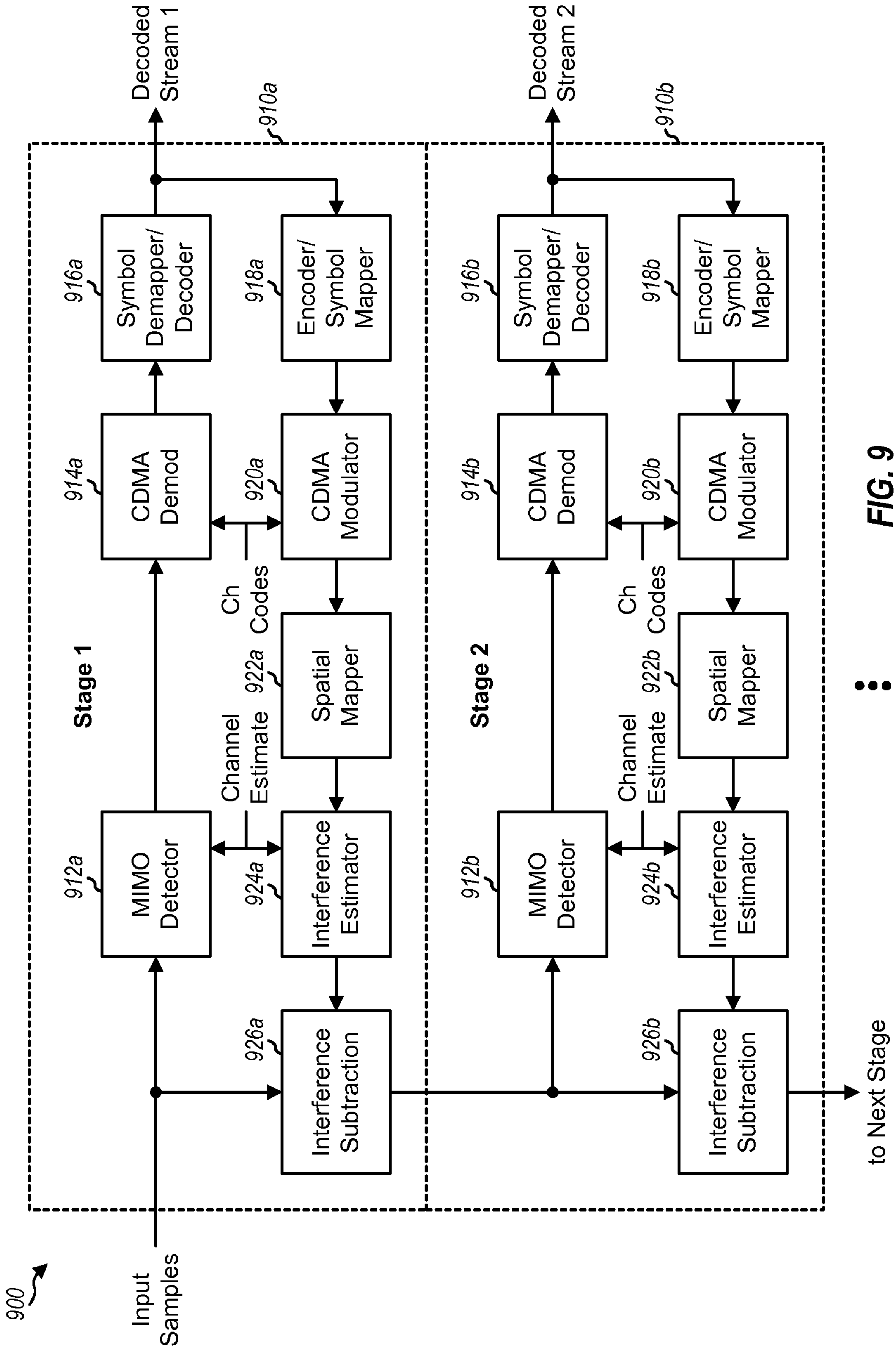
900
Input Samples
Stage 1
910a
912a
MIMO Detector
914a
CDMA Demod
916a
Symbol Demapper/ Decoder
Decoded Stream 1
918a
Encoder/ Symbol Mapper
920a
CDMA Modulator
Ch Codes
922a
Spatial Mapper
Channel Estimate
924a
Interference Estimator
926a
Interference Subtraction
Stage 2
910b
912b
MIMO Detector
914b
CDMA Demod
916b
Symbol Demapper/ Decoder
Decoded Stream 2
918b
Encoder/ Symbol Mapper
920b
CDMA Modulator
Ch Codes
922b
Spatial Mapper
Channel Estimate
924b
Interference Estimator
926b
Interference Subtraction
to Next Stage

