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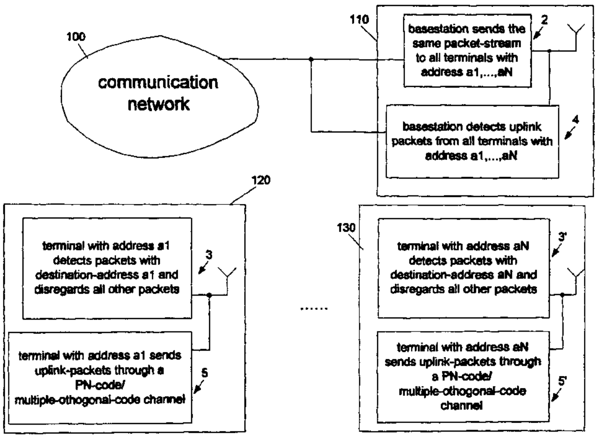
(54) Title: WIRELESS COMMUNICATION SYSTEMS AND METHODS USING PACKET DIVISION MULTIPLE ACCESS



(57) Abstract: A wireless multi-user communication system using packet division multiple access (PDMA). In the downlink direction from a base-station (110) to terminals (120 to 130), each downlink data packet from a communication network (100) has a destination address. The base transmitter (2) sends the downlink packets to all the terminals (120 to 130). Each terminal (120 to 130) receives the downlink packets, detects packets with the destination address the same as the terminal address, and disregards all other packets whose destination addresses are different than the terminal address. In the uplink direction from a terminal (120 to 130) to the base-station (110), each terminal (120 to 130) sends uplink packets together with the terminal's source address to the base-station (110) through a PN-code/multiple-orthogonal-code channel and changes its uplink data rate by changing its number of orthogonal-code frames. A novel method of using truncated long-period PN-code for spreading is used to avoid using complicated timing circuits.

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Wireless Communication Systems and Methods Using Packet Division Multiple Access

BACKGROUND OF THE INVENTION

This invention relates to multi-user wireless communication systems and methods using a novel method of packet division multiple access (PDMA), and accordingly to the manner of operation of communication systems with the invented system built in.

In existing multi-user wireless communication systems, the multiple access methods used are either frequency-division multiple access (FDMA), time-division multiple access (TDMA) or code-division multiple access (CDMA).

The FDMA and TDMA methods have advantages of low implementation-complexity and fast time-to-market, but their bandwidth efficiency is very low, particular for data communications such as the internet access. The low-bandwidth-efficiency of the FDMA and TDMA methods is due to the fact that the current FDMA/TDMA wireless communication systems assign one channel to one user, even though the user is receiving/transmitting a small amount of data at a low data rate and requires a very small amount of bandwidth.

The frequency division multiple access (FDMA) method is described in *Digital Communications* (third Ed., published by McGraw Hill in 1995) by J. G. Proakis, page 841-843 The FDMA method divides the available frequency band into a number of sub-bands. Each sub-band is referred to as a frequency channel and is assigned to one user. The frequency channel is always occupied by the user once it is assigned to the user, even if the user is not receiving any data during some long periods. For example, in the internet access a user downloads a lot of data during some periods, but in other long periods the user does not download any data and still occupies the frequency channel which cannot be accessed by other users. In order to make the frequency channel available for other users when this user is not downloading any data, the current FDMA method needs to disconnect the user from the channel. Disconnecting the internet user from the channel when the user is not downloading the data is not user-friendly and makes the quality-of-service very poor.

The time division multiple access (TDMA) method is described in *Digital Communications* (third Ed., published by McGraw Hill in 1995) by J. G. Proakis, page 841-843. The TDMA method divides each time frame into a number of smaller time-slots. Each time-slot is assigned to one user and is always occupied by the user once it is assigned to the user, even if the user is not receiving any data during some long periods. For example, in the internet access a user downloads a lot of data during some periods, but in other long periods the user does not download any data and still occupies the time-slot which cannot be accessed by other users. In order to make the time-slot available for other users when this user is not downloading any data, the current TDMA method needs to disconnect the user from the time-slot. Disconnecting the internet user when the user is not downloading the data is not user-friendly and makes the quality-of-service very poor.

