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(54) **CHANNEL CAPACITY OPTIMIZATION FOR PACKET SERVICES**

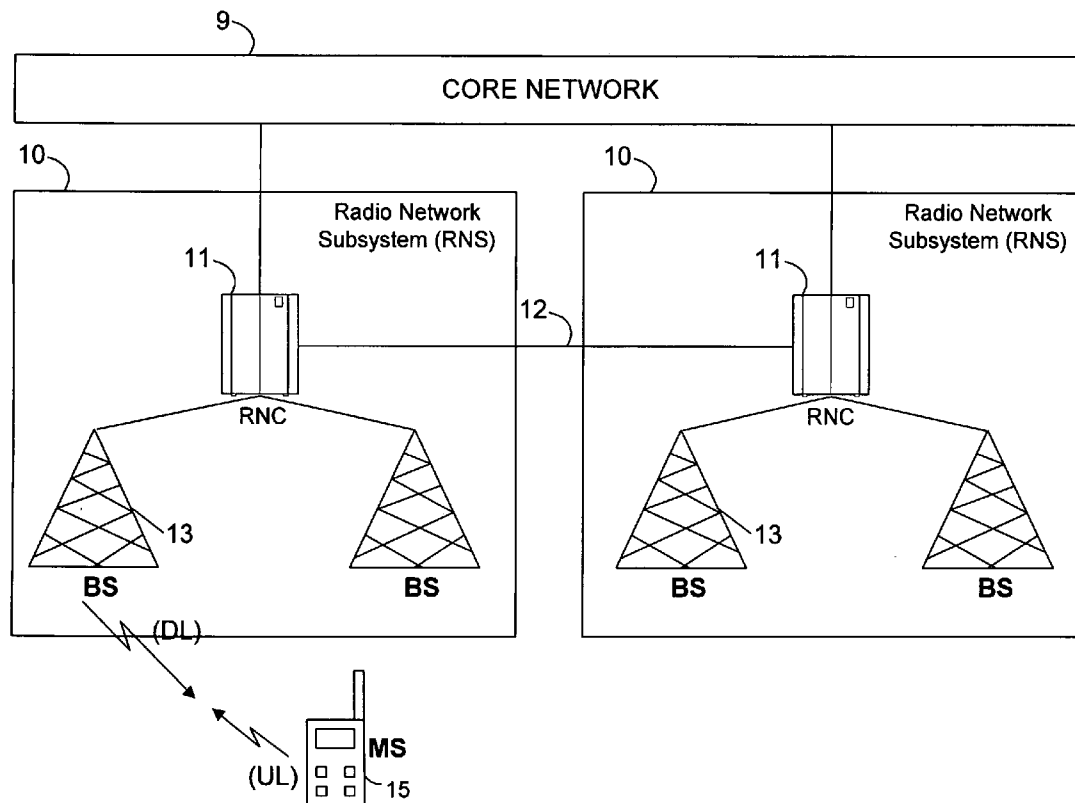(75) Inventor: **Emmanuel Kanterakis**, North Brunswick, NJ (US)