FIG. 9

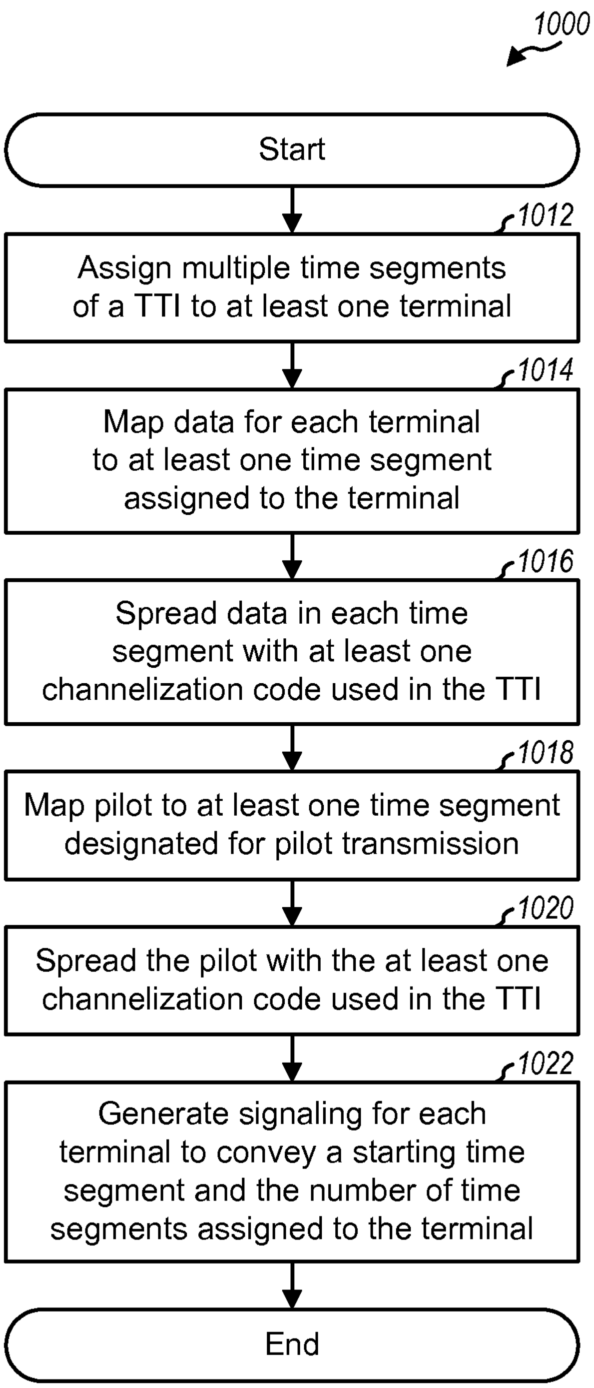
1000
Start
1012
Assign multiple time segments of a TTI to at least one terminal
1014
Map data for each terminal to at least one time segment assigned to the terminal
1016
Spread data in each time segment with at least one channelization code used in the TTI
1018
Map pilot to at least one time segment designated for pilot transmission
1020
Spread the pilot with the at least one channelization code used in the TTI
1022
Generate signaling for each terminal to convey a starting time segment and the number of time segments assigned to the terminal
End