The CDMA method has higher bandwidth-efficiency than the FDMA and TDMA methods since it allows multiple users to share the same frequency band such that one user can receive/transmit more data at a higher-speed data rate and utilize more bandwidth than the other users sharing the same frequency band if the other users are not receiving/transmitting a large amount of data at the same time. However, the existing CDMA method has a number of limitations including requiring a large bandwidth, consuming a lot of power for high data-rate transmission, and excessive circuit complexity for variable data-rate transmission.

The code division multiple access (CDMA) method is described in *Digital Communications* (third Ed., published by McGraw Hill in 1995) by J. G. Proakis, page 843. The problem of the CDMA is illustrated in the following example. Assuming that the highest raw data rate is 2 Mbps, the QPSK (quadratic phase-shift keying) modulation is used and the processing gain is 16. Then the bandwidth needed is $16*2/2\approx16$MHz, which is too large in many situations (for example, some commercial spectrum was auctioned by FCC in blocks of 10MHz each). One approach to overcoming the large bandwidth problem is to use a smaller processing gain, for example, 8 for the highest data rate 2Mbps. However, a smaller processing gain reduces the receiver sensitivity significantly (in this example by 3dB, a large number in radio frequency communications), and requires much more transmitting power, and therefore results in a much shorter battery life, shorter communication range and larger interference to other channels. A commonly used approach to reducing the power consumption and interference in CDMA is to use a larger processing gain (more chips per information bit) if the data rate is reduced, as is implemented in speech communications using CDMA since a person in a speech communication spends more than 50% of time listening rather than talking. This variable processing-gain method (variable number of chips per information bit) requires a complex and less reliable circuitry in the receiver since each different processing gain needs a different receiving circuitry and a rate-detection circuit is not always reliable.

Scalability of the existing CDMA, TDMA and FDMA is also limited. For example, if the processing gain in a CDMA system is 16, then there exist only 16 distinctive orthogonal codes to distinguish different users and therefore the number of users supported by the system is limited to 16 unless non-orthogonal codes are used which results in much lower-quality performance. TDMA and FDMA are circuit-switched access methods and are limited by the number of time-slots or sub-frequency bands.

An object of this invention is to use a novel method of packet division multiple access for a multi-user wireless communication system to increase the bandwidth efficiency, and maintain a low-implementation complexity.

Another object of this invention is to transmit/receive the downlink data for all users through one baseband/RF circuit which does not need a complicated variable-processing-gain approach (variable number of chips per information bit) used in the existing CDMA wireless systems.

Another object of this invention is to let all users' downlink data share the same frequency-band/hardware and enable a bursty high-data-rate user, such as an internet user downloading a picture, to secure a very-high-data rate when needed and release the bandwidth to other needed users once his downloading is completed.

Another object of this invention is to transmit/receive the uplink data for each user through a baseband/RF circuit which does not need a complicated variable-processing-gain approach used in the existing CDMA wireless systems.

Another object of this invention is to use a method of changing the number of orthogonal-code frames to change the data-rate and enable a bursty high-data-rate user, such as an internet user sending a large email file, to secure a high-data rate when needed and release the bandwidth to other needed users once his email-sending is completed.

Another object of this invention is to use different truncations of a long-period PN-code to distinguish different base-stations and terminals to avoid using complicated timing circuits needed in existing CDMA systems.

Another object of this invention is to use packets with different destination addresses to distinguish different terminals to accommodate a much larger number of users than the existing CDMA systems.

SUMMARY OF THE INVENTION

The goal of this invention is to use a novel method of packet division multiple access for a wireless communication system to increase the bandwidth efficiency, and maintain a low-implementation complexity.