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(57) **ABSTRACT**

A radio network controller (RNC) application controls packet communications through base stations serving wireless remote stations. In the embodiments, the RNC stores each packet received for a wireless remote station in a buffer and maintains a BCN counter value representing the amount of buffered data. The RNC maintains a maximum accumulation timer ($Timer_{acc}$), and it restarts an inter-packet arrival timer ($Timer_{int}$) upon receipt of each packet for the station. The RNC initiates transmissions to the station in response to certain events, including expiration of either of the timers $Timer_{int}$ and $Timer_{acc}$, and if the BCN counter value exceeds a threshold. However, the transmissions use either a dedicated channel cell-state or a forward access channel state, depending on which event triggered each transmission. The RNC also may instruct the remote station to return to the forward access channel state following communication in the dedicated channel cell-state.
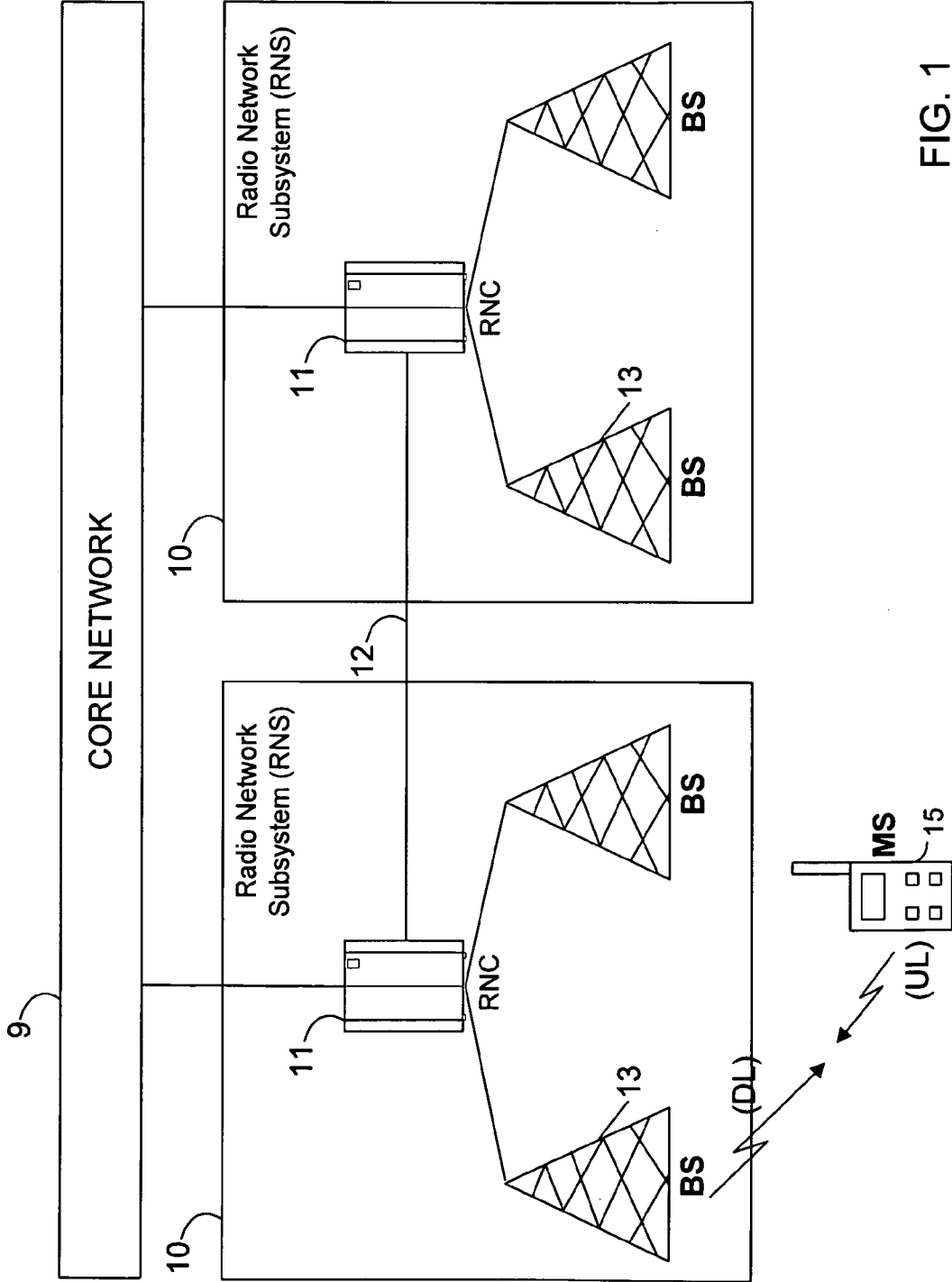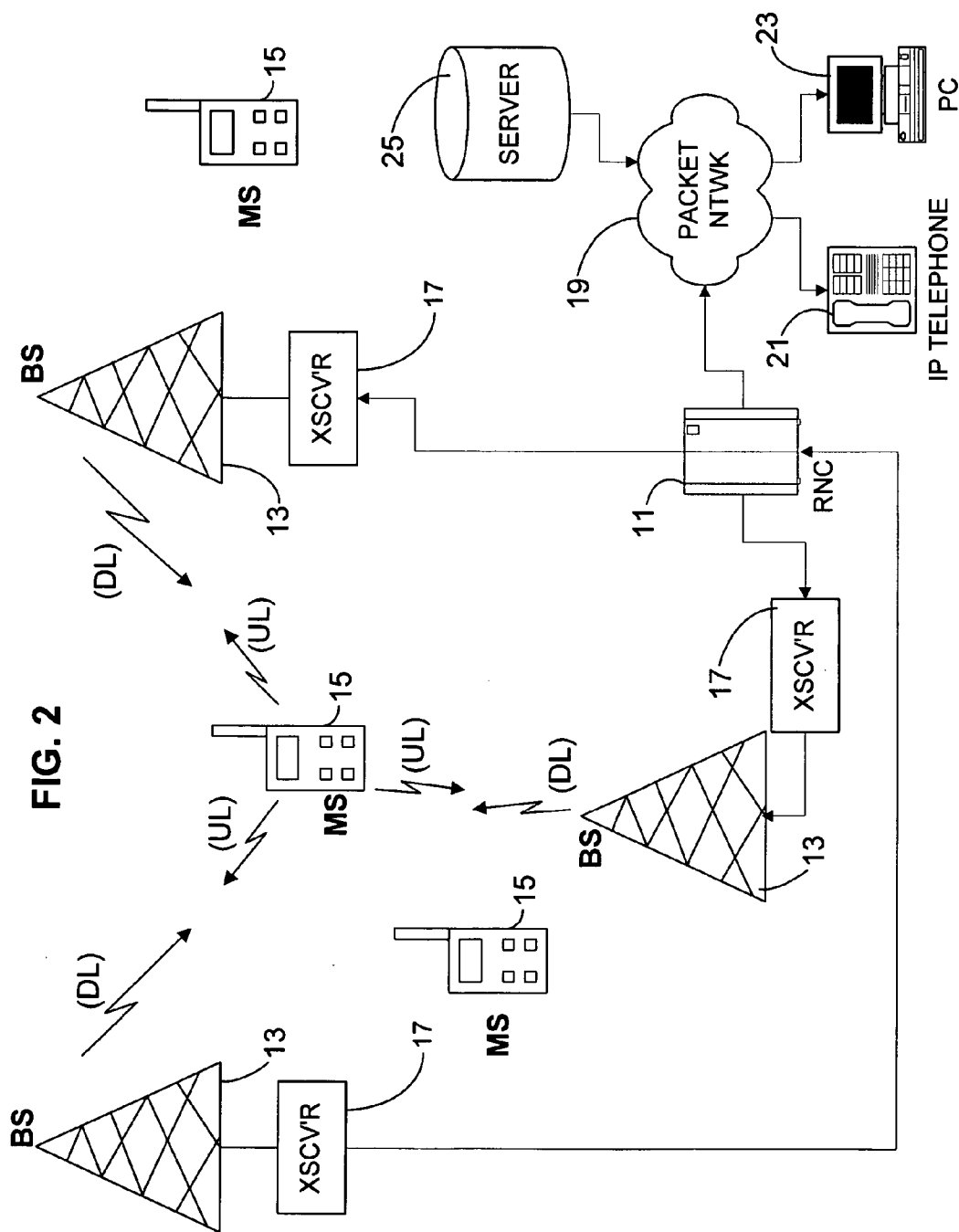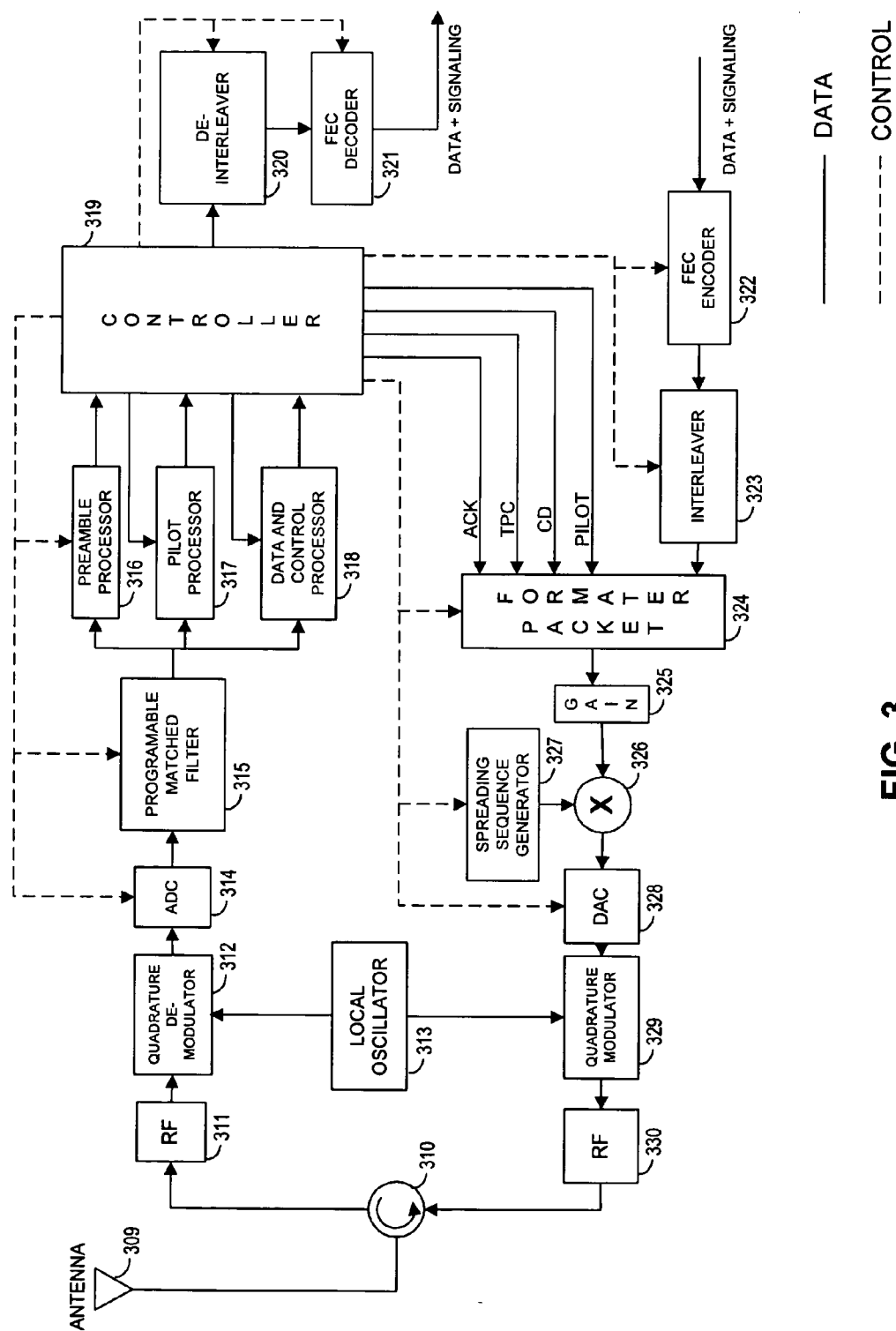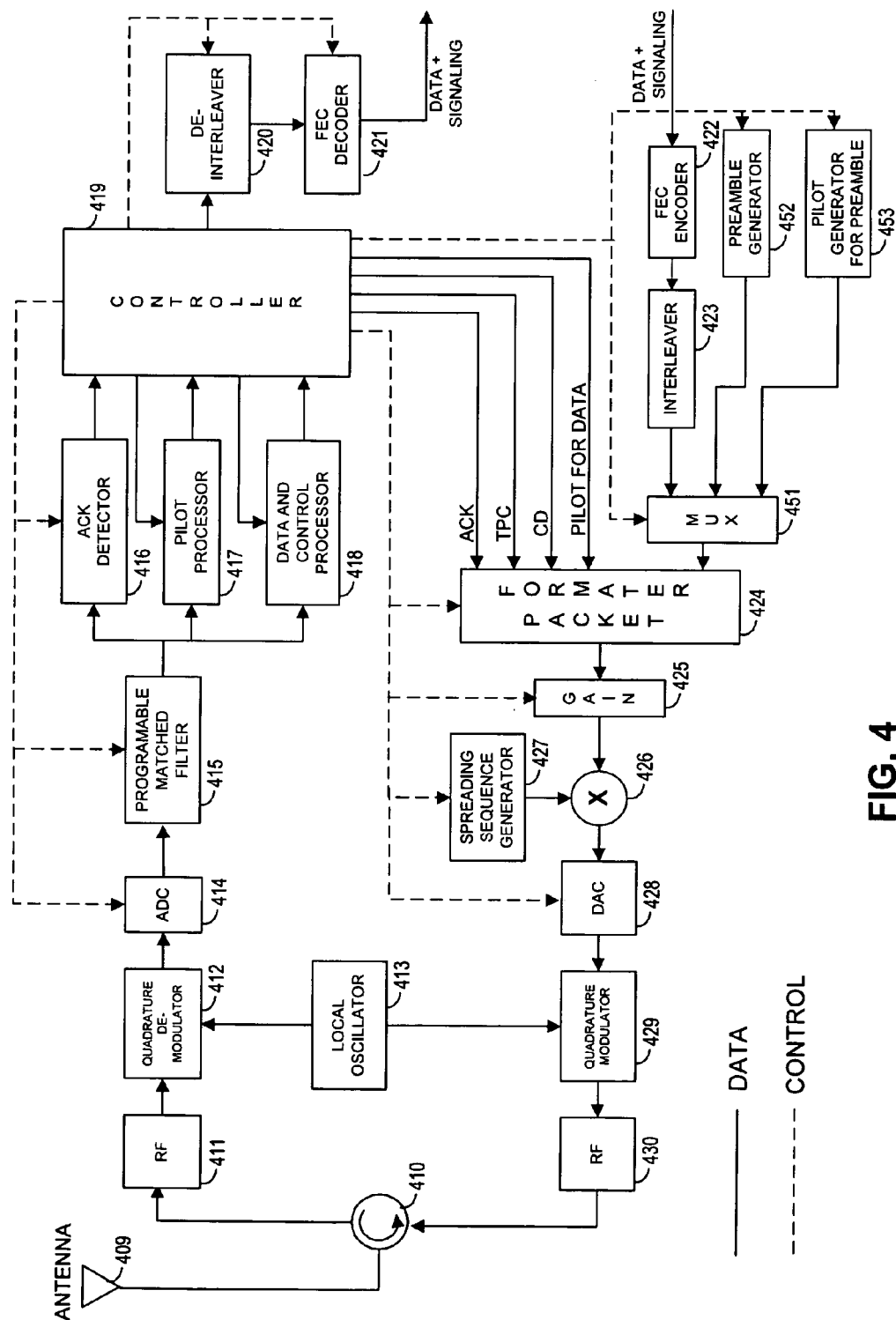
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

S51 — **Receive Packet for MS$_n$**

S52 — **Reset Timer$_{int}$, Timer$_{acc}$ and BCN**

S53 — Has Timer$_{acc}$ Expired?

S54 — New packet before Timer$_{int}$ expires?

S55 — **Buffer Packet Reset Timer$_{int}$ Update BCN**

S56 — Does BCN exceed BCN$_x$?

S57 — State Switch Decision Maker

S58 — **Schedule BS to send a PHY RECONFIG. to MS$_n$ to switch state (if necessary)**

S59 — **Schedule BS to send all packets in buffer to MS$_n$ immediately via Cell-DCH; Set BCN = 0**

S60 — **Schedule BS to send all packets in buffer to MSn immediately via Cell-FACH; Set BCN = 0**

S61 — State Switch-back Decision Maker

S62 — **Schedule BS to send a PHY RECONFIG. to MS$_n$ to switch state (if necessary)**

FIG. 6

FIG. 7

Reset Timer$_{acc}$ and Timer$_{int}$
Set BCN=0
Wait until New Packet Arrives

Update BCN, Set Timer$_{int}$=0

Current = Cell-DCH?