FIG. 10

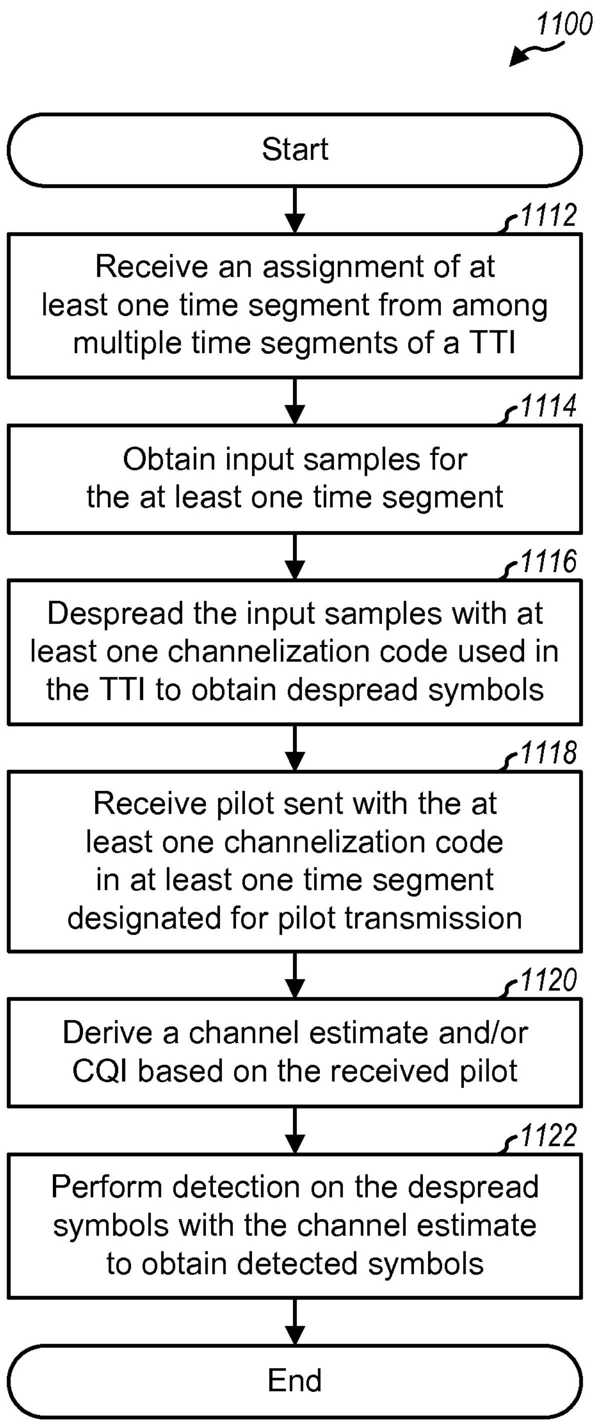
1100
Start
1112
Receive an assignment of at least one time segment from among multiple time segments of a TTI
1114
Obtain input samples for the at least one time segment
1116
Despread the input samples with at least one channelization code used in the TTI to obtain despread symbols
1118
Receive pilot sent with the at least one channelization code in at least one time segment designated for pilot transmission
1120
Derive a channel estimate and/or CQI based on the received pilot
1122
Perform detection on the despread symbols with the channel estimate to obtain detected symbols
End

FIG. 11

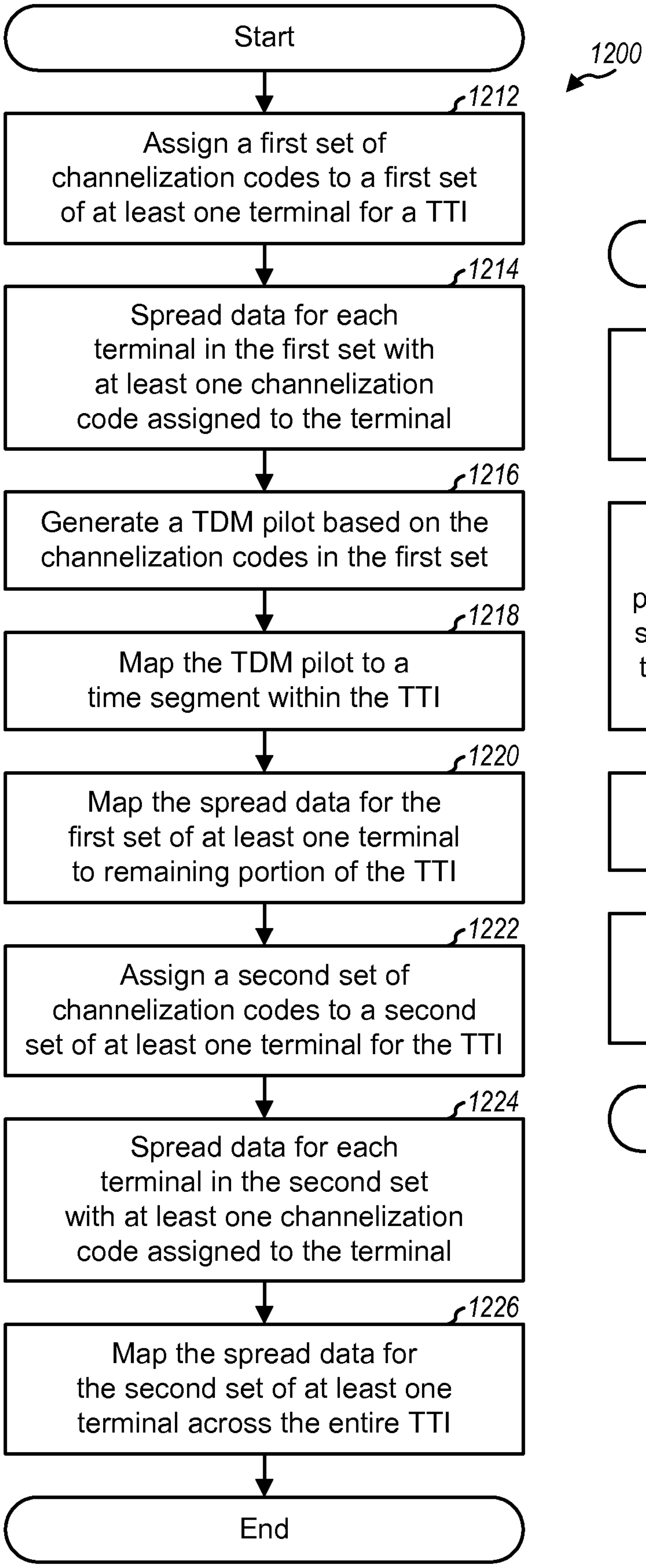
1200
Start
1212
Assign a first set of channelization codes to a first set of at least one terminal for a TTI
1214
Spread data for each terminal in the first set with at least one channelization code assigned to the terminal
1216
Generate a TDM pilot based on the channelization codes in the first set
1218
Map the TDM pilot to a time segment within the TTI
1220
Map the spread data for the first set of at least one terminal to remaining portion of the TTI
1222
Assign a second set of channelization codes to a second set of at least one terminal for the TTI
1224
Spread data for each terminal in the second set with at least one channelization code assigned to the terminal
1226
Map the spread data for the second set of at least one terminal across the entire TTI
End