The invented multi-user wireless communication system comprises at least one base-station communicating with *N* wireless terminals. Each base-station is connected to a communication network and comprises a base-transmitter and a base-receiver. Each wireless terminal comprises a terminal-transmitter and a terminal-receiver.

The data from the communication network may be a data stream or a plurality of packets with each packet having a source address and a destination address. The base-transmitter comprises a base-transmit-processing unit with a software function to implement a number of functions. First the data stream is packed into data-packets, or the packets from the communication network may be fragmented into smaller data-packets (optional). The downlink data-packets and downlink control-packets from a control-packet generator are reordered into a single downlink packet-stream. The downlink packet-stream is passed through a channel encoding software function.

One embodiment of the base-transmitter uses a spread-spectrum method to transmit the packets. The encoded downlink packet-stream is de-multiplexed into a stream of *M* frames with each frame having *m* bits. It is noted that pilot bits, such as a series of all *0*, which are known to both the terminals and the base-station, may be inserted into a frame, such as frame #1, for the purposes of identifying the channel, timing, frequency-offset and for other receiving purposes. Each frame is passed through an orthogonal/pseudo-noise-code (PN-code) spreading processing unit which generates a spread frame. The orthogonal-code may be, for example, a Walsh code which is unique for each frame inside a base-station. Each orthogonal-code is used to spread one downlink frame. Only one PN-code is used for each base-station and is different than the PN-codes used by other base-stations. The different PN-codes may be different truncations of a long-period PN-code or different time-shifted copies of the same PN-code. Then the spread frames are passed through a baseband/RF transmit processing unit and is transmitted to the air through an antenna.

Another embodiment of the base-transmitter uses a direct baseband modulation method, such as phase-shift-keying (PSK), quadrature amplitude modulation (QAM) or multi-carrier modulation without spread spectrum, to transmit the packets. The encoded downlink packet stream is passed through a baseband modulation unit which generates a modulated downlink signal. Then the modulated downlink signal is passed through an RF transmit processing unit and is transmitted to the air through an antenna.

The terminal-receiver receives the RF-processed spread frames or modulated downlink signal.

In one embodiment of the terminal-receiver, the received RF-processed spread frames are passed through an RF/baseband receive processing unit which generates a composite signal of M received spread frames. The received composite signal is passed through an orthogonal/PN-code despreading unit by using the orthogonal/PN-codes which are the same as the orthogonal/PN-codes used in the base-transmitter. The orthogonal/PN-code despreading unit then generates received frames which are de-multiplexed and channel-decoded into a received downlink packet stream. The received downlink packet stream would be identical to the transmitted downlink packet stream in the base-transmitter if the receiving error rate is zero. The received downlink packet stream is passed through a terminal-receiving processing unit which detects downlink control packets and downlink data packets with a destination address identical to the address assigned to the terminal, and disregards all other packets with addresses different than the terminal's address. The detected downlink control packets are sent to a control-data processing unit and the detected downlink data packets are sent to an internet browser/audio/video terminal.

In another embodiment of the terminal-receiver, the received RF-processed modulated downlink signal is passed through an RF-receive processing unit which generates a received modulated downlink signal. The received modulated downlink signal is passed through a baseband demodulation unit and channel-encoding unit which generates a received packet stream. The received packet stream would be identical to the transmitted packet-stream in the base-transmitter if the receiving error rate is zero. The received packet-stream is passed through a terminal-receiving processing unit which detects control-packets and data-packets with a destination address identical to the address assigned to the terminal, and disregards all other packets with addresses different than the terminal's address. The detected control-packets are sent to a control-data processing unit and the detected data-packets are sent to an internet browser/audio/video terminal.

In the direction of uplink (from the terminals to the base-station), the terminal-transmitter of each terminal packs data from the browser/audio/video terminal into an uplink packet stream. The uplink packet stream is channel-encoded. The encoded uplink packet stream is sent to the base-station through channels.