Timer$_{acc}$ Expired?

BCN>BCN$_x$?

New Packet Arrived

Timer$_{int}$ Expired?

Schedule BS to send packets in buffer to MS$_n$ immediately via FACH
Set BCN=0

Schedule BS to send a PHY RECONFIG. to MS$_n$ to switch to Cell-DCH (if necessary)

Schedule BS to send all packets in buffer to MS$_n$ via DSCH
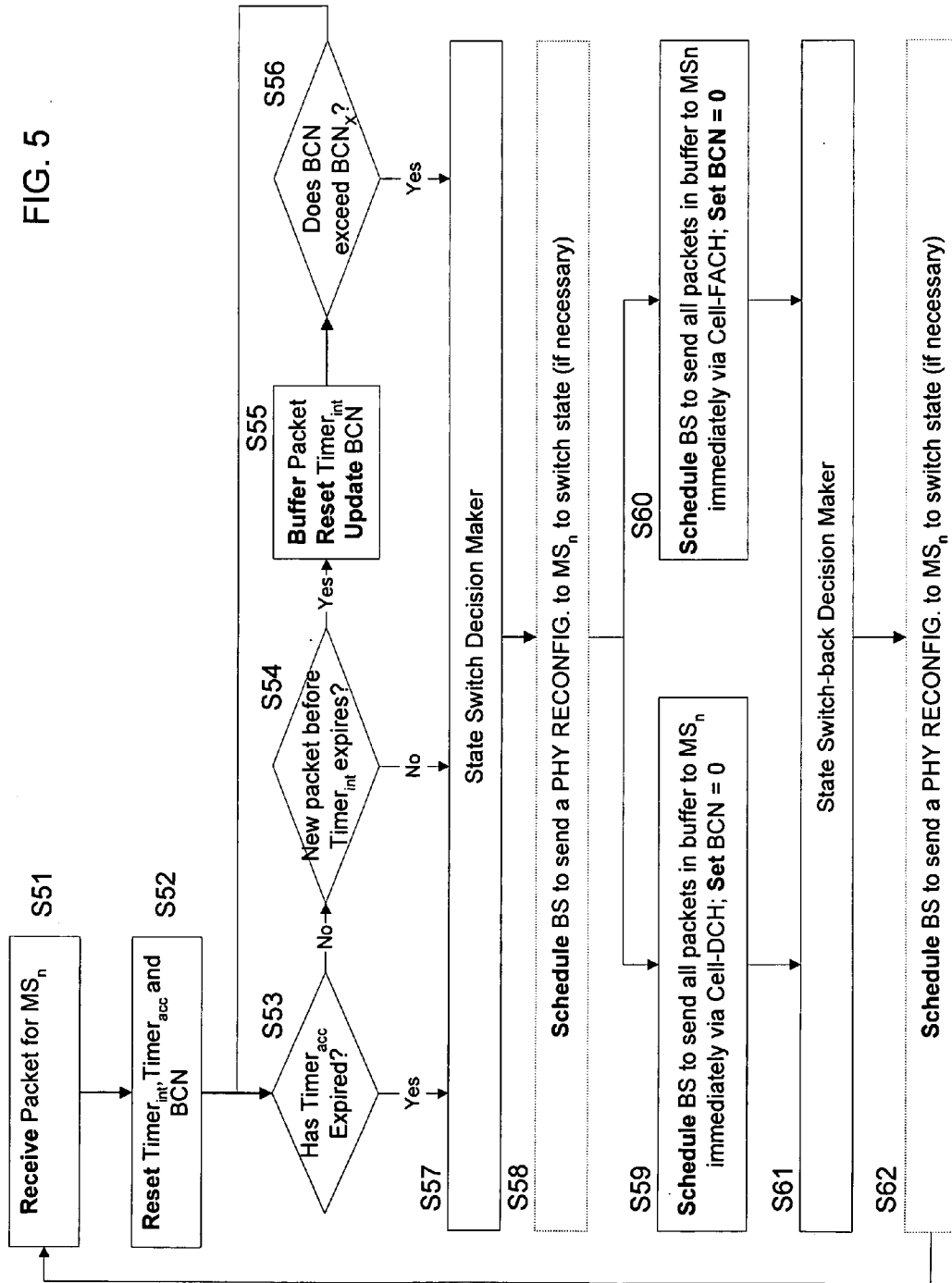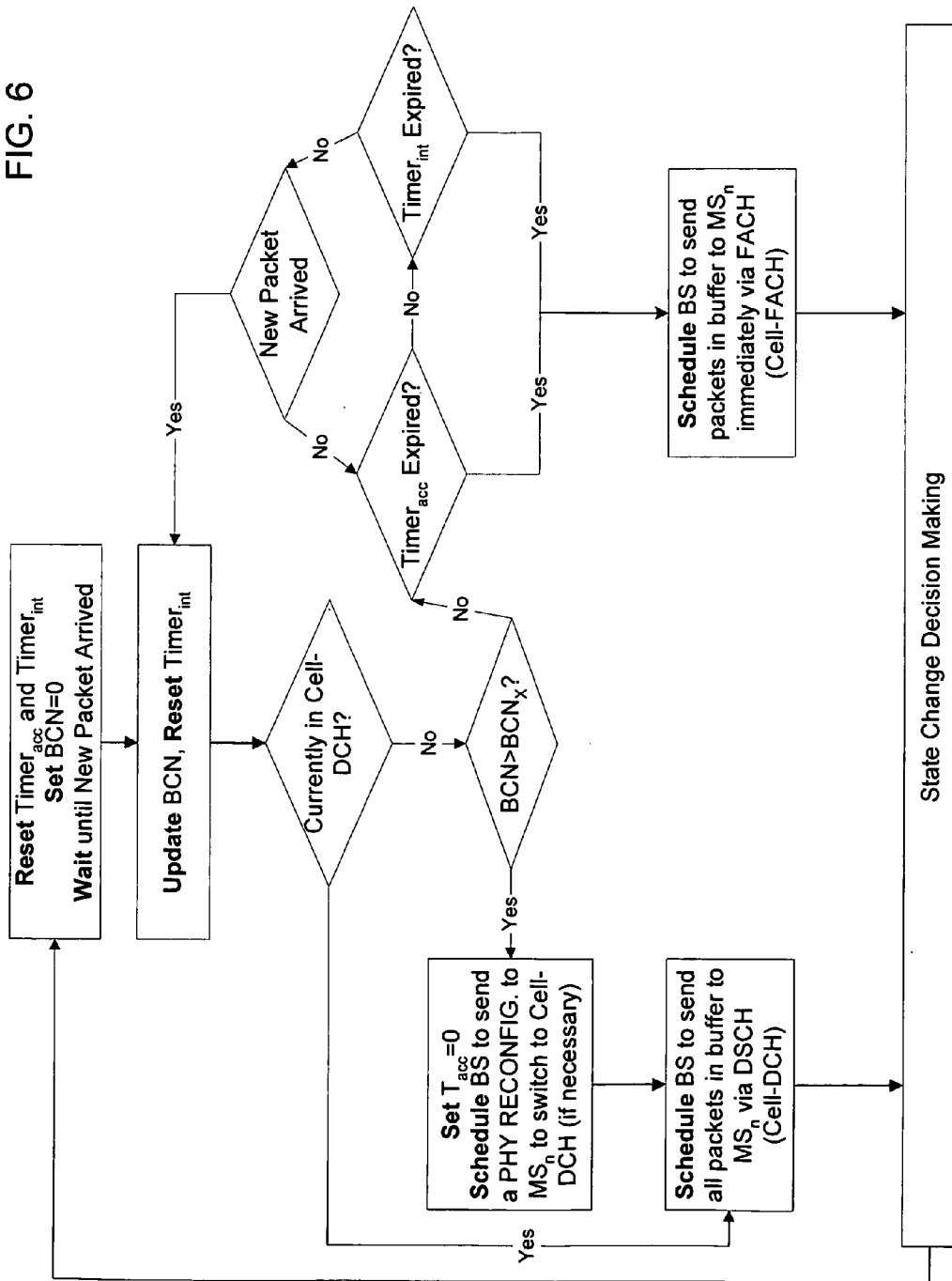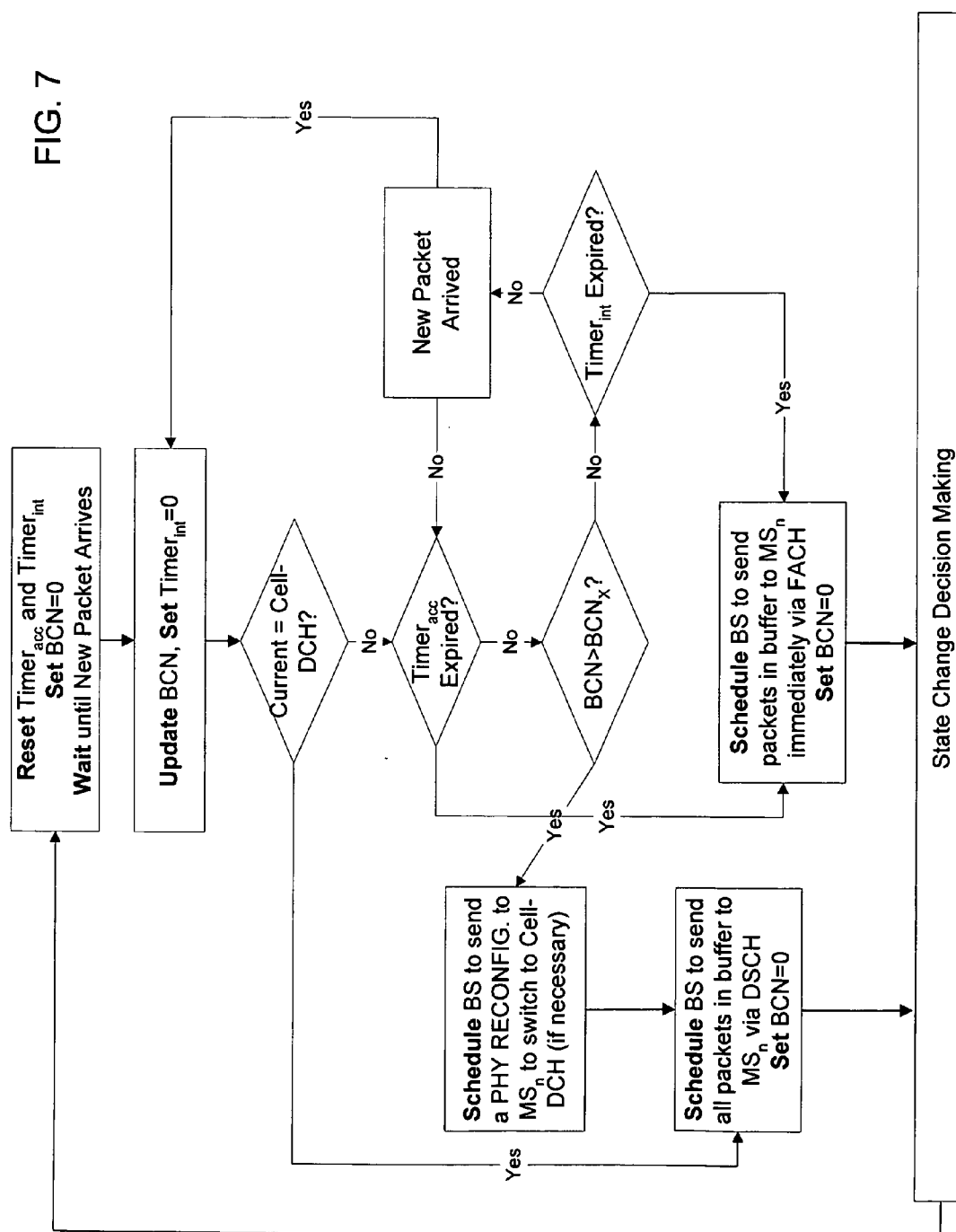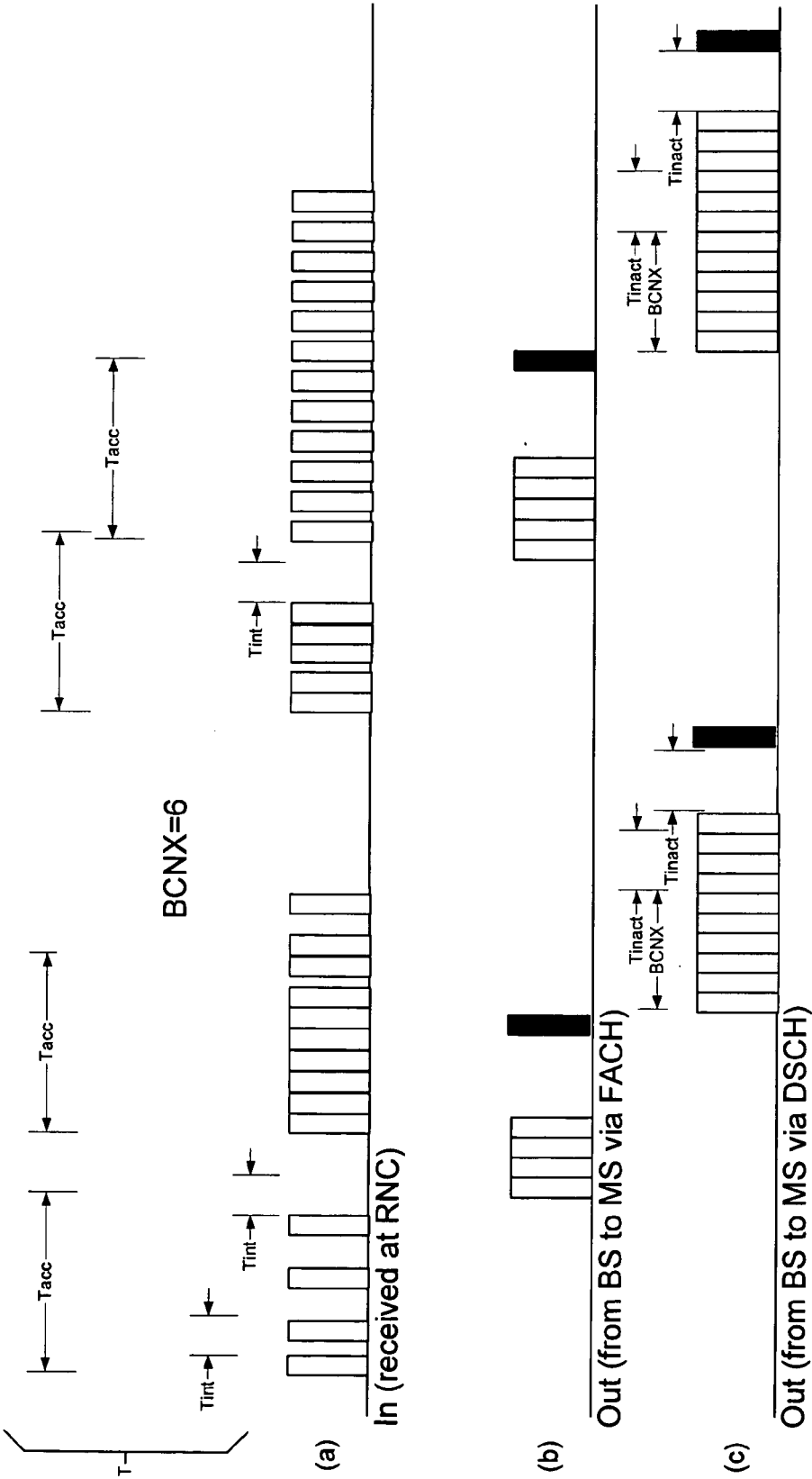Set BCN=0