FIG. 12

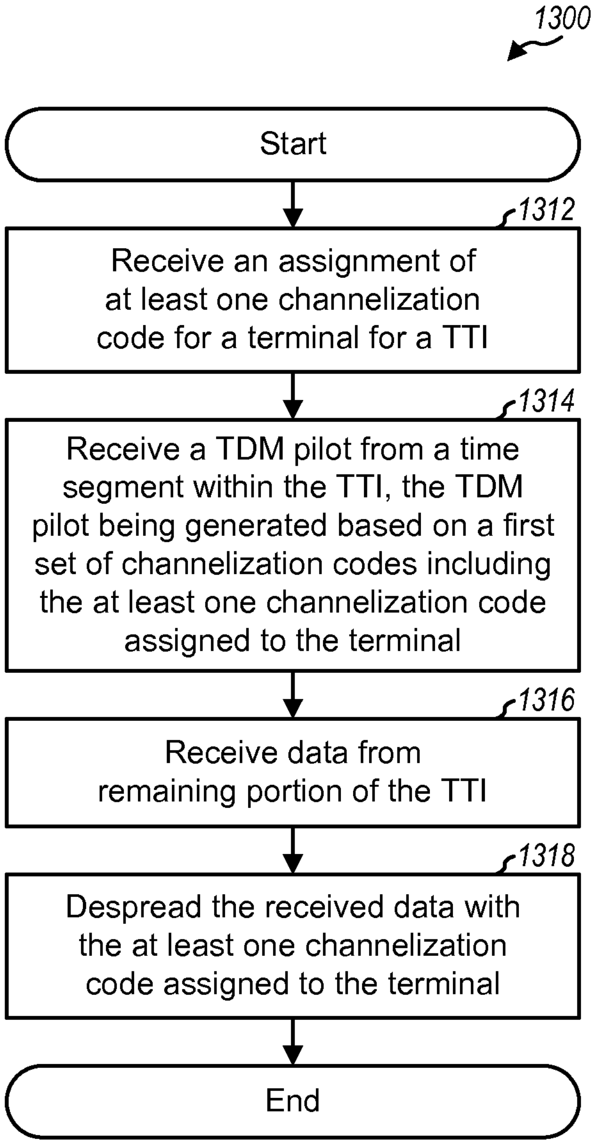
1300
Start
1312
Receive an assignment of at least one channelization code for a terminal for a TTI
1314
Receive a TDM pilot from a time segment within the TTI, the TDM pilot being generated based on a first set of channelization codes including the at least one channelization code assigned to the terminal
1316
Receive data from remaining portion of the TTI
1318
Despread the received data with the at least one channelization code assigned to the terminal
End

FIG. 13