In one embodiment of the terminal-transmitter, the uplink-data packets are passed through an orthogonal/PN-code spreading unit which generates uplink spread frames. Each unique PN-code with a plurality of orthogonal codes represents an uplink channel. The orthogonal-code may be, for example, a Walsh code. Each PN-code is unique for each terminal and may be a truncation of a long-period PN-code different than other terminals' truncations or a time-shifted copy of the same PN-code different than other terminals' time-shift. Each uplink channel may be multiplexed with pilot symbols which are known to both the terminals and the base-station and are used for channel estimation, frequency estimation and other receiving processing. Finally the uplink spread frames are passed through a baseband/RF transmit processing unit and sent to the air through the antenna.

In another embodiment of the terminal-transmitter, the uplink packet stream is passed through a baseband modulation unit which generates a modulated uplink signal without spread spectrum. The modulated uplink signal is passed through an RF transmit processing unit and sent to the air through the antenna.

The RF-processed signals from all the terminal-transmitters are received by the base-station receiver. In one embodiment of the base-station receiver, the RF-processed signals are passed through an RF/base-band-receive processing unit which generates received spread frames. The received spread frames are composite signals of uplink spread framess from all terminals, which are sent to an orthogonal/PN-code despreading unit. The orthogonal/PN-codes are the same as the codes used in the terminal-transmitters. The orthogonal/PN-code despreading unit generates received uplink-packets for each terminal. The received packets are passed through a channel-decoder. Then uplink-requests are detected from the received packets and are sent to the control-packet generator. The uplink data-packets are also detected from the received packets and are reordered/multiplexed into a packet stream and sent to the communication network.

In another embodiment of the base-station receiver, the RF-processed signals are passed through an RF-receive processing unit which generates received modulated uplink signal. The received modulated uplink signal is composite signals of modulated uplink signals from all terminals. The received modulated uplink signal is sent to a baseband demodulation unit, which generates received uplink-packets for all terminals. The received uplink packets are passed through a channel-decoder. Then the uplink packets are reordered/multiplexed and sent to the network.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram illustrating one embodiment of the multi-user wireless communication system using PDMA in this invention.

Figure 2a is a schematic diagram illustrating one embodiment of the base transmitter of the multi-user wireless communication system in this invention.

Figure 2b is a schematic diagram illustrating another embodiment of the base transmitter of the multi-user wireless communication system in this invention.

Figure 3a is a schematic diagram illustrating one embodiment of the terminal receiver of the multi-user wireless communication system in this invention.

Figure 3b is a schematic diagram illustrating another embodiment of the terminal receiver of the multi-user wireless communication system in this invention.

Figure 4a is a schematic diagram illustrating one embodiment of the base receiver of the multi-user wireless communication system in this invention.

Figure 4b is a schematic diagram illustrating another embodiment of the base receiver of the multi-user wireless communication system in this invention.

Figure 5a is a schematic diagram illustrating one embodiment of the terminal transmitter of the multi-user wireless communication system in this invention.

Figure 5b is a schematic diagram illustrating another embodiment of the terminal transmitter of the multi-user wireless communication system in this invention.

Figure 6 is a schematic diagram illustrating one example of the downlink packet stream in this invention.

Figure 7 is a schematic diagram illustrating one example of the uplink packet stream in this invention.

Figure 8 is a schematic diagram illustrating an embodiment of the base orthognal/PN-code despreading processing for each terminal.

DETAILED DESCRIPTION

Referring to Figure 1, the invented multi-user wireless communication system comprises at least one base-station 110 connected to a communication network 100 and communicating with N wireless terminals 120, 130 etc. with addresses $a1$, $a2$, ..., aN. Each base-station 110 comprises a base transmitter 2 and a base receiver 4. Each wireless terminal 120 or 130 etc. comprises a terminal transmitter and a terminal receiver.