State Change Decision Making

FIG. 8

CHANNEL CAPACITY OPTIMIZATION FOR PACKET SERVICES

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 60/290,642 entitled "CHANNEL CAPACITY OPTIMIZATION FOR PACKET SERVICES " filed on May 15, 2001, the disclosure of which is entirely incorporated herein by reference.

FIELD OF ENDEAVOR

[0002] The present subject matter relates to spread-spectrum communications, and more particularly to a code-division-multiple-access (CDMA) cellular, packet-switched communication system, which comprises a radio network controller (RNC), a plurality of base stations and a plurality of remote stations. The subject matter relates more particularly to methods to facilitate transitions between different channels and performance of the channels, in such a system.

BACKGROUND

[0003] Recent developments in wireless communications technologies have allowed expansion of service offerings from the original voice telephone service model to include a number of services supporting packet data communications. As customers become increasingly familiar with data services offered through landline networks, they are increasingly demanding comparable Quality of Service (QoS) data communications in the wireless domain, for example to maintain service while mobile subscribers roam freely or to provide remote service in locations where wireless loops are preferable to landline subscriber loops. A number of technologies support packet data communications in the wireless domain.

[0004] Under the currently proposed W-CDMA technical specification, there is only one type of dedicated transport channel, the Dedicated Channel (DCH), which can be either a downlink or an uplink transport channel. There are six types of common transport channels:

[0005] 1. The Broadcast Channel (BCH)—downlink;

[0006] 2. The Forward Access Channel (FACH)—downlink;

[0007] 3. The Paging Channel (PCH)—downlink;

[0008] 4. The Random Access Channel (RACH)—uplink;

[0009] 5. The Common Packet Channel (CPCH)—uplink; and

[0010] 6. The Downlink Shared Channel (DSCH)—shared downlink, associated with one or several downlink DCH.

[0011] With these transport channels, there are two states in the connected mode that can potentially be used to transfer packet data over the W-CDMA air interface: the Cell-FACH state and the Cell-DCH state.

[0012] In the Cell-FACH state, there are two sub-states: the RACH/FACH sub-state and the CPCH/FACH sub-state. A mobile station in the CPCH/FACH sub-state is prepared to send packets via the CPCH while tuned in to the FACH for downlink messages. In the Cell-FACH state, the Radio Network Controller (RNC) can allocate RACH or CPCH

resources for uplink transmission. CPCH and RACH may be assigned by the RNC as default channels in the uplink without using uplink resources until they are needed for transmission of uplink data. RACH is able to transmit very small Packet Data Units (PDUs) effectively. RACH capacity is limited to 9 bytes at cell edge or to 75 bytes when the mobile station is close to the base station. Sequential RACH transmissions may be used to transport more PDUs than a single RACH may carry, however, the RACH access procedure must be executed for each RACH access and the subsequent delay is significant. The RNC sets a threshold measurement of traffic volume in the mobile station, essentially instructing the mobile station to send a measurement report to the RNC when, for example, the traffic volume in the mobile station uplink buffer exceeds the capacity of two RACH transmissions. That would be the load at which it would make sense to utilize a higher capacity channel to transmit the buffered uplink data. If the measurement report is triggered, the RNC may assign CPCH resources to empty the uplink buffer or can switch the mobile station to Cell-DCH state.

[0013] CPCH may be assigned instead of RACH, to provide higher capacity uplink transport. A single CPCH access may transport up to 576×16 bytes of data at the cell edge (64 frames at SF 16) or up to 36,864 bytes when the mobile station is near the base station (64 frames at Spreading Factor 4). When CPCH resources are assigned to a mobile station, the RNC sets a threshold measurement of traffic volume in the mobile station, essentially instructing the mobile station to send a measurement report to the RNC when traffic volume in the mobile station uplink buffer exceeds the capacity of five to ten CPCH transmissions. Consecutive RACH or CPCH accesses may be used until the uplink buffers are emptied.