In the downlink direction from the base-station 110 to the terminals 120, 130 etc., the data from the communication network 100 may be a data stream or a plurality of packets with each packet having a source address and a destination address. The base transmitter 2 packs the data from the network 100 into a downlink packet stream consisting of all the packets with the destination addresses *a1, a2, ..., aN*, and sends the downlink packet stream to all the *N* terminals. Each terminal receives the downlink packet stream and detects packets with the destination address the same as the terminal address, and disregards all other packets in the downlink packet stream. For example, the terminal 120 with the address *a1* receives the packet stream and detects packets with the destination address *a1*, and disregards all other packets in the downlink packet stream with destination addresses *a2, a3, ..., aN.*

In the uplink direction from a terminal to the base-station 110, each terminal 120 or 130 etc. sends uplink packets together with the terminal's source address to the base-station 110 through a PN-code/multiple-orthogonal-code channel.

Referring to Figure 2a and Figure 2b, the base transmitter 2 comprises a base-transmit-processing unit 201 or 211 with a software function to implement a number of functions. First the data stream from the communication network 100 is packed into downlink data-packets or fragmented into smaller downlink data-packets. A control-packet generator 202 generates downlink control-packets containing control information such as the amount of uplink bandwidth available to a particular terminal. The downlink data-packets and the downlink control packets are reordered into a single downlink packet stream. The downlink packet stream is passed through a channel encoding software function. Each downlink control packet or the downlink data packet comprises a destination address which is identical to the address of one of the terminals. The destination address of a downlink control packet may be set to a unique number which can be accepted by all terminals to transmit common control messages. The downlink packet stream contains all packets destined to all terminals *a1, a2, ..., aN.*

In one embodiment of the base-transmitter shown in Figure 2a, a spread-spectrum method is used to transmit the downlink packets. The encoded downlink packet stream is de-multiplexed into a stream of *M* downlink frames with each downlink frame having *m* bits. It is noted that pilot bits, such as a series of all *0*, which are known to both the terminals and the base-station, may be inserted into a downlink frame, such as frame #1, for the purposes of identifying the channel, timing, frequency-offset and other receiving purposes. Each frame is passed through an orthogonal/pseudo-noise-code (PN-code) spreading unit 204, which generates a downlink spread frame. The orthogonal-code may be, for example, a Walsh code which is unique for each downlink frame inside a base-station. Each orthogonal-code is used to spread one downlink frame. Only one PN-code is used for each base-station and is different than the PN-codes used by other base-stations. The one PN-code is used to spread all downlink frames in the base-station. The different PN-codes may be different truncations of a long-period PN-code, which have a small cross-correlation independent of the relative timing of the PN-codes. The different PN-codes may be also different time-shifted copies of the same PN-code, as is implemented in the existing CDMA systems. Each chip of the long-period PN-code may be a binary number (either 0,1 pair or 1,-1 pair) or a complex number with its real and imaginary components to be binary chips of binary long-period PN-codes. Then the downlink spread frames are passed through a baseband/RF transmit processing unit 205 and are transmitted to the air through an antenna 206.

For example, suppose a 64-chip Walsh code is used as the orthogonal code with 64 code word *w0, w1, ..., w63*. Each of the code words *w0, w1, ..., w63* has 64 chips such that it takes the form of *wi(0), wi(1), ..., wi(63)* for *i=0,1,...,63*. The cross-correlation of the orthogonal codes *wi* is zero if the timing is syncronized. The PN-code *p* used for the base transmitter is a 256-chip truncation of a long-period PN code with a period of 2^{64} such that the PN-code *p* takes the form of *p(0), p(1), ..., p(255)* with a period of 256. The PN code *p* may be a stream of complex numbers with its real and imaginary parts to be different truncations of the long-period PN code. Each orthogonal code *wi* is used to spread one downlink frame and therefore there are *M=64* downlink frames. Assume a downlink packet stream shown in Figure 6 is represented by symbol *s(0), s(1), ...* which contain downlink packets with destination addresses *a1,a2,... aN* for all terminals. The symbols *s(0),s(1),...* may be real numbers or complex numbers. Assume the downlink packet stream *s(0), s(1), ...* is demultiplexed into *64* frames with a frame-length of 32 symbols. That is, the first *64*32* symbols are demultiplexed into