[0014] In the Cell-DCH state, there are the DCH/DCH sub-state and the DCH/DCH+DSCH sub-state. That means the mobile station sends packet data via the DCH uplink and is tuned to receive data downlink via either the DCH or the DCH+DSCH. The DSCH is a code-sharing mechanism in the downlink direction and is more desirable when data traffic is bursty. The DCH is more suitable for streaming traffic and is not a resource efficient means of transmitting bursty uplink data. In the uplink, DCH is different in that dedicated resources in the uplink must be allocated by the RNC without complete knowledge about the amount of data to be transmitted in the uplink. For this reason an inactivity timer is used in DCH to determine if the uplink buffer at a mobile station is emptied. The RNC will measure the time period in the uplink during which there is no uplink data transmission. When this period exceeds the inactivity timer setting, the RNC will reconfigure the mobile station to Cell-FACH. In the downlink, the Radio Network Controller (RNC) can allocate either DCH or DCH+DSCH resources for packet data transmission. Similarly, the RNC does not have complete knowledge of future packet arrivals and uses instead inactivity timers to measure the time period in the downlink during which there is no data transmission. When this period exceeds the inactivity timer setting, the RNC will reconfigure the mobile station to Cell-FACH. These inactivity timers in CELL-DCH lead to substantial overhead and inefficiencies when the data traffic is bursty, thus reducing capacity.

[0015] For certain types of packet data applications (e.g. interactive service), ideally, one would like to use a Cell-FACH (e.g. CPCH/FACH sub-state) for uplink traffic and switch to a Cell-DCH state (e.g. DCH/DCH+DSCH sub-state) for downlink traffic. The reason is that there are certain deficiencies with both states. In Cell-FACH state, FACH downlink does not have closed loop power control and has only limited capability to handle large packets, whereas in the Cell-DCH state, as in any circuit-switched packet channel, there is a lot of wastage of limited resources. However, a problem with the proposed frequent switching is that a mobile station while residing in the Cell-DCH state cannot be de-allocated immediately after transmission of packet data due to the inactivity timer.

[0016] Also, when a group of packets arrive from afar, as in the case of a backbone network, there will often be time-gaps between these packets. When the RNC assigns channel resources immediately after the arrival of the first packet and does not release such resources until the last packet of the train arrives, the channel hold-up time will increase, thus creating inefficiencies.

SUMMARY

[0017] The inventions disclosed here deal with this type of deficiencies in the Cell-DCH state and the transition criteria or improvement between the Cell-FACH and Cell-DCH states on CDMA networks. The concepts and improvements described herein can also be generalized and applied to other channels as well as to other wireless digital packet communication networks.

[0018] The inventive concepts include a method for grouping a plurality of packets and sending these grouped packets in a shorter connecting time. This methodology introduces a quick release, for example, of the DCH resource associated with DCH or DCH+DSCH. By grouping the plurality of packets or reducing the release time of the DCH, the mobile station will more easily oscillate between the Cell-FACH and Cell-DCH states to support interactive type or the near-real time conversational applications of packet communications.

[0019] A general objective of the invention is to remove the inefficiencies associated with bursty data.

[0020] A further objective is to efficiently configure limited physical channel resources to various mobile stations. By reducing the connection time of a channel, the mobile station also reduces power consumption.

[0021] Another objective relates to provide a mechanism to release the DCH resources associated with the Cell-DCH state quickly.

[0022] A further objective is to enable mobile stations to oscillate between the Cell-FACH and Cell-DCH states.

[0023] A wireless packet communication network, such as a code-division-multiple-access (CDMA) telecommunication system employing spread-spectrum modulation, has a radio network controller (RNC) and a plurality of base stations, which serve a plurality of mobile stations. The term "mobile station" is used here to refer to any wireless remote user station, most examples of which are moveable, although some maybe used in fixed wireless applications. In a CDMA embodiment, each base station has a BS-spread-

spectrum transmitter and a BS-spread-spectrum receiver. Each of the mobile stations has an MS-spread-spectrum transmitter and an MS-spread-spectrum receiver.

[0024] The RNC may be a physical network control node or a control application running on a network node that also implements other functions, for example on each of the base stations. In the preferred embodiment, the RNC monitors channel configuration, based on traffic measurement information of communications through the base stations for the mobile stations. Based on the traffic demand or a projection thereof, the RNC configures the physical channel resources within each cell.

[0025] The Radio Network Controller (RNC) waits to receive a packet for a mobile station (MS) from a core network. In accord with one inventive technique, while waiting for the first packet, the RNC sets its maximum packet accumulation timer, $Timer_{acc}$, to a predetermined time and resets the buffer content number, of the BCN buffer. The T_{acc} is preferably less than the time that causes the communication or application to time-out (e.g. TCP/IP time-out).

[0026] Upon receiving the packet, the RNC keeps the packet in its buffer and resets its maximum inter-packet arrival timer, $Timer_{int}$, and updates the BCN counter value. The RNC then compares the updated BCN counter value with a predetermined BCNX, the buffer size threshold for switching to Cell-DCH state. If the BCN counter value is less than BCNX, the RNC will wait for a next packet for the same recipient MS until $Timer_{int}$ expires. If the RNC receives a next packet for the recipient MS before $Timer_{int}$ expires, upon receiving the next packet, it again keeps this next packet, along with any previously accumulated ones, in its buffer, resets $Timer_{int}$, updates the BCN counter value and compares BCN counter value with BCNX. The RNC repeats this process until any one of three conditions is met: (1) No further packet for the same recipient MS arrives before $Timer_{int}$ expires; (2) $Timer_{acc}$ expires; or (3) BCN counter value is greater than BCNX. In the case of (1) or (2), since the Cell-DCH switch criteria has not been triggered, the RNC will schedule the BS to send all accumulated packet(s) in its buffer to the recipient MS via FACH (Cell-FACH). In the case of (3), the Cell-DCH switch criteria is triggered, the RNC will send out a Physical Channel Reconfiguration message to instruct the recipient MS to switch to Cell-DCH and schedule the BS to send all accumulated packets in its buffer to the recipient MS via DCH or DSCH (Cell-DCH). Upon scheduling the delivery of any packets in the buffer from the BS to the MS, the RNC resets its BCN counter value to zero.

[0027] Upon delivery of the packets, the RCN will need to determine whether the MS should stay in its current state or switch to another state. The detailed description teaches a method for such determination, although the determination to switch states may be based on other conventional methods common in the art.

[0028] The RNC can detect if another packet has arrived for the recipient MS within T_{inact} ms. T_{inact} can be set to zero or any other values deemed appropriate. T_{inact} can also be a variable set to coincide with the end of the scheduled transmission of the accumulated packets. If there is not another packet for recipient MS within T_{inact} ms, the RNC will schedule a Physical Channel Reconfiguration message

to instruct the recipient MS to release the DSCH and switch back to Cell-FACH state. Likewise, the buffer size also provides a way to measure congestion in the current channel. When the packet arrival rate exceeds the rate at which RNC can send out packets, packet accumulation will result in a large buffer. The RNC monitors the buffer content/size and when the buffer size exceeds a pre-determined threshold, the RNC will configure the BS to send the accumulated and scheduled packets via DCH.

[0029] Aspects of invention include methodologies for implementing such allocation of channel resources for packet transmissions based on traffic conditions, using the techniques outlined above. Other aspects of invention relate to networks and/or network controllers or other components for implementing those techniques.

[0030] Additional objects, advantages and novel features of the embodiments will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the embodiments. The objects and advantages of the inventive concepts may be realized and attained by means of the methodologies, instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The drawing figures depict preferred embodiments by way of example, not by way of limitations. In the figures, like reference numerals refer to the same or similar elements.

[0032] **FIG. 1** is a functional block diagram of a simplified CDMA Terrestrial Radio Access network architecture, capable of implementing the communications in accord with the present invention.

[0033] **FIG. 2** is a functional block diagram of a CDMA network, capable of implementing the communications in accord with the present invention.

[0034] **FIG. 3** is a functional block diagram of a spread spectrum base station for use in a network of the type shown in **FIG. 2**.

[0035] **FIG. 4** is a functional block diagram of a spread spectrum remote or mobile station for use in a network of the type shown in **FIG. 2**.

[0036] **FIG. 5** is a process flow diagram illustrating an example of the RNC scheduling procedure.

[0037] **FIG. 6** is a more detailed process flow diagram of **FIG. 5** illustrating an example of the RNC scheduling procedure using buffer size as the switch criteria.

[0038] **FIG. 7** is a more detailed process flow diagram of **FIG. 5** illustrating an example of the RNC scheduling procedure using accumulation timer as the switch criteria.

[0039] **FIG. 8** is a timing diagram showing several examples of receipt and transmission of groups of packets for a particular mobile station, and the relationship thereof to certain timers used in one embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0040] The subject matter disclosed involves a packet mode DCH/DCH+DSCH methodology for releasing the DCH resources associated with Cell-DCH state in a spread spectrum wireless communication network. The inventive access methodology accommodates bursty traffic in an optimum manner. Reference now is made in detail to the presently preferred embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

[0041] In a preferred embodiment (**FIGS. 1 and 2**), the CDMA system comprises a radio network controller (RNC) **11**, a plurality of base stations **13** and a plurality of mobile stations **15**. **FIG. 1** shows a simplified CDMA Terrestrial Radio Access network architecture As such, **FIG. 1** provides a relatively higher level illustration, with a core network **9** providing two-way packet data communications to and from a plurality of radio network subsystems (RNSs) **10**. The RNCs **11** in the radio network subsystems **10** may be interconnected, for example by the line **12**.

[0042] With reference to the more detailed version shown in **FIG. 2**, each base station (BS) **13** has BS-spread-spectrum transmitter and a BS-spread-spectrum receiver, shown as a single transceiver (XSCV'R) system **17** for simplicity in this drawing. Each of the mobile stations (MS) **15** has an MS-spread-spectrum transmitter and an MS-spread-spectrum receiver (not separately shown). Exemplary transmitters and receivers for use in the BS and MS network elements are discussed in more detail below with regard to **FIGS. 3 and 4**. In a typical embodiment, the radio network controller (RNC) **11** provides two-way packet data communications to a wide area network, shown by way of example as a packet-switched network **19**. The RNC **11** and the network **19** provide the MS units **15** with two-way packet data communications services to enable communication to and from devices, represented by way of example by the IP telephone **21**, the personal computer (PC) **23** and the server **25**.

[0043] The CDMA system provides a number of logically different channels for upstream and downstream communications over the air-link interface. Each channel is defined by one or more of the codes, for example the spreading code and/or the scrambling code. Several of the channels are common channels, but most of the channels are used for uplink or downlink packet communications between the base stations **13** and the mobile stations **15**.

[0044] The RNC **11** measures traffic through the base stations **13** going to and from the mobile stations **15**. In this way, the radio network controller (RNC) **11** monitors traffic demand in the illustrated network. The RNC **11** assigns physical channel resources to the mobile stations **15**, by re-configuring the state of packet data connected mode of each mobile station **15** within each cell of each base station **13**. Each mobile station **15** in packet data connected mode is either in Cell-FACH state or in Cell-DCH state.

[0045] As noted earlier, the Cell-DCH state includes two sub-states the DCH/DCH sub-state and the DCH/DCH+DSCH sub-state. In each sub-state, the mobile station (MS) **15** sends packet data via the Dedicated CHannel (DCH) uplink. The mobile station (MS) **15** tunes to receive downlink data, via either the DCH or the DCH+DSCH. In the downlink, the Radio Network Controller (RNC) **11** allocates either DCH or DCH+DSCH resources for packet data transmission. The Downlink Shared CHannel (DSCH) is a Physi-

cal Channel that provides a code-sharing mechanism in the downlink direction and is desirable when data traffic is bursty.

[0046] The Cell-FACH state also has two sub-states: the RACH/FACH sub-state and the CPCH/FACH sub-state. A mobile station in the CPCH/FACH sub-state is prepared to send packets via the CPCH while tuned in to the FACH for downlink messages. In the Cell-FACH state, the Radio Network Controller (RNC) **11** can allocate RACH or CPCH resources for uplink transmission.

[0047] In accord with the present access methodology, when the RNC **11** first receives packets for a mobile station (MS) from the core or from the packet network, the RNC allocates resources for their transmission. The RNC **11** buffers the first packet and resets two timers. One timer Timer$_{int}$ specifies the maximum inter-packet arrival time T$_{int}$, that is to say, the maximum time that the RNC **11** will wait between packets intended for one station **15** without transmitting. The other timer Timer$_{acc}$ specifies the maximum packet accumulation time T$_{acc}$, that is to say, the maximum time over which the RNC **11** will accumulate packets intended for one station **15** without transmitting. The RNC **11** also updates its buffer size denotes by the BCN counter value.

[0048] The BCN counter value is compared to BCNX, a predetermined threshold for switching to Cell-DCH state. If the BCN counter value exceeds BCNX, then the RNC **11** can proceed to immediate transmission of the accumulated packets to the recipient mobile station MS **15** by first switching the MS **15** to the Cell-DCH state.

[0049] The maximum packet accumulation timer Timer$_{acc}$ defines the time limit T$_{acc}$ within which the network side components, e.g. the RNC and the base station, must transmit the oldest of the accumulated data. The T$_{acc}$ is preferably less than the time that causes the communication or application to time-out (e.g. TCP/IP time-out). At the end of this time, the RNC **11** will initiate transmission of whatever packet or packets it has received from the core network **9** or the packet network **19** since the receipt of the first (oldest) packet in the buffer (and activation of the timers). The RNC **11** initiates transmission of the buffered packets for the particular station **15**, on a first-in-first-out basis. The expiration of Timer$_{acc}$ causes the system to transmit using the Cell-FACH state.

[0050] The maximum inter-packet arrival time T$_{int}$, specified by the timer Timer$_{int}$, defines a time limit to wait for new packets to arrive from the core network **9** or the packet network **19**, intended for the particular mobile station **15**. If no packets arrive, within this time interval, then the RNC **11** shall proceed to the immediate transmission of the buffered packet data to the recipient mobile station MS **15**.

[0051] When no additional packets arrive for the same recipient MS within a T$_{int}$ interval, the RNC **11** immediately sends all accumulated packet(s) in its buffer through base station (BS) **13** to the recipient MS **15** via FACH (Cell-FACH). However, if the RNC **11** receives a new packet, for the recipient MS, before timer Timer$_{int}$ expires, the RNC **11** adds that new packet to those previously accumulated in its buffer, resets Timer$_{int}$, updates the value for the BCN counter, and waits again for the next packet. The RNC repeats this process until the limit T$_{acc}$ for Timer$_{acc}$ expires.

When Timer$_{acc}$ expires, the RNC **11** schedules the base station (BS) **13** to send all accumulated packets in its buffer to the recipient MS **14** via FACH.

[0052] If at anytime the updated BCN counter value exceeds BCNX, the RNC **11** sends a Physical Channel Reconfiguration message to instruct the recipient MS to switch back to Cell-DCH and then sends all accumulated packets in its buffer, to the recipient MS **14** via DCH or DSCH (Cell-DCH).

[0053] If the RNC **11** has scheduled transmission in the Cell-DCH state, the RNC preferably detects if there is another packet arriving for recipient MS within a period of T$_{inact}$ ms, that is to say within a maximum inactivity interval. If there is no further packet for the recipient MS **15** within T$_{inact}$ time, the RNC **11** schedules a Physical Channel Reconfiguration message to instruct the recipient MS to release the DSCH and switch back to Cell-FACH.

[0054] FIG. 3 illustrates a presently preferred embodiment of a BS spread-spectrum transmitter and a BS spread-spectrum receiver, essentially in the form of a base-band processor for performing the PHY layer functions. The BS spread-spectrum transmitter and the BS spread-spectrum receiver form one of the transceivers **17** at a base station **13**. The BS spread-spectrum receiver includes an antenna **309** coupled to a circulator **310**, a receiver radio frequency (RF) section **311**, a local oscillator **313**, a quadrature demodulator **312**, and an analog-to-digital converter **314**. The receiver RF section **311** is coupled between the circulator **310** and the quadrature demodulator **312**. The quadrature demodulator is coupled to the local oscillator **313** and to the analog to digital converter **314**. The output of the analog-to-digital converter **315** is coupled to a programmable-matched filter **315**.

[0055] A preamble processor **316**, pilot processor **317** and data-and-control processor **318** are coupled to the programmable-matched filter **315**. A controller **319** is coupled to the preamble processor **316**, pilot processor **317** and data-and-control processor **318**. A de-interleaver **320** is coupled between the controller **319** and a forward-error-correction (FEC) decoder **321**. The decoder **321** outputs data and signaling received via the UL channel to the MAC layer (not shown).

[0056] The BS spread-spectrum transmitter includes a forward-error-correction (FEC) encoder **322** coupled to an interleaver **323**. A packet formatter **324** is coupled to the interleaver **323** and to the controller **319**. A variable gain device **325** is coupled between the packet formatter **324** and a product device **326**. A spreading-sequence generator **327** is coupled to the product device **326**. A digital-to-analog converter **328** is coupled between the product device **328** and quadrature modulator **329**. The quadrature modulator **329** is coupled to the local oscillator **313** and a transmitter RF section **330**. The transmitter RF section **330** is coupled to the circulator **310**.

[0057] The controller **319** has control links coupled to the analog-to-digital converter **314**, the programmable-matched filter **315**, the preamble processor **316**, the digital-to-analog converter **328**, the spreading sequence generator **327**, the variable gain device **325**, the packet formatter **324**, the de-interleaver **320**, the FEC decoder **321**, the interleaver **323** and the FEC encoder **322**.

[0058] A received spread-spectrum signal from antenna **309** passes through circulator **310** and is amplified and

filtered by the receiver RF section **311**. The local oscillator **313** generates a local signal, which the quadrature demodulator **312** uses to demodulate in-phase and quadrature phase components of the received spread-spectrum signal. The analog-to-digital converter **314** converts the in-phase component and the quadrature-phase component to digital signals. These functions are well known in the art, and variations to this block diagram can accomplish the same functions.

[0059] The programmable-matched filter **315** despreads the received spread-spectrum signal components. A correlator, as an alternative, may be used as an equivalent means for despeading the received spread-spectrum signal.

[0060] The preamble processor **316** detects a preamble portion of the received spread-spectrum signal. The pilot processor **317** detects and synchronizes to a pilot portion of the received spread-spectrum signal. The data and control processor **318** detects and processes the data portion of the received spread-spectrum signal. Detected data passes through the controller **319** to the de-interleaver **320** and FEC decoder **321**. Data and signaling from the up-link are outputted from the FEC decoder **321** to the higher layer elements in or associated with the BS **13** and through the link to the RNC **11**.

[0061] The RNC **11** supplies data and signaling over a link to the base station. In the BS transceiver, the MAC layer elements supply data and signaling information, intended for down-link transmission, to the input of the FEC encoder **322**. The signaling and data are FEC encoded by the FEC encoder **322**, and interleaved by the interleaver **323**. The packet formatter **324** formats data, signaling, acknowledgment signal, collision detection signal, pilot signal and transmitting power control (TPC) signal into appropriate packets. Each packet is outputted from the packet formatter **324**, and the packet level is amplified or attenuated by the variable gain device **325**. The packet is spread-spectrum processed by the product device **326**, with a spreading chip-sequence from the spreading-sequence generator **327**. The packet is converted to an analog signal by the digital-to-analog converter **328**, and in-phase and quadrature-phase components are generated by the quadrature modulator **329** using a signal from local oscillator **313**. The modulated down-link packet is translated to a carrier frequency, filtered and amplified by the transmitter RF section **330**, and then it passes through the circulator **310** and is radiated by antenna **309**.