frame *#0 s(0), s(1),...,s(31),*

frame *#1 s(32), s(33), ..., s(32+31),*

...,

frame *#63 s(32*63), s(32*63+1), ..., s(32*63+31).*

And the next *64*32* symbols are demultiplexed into *64* frames using the same process. The symbols of each downlink frame stream is then represented by

f0(0), f0(1), ... ,f0(31), f0(32), ... for frame *#0*,

f1(0), f1(1), ... ,f1(31), f1(32), ... for frame *#1*,

...,

f63(0), f63(1), ... ,f63(31), f63(32), ... for frame *#63*.

Some of the frames, such as frame #0, may be a pilot frame with all symbols to be zero which are known to both the terminals and the base-station and are used to aid the receiving processing, such as channel estimation, timing, frequency offset estimation etc. The spreading operation is to convert each symbol *fi(j)* (frame-number *i=0, ... 63*, symbol-number *j=0, ... 31,32, ...*) into *64* chips in the following fashion:

*f0(0)*w0(0)*p(0), ... , f0(0)*w0(63)*p(63),*

*f0(1) *w0(0)*p(64), ... , f0(1) *w0(63)*p(64+63),*

... for frame *#0*,

*f1(0)*w1(0)*p(0), ... , f1(0)*w1(63)*p(63),*

*f1(1) *w1(0)*p(64), ... , f1(1) *w1(63)*p(64+63),*

... for frame *#1*,

......,

*f63(0)*w63(0)*p(0), ... , f63(0)*w63(63)*p(63),*

*f63(1) *w63(0)*p(64), ... , f63(1) *w63(63)*p(64+63),*

... for frame *#63*.

It is seen from the above example that each frame has a unique orthogonal code *wi* and each base transmitter has a unique PN code *p*.

The downlink spread frames in chips are passed through a baseband/RF transmit processing unit 205 and are transmitted to the air through an antenna 206.

Another embodiment of the base-transmitter shown in Figure 2b uses a direct baseband modulation method, such as phase-shift-keying (PSK), quadrature amplitude modulation (QAM) or multi-carrier modulation without spread spectrum, to transmit the packets. The encoded downlink packet stream from 211 is passed through a baseband modulation unit 213 which generates a modulated downlink signal. Then the modulated downlink signal is passed through an RF transmit processing unit 214 and is transmitted to the air through an antenna 215.

The terminal-receiver 3 receives the RF-processed spread frames or modulated downlink signal.

Referring to Figure 3a, in one embodiment of the terminal-receiver 3, the received RF-processed spread frames are passed through an RF/baseband receive processing unit 302 which generates a composite signal of M received spread frames. The received composite signal is passed through an orthogonal/PN-code despreading unit 304 by using the orthogonal/PN-codes identical to the orthogonal/PN-codes used in the base-transmitter 2. The orthogonal/PN-code despreading unit 304 then generate received downlink frames which are de-multiplexed and channel-decoded at 305 into a received downlink packet stream. The received downlink packet stream would be identical to the transmitted downlink packet stream in the base-transmitter 2 if the receiving error rate is zero. The received downlink packet stream is passed through a terminal-receiving processing unit 306 which detects downlink control-packets and downlink data-packets with a destination address identical to the address assigned to the terminal, and disregards all other packets with addresses different than the terminal's address. The detected downlink control-packets are sent to a control-data processing unit 307 and the detected downlink data-packets are sent to an internet browser/audio/video terminal 308.

For example, the composite signal of M received spread frames can be expressed as

$$r(0)=[f0(0)*w0(0)+f1(0)*w1(0)+\ldots+f63(0)*w63(0)]*p(0),$$

$$\ldots,$$

$$r(63)=[f0(0)*w0(63)+f1(0)*w1(63)+\ldots+f63(0)*w63(63)]*p(63),$$

$$r(64)=[f0(1)*w0(0)+f1(1)*w1(0)+\ldots+f63(1)*w63(0)]*p(64),$$

$$\ldots,$$

$$r(64+63)=[f0(1)*w0(63)+f1(1)*w1(63)+\ldots+f63(1)*w63(63)]*p(64+63),$$

$$\ldots\ldots$$

where it is assumed that the exact samping-timing is acquired, the channel-distortion has been compensated and the noise-term is ignored.