[0062] **FIG. 4** shows an embodiment of an MS spread-spectrum transmitter and an MS spread-spectrum receiver, essentially in the form of a base-band processor for performing the PHY layer transceiver functions. The MS spread-spectrum transmitter and the MS spread-spectrum receiver are located at the remote or mobile station (MS) **15**. The MS spread-spectrum receiver includes an antenna **409** coupled to a circulator **410**, a receiver radio frequency (RF) section **411**, a local oscillator **413**, a quadrature demodulator **412**, and an analog-to-digital converter **414**. The receiver RF section **411** is coupled between the circulator **410** and the quadrature demodulator **412**. The quadrature demodulator is coupled to the local oscillator **413** and to the analog to digital converter **414**. The output of the analog-to-digital converter **415** is coupled to a programmable-matched filter **415**.

[0063] An acknowledgment detector **416**, pilot processor **417** and data-and-control processor **418** are coupled to the

programmable-matched filter **415**. A controller **419** is coupled to the acknowledgment detector **416**, pilot processor **417** and data-and-control processor **418**. A de-interleaver **420** is coupled between the controller **419** and a forward-error-correction (FEC) decoder **421**. The decoder **421** outputs data and signaling received via the DL channel to the MAC layer elements (not shown) of the MS.

[0064] The MS spread-spectrum transmitter includes a forward-error-correction (FEC) encoder **422** coupled to an interleaver **423**. A packet formatter **424** is coupled through a multiplexer **451** to the interleaver **423**. The packet formatter **424** also is coupled to the controller **419**. A preamble generator **452** and a pilot generator **453** are coupled to the multiplexer **451**. A variable gain device **425** is coupled between the packet formatter **424** and a product device **426**. A spreading-sequence generator **427** is coupled to the product device **426**. A digital-to-analog converter **428** is coupled between the product device **428** and quadrature modulator **429**. The quadrature modulator **429** is coupled to the local oscillator **413** and a transmitter RF section **430**. The transmitter RF section **430** is coupled to the circulator **410**.

[0065] The controller **419** has control links coupled to the analog-to-digital converter **414**, the programmable-matched filter **415**, the acknowledgment detector **416**, the digital-to-analog converter **428**, the spreading sequence generator **427**, the variable gain device **425**, the packet formatter **424**, the de-interleaver **420**, the FEC decoder **421**, the interleaver **423**, the FEC encoder **422**, the preamble generator **452** and the pilot generator **453**.

[0066] A received spread-spectrum signal from antenna **409** passes through circulator **410** and is amplified and filtered by the receiver RF section **411**. The local oscillator **413** generates a local signal, which the quadrature demodulator **412** uses to demodulate in-phase and quadrature phase components of the received spread-spectrum signal. The analog-to-digital converter **414** converts the in-phase component and the quadrature-phase component to digital signals. These functions are well known in the art, and variations to this block diagram can accomplish the same functions.

[0067] The programmable-matched filter **415** despreads the received spread-spectrum signal components. A correlator, as an alternative, may be used as an equivalent means for despeading the received spread-spectrum signal.

[0068] The acknowledgment detector **416** detects certain acknowledgments in the received spread-spectrum signal. The pilot processor **417** detects and synchronizes to a pilot portion of the received spread-spectrum signal. The data and control processor **418** detects and processes the data portion of the received spread-spectrum signal. Detected data passes through the controller **419** to the de-interleaver **420** and FEC decoder **421**. Data and signaling from the DL are outputted from the FEC decoder **421** to the higher level elements in or associated with the MS **15**.

[0069] In the MS transceiver, the MAC layer elements supply data and signaling information intended for transmission over the up-link channel, to the input of the FEC encoder **422**. Data and signaling information are FEC encoded by FEC encoder **422**, and interleaved by interleaver **423**. The preamble generator **452** generates a preamble, and the pilot generator **453** generates a pilot for the preamble.

The multiplexer **451** multiplexes the data, preamble and pilot, and the packet formatter **424** formats the preamble, pilot and data into a common-packet channel packet. Further, the packet formatter **424** formats data, signaling, acknowledgment signal, collision detection signal, pilot signal and TPC signal into a packet. The packet formatter **424** outputs the packet, and the packet level is amplified or attenuated by variable gain device **425**. The packet is spread-spectrum processed by product device **426**, with a spreading chip-sequence from spreading-sequence generator **427**. The packet is converted to an analog signal by digital-to-analog converter **428**, and quadrature modulator **429** using a signal from local oscillator **413** generates in-phase and quadrature-phase components. The modulated up-link packet is translated to a carrier frequency, filtered and amplified by the transmitter RF section **430** and then it passes through the circulator **430** and is radiated by the antenna **409**.

[0070] U.S. Pat. No. 6,169,759 to Kanterakis et al. issued Jan. 2, 2001 provides a more detailed description of the operation of the PHY transceivers shown in **FIGS. 3 and 4**, for example in a CPCH type channel transmission.

[0071] **FIG. 5** is a flow-chart illustrating the inventive processing, from the perspective of the RNC and/or one of the associated base stations.

[0072] **FIG. 8** is an illustration of several examples of incoming and outgoing packets of the RNC **11**, in relation to the various timers and shows several examples, which are useful in explaining the inventive operations. The top line of pulses (a) represents incoming packets, for example as received at the RNC **11**. The timing intervals T appear above that line. The middle line (b) represents packet transmissions from the base station (BS) **13** to a specific mobile station (MS) **15** via FACH. The bottom line (c) represents packet transmissions from the base station (BS) **13** to a specific mobile station (MS) **15** via DSCH.

[0073] Assume for example, that the RNC **11** received the first four packets, as shown to the left on line (a) of **FIG. 8**. Upon receipt of the first packet (S**51** in **FIG. 5**), the RNC **11** resets and starts operation of the maximum inter-packet arrival timer, Timer$_{int}$, and the maximum packet accumulation timer, Timer$_{acc}$ (step S**52**). The RNC **11** also sets the value of the BCN counter for the amount of data in its packet buffer.

[0074] The timers may be implemented in any convenient manner. For example, any of the timers used herein can use a downcount approach, that is to say reset to maximum and downcount to zero. Any of the timers may alternatively implement an up-count approach, where the timer is reset to 0 and counts up to a maximum or threshold value. The timers could be analog, but preferably are implemented as digital logic, as part of the RNC application program.

[0075] In the process flow of **FIG. 5**, the RNC **11** checks the status of Timer$_{acc}$ in step S**53**. If the check of Timer$_{acc}$ indicates that the maximum packet accumulation time T$_{acc}$ has not passed since the arrival of the first packet, then the RNC **11** checks to determine if a new packet has been received before expiration of Timer$_{int}$ (step S**54**). If a new packet has arrived within the T$_{int}$ interval, the process branches from S**54** to S**55**. The RNC **11** places the packet in its buffer. The maximum inter-packet arrival timer Timer$_{int}$

is reset each time one of the packets for the mobile station MS arrives before that timer expires (S**55**). Also, the RNC increments the BCN counter value to reflect buffering of the data of the new packet. After each reset of the inter-packet arrival timer Timer$_{int}$, the RNC checks the amount of the buffered data (S**56**) and if the BCN counter does not exceed the threshold BCNX, the RNC processing loops back to step S**53**.

[0076] In this first illustrated example (first part of **FIG. 8**), the RNC **11** receives only the four packets, and at some point after receipt of the fourth packet, the maximum packet accumulation timer Timer$_{acc}$ runs out. When Timer$_{acc}$ expires, the process flow branches at step S**53** to the state switch decision in step S**57** (**FIG. 5**). In the example (**FIG. 8**), the RNC **11** causes the base station BS **11** to send all accumulated packets in its buffer to the recipient MS$_n$ via FACH. Hence, in line (b) of **FIG. 8**, the BS begins sending the four packets sequentially, starting substantially at the time when Timer$_{acc}$ expired.

[0077] The RNC will use the Cell-DCH state only when the BCN counter value exceeds BCNX and when it has received packets and the MS$_n$ is still in the Cell-DCH state. In this case, assuming the MS$_n$ was in the Cell-FACH state, the first four pulses received by the RNC (**FIG. 8**, first part line (a) and of line (b)), will be sent by FACH (S**60**), and there is no need for a PHY RECONFIG message. As a result, the base station sends the four accumulated packets in a group and the mobile station **15** receives the packets as a FACH communication.

[0078] In the next example shown in **FIG. 8**, the RNC subsequently receives a series of ten packets intended for the mobile station (MS) **15**, with somewhat random spacing therebetween (next ten packets on line (a)). In this example, the size of the buffered packet data reaches the switch threshold, BCNX, after receipt of the sixth packet but before the maximum packet accumulation timer Timer$_{acc}$ runs out. Hence, the process flow in **FIG. 5** reaches the state switch decision S**57** from the BCN counter value threshold decision S**56**. In response, the RNC **11** causes the base station BS **11** to send a Physical Channel Reconfiguration Message (S**58**) to the MS$_n$ **15** and then send all accumulated packets in its buffer to the recipient MS$_n$ via DSCH (S**59**), at this point the latest six buffered packets, as shown in line (c) of **FIG. 8**. Stated another way, because the buffered data exceeds the threshold before any timer expires, and the previous state was for Cell-FACH transmission, the RNC decides to switch to DSCH to provide a 'Cell-DCH' communication.

[0079] In this embodiment, the RNC **11** also implements an inactivity timer Timer$_{inact}$. If further packets are received before Timer$_{inact}$ expires, the new packets are transmitted while still in the Cell-DCH transmission. In continuing with this second example, after the first six packets in the buffer are transmitted, the inactivity timer Timer$_{inact}$ does not expire before more packets destined for this mobile station **15** arrive. Thus, the RNC will transmit the remaining four packets while in the Cell-DCH state.

[0080] A decision is made in Step S**61** (in **FIG. 5**), and the RNC **11** instructs the base station (BS) to transmit a Physical Channel Reconfiguration message (step S**62**) to the mobile station (MS), as shown by the subsequent shaded pulse in **FIG. 8**, line (c). Receipt of the Reconfiguration message causes the intended mobile station (MS) to release the DSCH and switch back to Cell FACH state.

[0081] In the third illustrated example in **FIG. 8**, the RNC receives five packets for the mobile station. In this case, the timer Timer$_{int}$ expires first. Since MS$_n$ is still in the Cell-FACH state, the RNC **11** does not send a Physical Channel Reconfiguration message. Essentially, in such a case, the RNC **11** transmits the currently buffered packets via FACH while MS **15** is in the Cell-FACH state. The remaining twelve packets in **FIG. 8** are transmitted using the Cell-DCH state since the BCN counter value reaches BCNX before any other timer expires.

[0082] **FIGS. 6 and 7** show alternate embodiments of somewhat more detailed process flows, for the transmission timing and state decision processing by the RNC **11**. The Radio Network Controller (RNC) **11** waits to receive a packet for a mobile station (MS) from a core network. While waiting for the first packet, the RNC sets its maximum packet accumulation timer, Timer$_{acc}$, to a predetermined time and its buffer content number, BCN counter value, to zero. The value of T$_{acc}$ is preferably less than the time that causes the communication or application to time-out (e.g. TCP/IP time-out).

[0083] Upon receiving a packet, the RNC **11** loads the packet into its buffer and updates the BCN counter value accordingly.

[0084] In the embodiment of **FIG. 6**, for example, the RNC next compares the updated BCN counter value with a predetermined BCNX value, the buffer size threshold for switching to Cell-DCH state. If the BCN counter value is less than BCNX, the RNC will wait for reception of a next packet destined for the same recipient MS, until either the timer Timer$_{int}$ or the timer Timer$_{acc}$ expires. If the RNC receives a next packet for the recipient MS before either timer expires, upon receiving the next packet, it again keeps this next packet in the buffer, along with any previously accumulated ones. At this time, the RNC again resets the timer Timer$_{int}$, updates the value of the BCN counter for the size of the data stored in the buffer and compares the BCN counter value with BCNX.

[0085] In the embodiment of **FIG. 6**, the RNC repeats this process until any one of three conditions is met: (1) No further packet for the same recipient MS arrives before Timer$_{int}$ expires; (2) Timer$_{acc}$ expires; or (3) BCN counter value is greater than BCNX. When any one of these events occurs, the RNC resets the value of Timer$_{acc}$.

[0086] If the buffer size value kept in the BCN counter exceeds BCNX, the Cell-DCH switch criteria is triggered, therefore the RNC will send out a Physical Channel Reconfiguration message (if necessary) to instruct the recipient MS to switch to Cell-DCH. The RNC next schedules the BS to send all accumulated packets in its buffer to the recipient MS via DCH or DSCH (Cell-DCH). In the embodiment of **FIG. 6**, when the packets are transmitted, the RNC checks to see if any further new packet has been received. If so, the RNC returns and schedules transmission of the additional packet(s) via the existing Cell-DCH state. This transmission loop repeats unless or until there is no further new packet to send for the time specified by the inactivity timer Timer$_{inact}$, at which point a new decision is made as to the state change and processing returns to expectation of a packet and waiting to receive a new first packet.

[0087] In the embodiment of **FIG. 6**, if the Cell-DCH switch criteria has not been triggered, the RNC will schedule the BS to send all accumulated packet(s) in its buffer to the recipient MS via FACH (Cell-FACH). Upon scheduling the delivery of any packets in the buffer from the BS to the MS, the RNC resets its BCN counter value to zero. However, if the current cell state is Cell-DCH transmission, the processing enters the loop for checking for a new packet and if found scheduling the BS to send all accumulated packets in its buffer to the recipient MS via DCH or DSCH (Cell-DCH).

[0088] As noted, the initial steps in the embodiment of **FIG. 7** are similar to those in **FIG. 6**. Upon receiving a packet, the RNC loads the packet in its buffer and updates the BCN counter value. In the embodiment of **FIG. 7**, the RNC resets the arrival timer Timer$_{int}$. The RNC then checks to be sure that the accumulation timer Timer$_{acc}$ has not expired, and if not, the RNC compares the updated BCN counter value with the buffer size threshold BCNX for switching to Cell-DCH state. If the BCN counter value is less than BCNX, the RNC checks the arrival timer Timer$_{int}$ and whether or not it has received another packet. In this way, the RNC will wait for a next packet for the same recipient MS until Timer$_{int}$ expires.

[0089] If the RNC receives a next packet for the recipient MS before Timer$_{int}$ expires, upon receiving the next packet, it again stores this next packet, along with any previously accumulated ones, in its buffer, resets the Timer$_{int}$, updates the BCN counter value and checks the BCN counter value and the timer Timer$_{acc}$. Again, the RNC repeats this process until any one of three conditions is met: (1) No further packet for the same recipient MS arrives before Timer$_{int}$ expires; (2) Timer$_{acc}$ expires; or (3) BCN counter value is greater than BCNX.

[0090] It is contemplated that some implementations will use Timer$_{acc}$ as the criteria to switch to Cell-DCH transmission. In such an embodiment, if after buffering one or more packets, the accumulation timer Timer$_{acc}$ expires, the RNC will send out a Physical Channel Reconfiguration message (if necessary) to instruct the recipient MS to switch to Cell-DCH.

[0091] However, in the illustrated embodiment, the RNC checks the transmission state and the Timer$_{acc}$ state. If not already in the Cell-DCH state and the Timer$_{acc}$ has not expired, the RNC checks the BCN counter value. If that value exceeds the threshold BCNX, the RNC next schedules the BS to send all accumulated packets in its buffer to the recipient MS via DCH or DSCH (Cell-DCH). In the embodiment of **FIG. 7**, if the Cell-DCH switch criteria has not been triggered, the RNC will schedule the BS to send all accumulated packet(s) in its buffer to the recipient MS via FACH (Cell-FACH). Upon scheduling the delivery of any packets in the buffer from the BS to the MS, the RNC resets its BCN counter value to zero. However, when a new packet arrives, if the current cell state is Cell-DCH transmission, the processing jumps to the step for sending all packets in its buffer to the recipient MS via DCH or DSCH (Cell-DCH).

[0092] In either embodiment (**FIG. 6** or **FIG. 7**), in the Cell-DCH state, the RNC can detect if there is another packet arriving for recipient MS within T$_{inact}$ ms from the time the last packet was transmitted while in the Cell-DCH state. Timer$_{inact}$ is reset to T$_{inact}$ at the time the last packet was transmitted while in the Cell-DCH state. If there is not another packet for recipient MS within T$_{inact}$ ms, the RNC

will schedule a Physical Channel Reconfiguration message to instruct the recipient MS to release the DSCH and switch back to Cell-FACH state. Likewise, the buffer size also provides a way to measure congestion in the current channel. When the packet arrival rate exceeds the rate at which the RNC can send out packets, packet accumulation will result in a large buffer. The RNC monitors the buffer content/size and when the buffer size exceeds a pre-determined threshold, the RNC will configure the BS to send the accumulated and scheduled packets via DCH.

[0093] In the embodiments, the state control processing was implemented in the radio network controller (RNC) **11**. The RNC **11** may be implemented as a separate packet switching node in the network, which has sufficient processing capability that is programmed to detect conditions and provide instructions to the base stations, in the manner outlined above. Such an RNC node can be implemented with a general purpose programmable device having the appropriate packet interfaces for the necessary communications and sufficient processing and memory capacity necessary to perform the necessary routing and control functions. Such a device is then programmed with the executable code to implement the desired one of the processing embodiments, as part of its programming to implement its other channel allocation and routing functions in the context of the CDMA network.

[0094] The term radio network controller or RNC as used herein refers to a control functionality or application, for monitoring packet traffic and assigning radio-link resources through control of the base stations. As shown in the drawings and described above, the exemplary RNC **11** may take the form of a physically separate node between the core network and a number of base stations within one radio network system. Those skilled in the art will recognize, however, that the control functionality of the RNC may actually reside at any convenient network location or locations. For example, the RNC functionality may be combined with that of one or a distributed number of the base stations. Alternatively, the RNC functionality may be implemented in a higher-level network node, for example within another layer of controller.

[0095] While the foregoing has described what are considered to be the best mode and/or other preferred embodiments, it is understood that various modifications may be made therein and that the invention or inventions disclosed herein may be implemented in various forms and embodiments, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the inventive concepts.

1. In a wireless packet communication network comprising a plurality of base stations for serving a wireless remote station, a method of packet transmission to the wireless remote station, comprising the steps of:

(a) upon receiving a first packet intended for the wireless remote station, placing the packet in a buffer and starting an accumulation timer;

(b) starting an inter-packet arrival timer;

(c) if an amount of data stored in the buffer exceeds a threshold value, sending a message to the wireless remote station to enter a cell-state for dedicated channel communications, and causing a base station to transmit all data from the buffer to the wireless remote station over an assigned down-link channel of the wireless packet communication network in the dedicated channel cell-state;

(d) if the amount of data stored in the buffer does not exceed the threshold value, waiting for arrival of a further packet intended for the wireless remote station;

(e) if a further packet intended for the wireless remote station arrives before expiration of the inter-packet arrival timer, placing the further packet in the buffer, re-starting the inter-packet arrival timer and returning to step (c) to continue further performance of steps of the method; and

(f) if the accumulation timer expires while there is data in the buffer, or if no further packet intended for the wireless remote station arrives before expiration of the inter-packet arrival timer, causing the base station to transmit data from the buffer to the wireless remote station over a channel for forward access communications.

2-24. (canceled)

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