Then the orthogonal/PN-code despreading unit 304 performs the operation of

$d0(0)=r(0)*w0(0)*p(0)+\ldots+r(63)*w0(63)*p(63),$

$d0(1)=r(64)*w0(0)*p(64)+\ldots+r(64+63)*w0(63)*p(64+63),$

…… for frame #0,

$d1(0)=r(0)*w1(0)*p(0)+\ldots+r(63)*w1(63)*p(63),$

$d1(1)=r(64)*w1(0)*p(64)+\ldots+r(64+63)*w1(63)*p(64+63),$

…… for frame #1,

……

$d63(0)=r(0)*w63(0)*p(0)+\ldots+r(63)*w63(63)*p(63),$

$d63(1)=r(64)*w63(0)*p(64)+\ldots+r(64+63)*w63(63)*p(64+63),$

…… for frame #63

The received downlink frames are then

$d0(0), d0(1), \ldots, d0(31), \ldots$ for frame #0,

$d1(0), d1(1), \ldots, d1(31), \ldots$ for frame #1,

……

$d63(0), d63(1), \ldots, d63(31), \ldots$ for frame #63.

It is noted that if the PN-code chips $p(j)$ are complex numbers, then the conjugate numbers of $p(j)$ should be used to replace $p(j)$ in the above equations for $di(j)$.

The multiplexing operation of 305 is to restore the received downlink packet stream from the received downlink frames as

$d0(0), d0(1), \ldots, d0(31), d1(0), d1(1), \ldots, d1(31), \ldots\ldots, d63(0), d63(1), \ldots, d63(31), d0(32), d0(32+1), \ldots, d0(32+31), d1(32), d1(32+1), \ldots, d1(32+31), \ldots\ldots, d63(32), d63(32+1), \ldots, d63(32+31), \ldots\ldots$

The above received downlink packet stream should be identical to the transmitted downlink packet stream shown in Figure 6 if the receiving error-rate is zero. After channel decoding at 305 and ignoring the pilot packets, the above received downlink packet stream can be represented as

Pack(1,a1), pack(2,aN), pack(3,a2), Pack(4,a1), pack(5,a1), pack(6,a2), ...

where *a1,aN,a2 etc.* are the destination addresses of the received packets and the numbers *1,2,3,etc.* represent the receiving time sequence of the packets. The terminal-receiving processing unit 306 then detects the downlink control-packets and downlink data-packets with a destination address identical to the address assigned to the terminal, and disregards all other packets with addresses different than the terminal's address. That is, if the terminal's address is *a1*, then it detects received packets *pack(1,a1), pack(4,a1), pack(5,a1),etc.* with the destination address *a1*, and disregards all other packets *pack(2,aN), pack(3,a2), pack(6,a2),etc.* whose destination addresses are not *a1*. The detected downlink control-packets are sent to a control-data processing unit 307 and the detected downlink data-packets are sent to an internet browser/audio/video terminal 308.

Referring to Figure 3b, in another embodiment of the terminal-receiver 3, the received RF-processed modulated downlink signal is passed through an RF-receive processing unit 312 which generates a received modulated downlink signal. The received modulated downlink signal is passed through a baseband demodulation unit 313 which generates a received encoded downlink packet stream. After channel decoding at 314, a received downlink packet stream is generated which, if the receiving error rate is zero, would be identical to the transmitted downlink packet stream at the base-transmitter 2. The received downlink packet-stream is passed through a terminal-receiving processing unit 306 which detects control-packets and data-packets with a destination address identical to the address assigned to the terminal, and disregards all other packets with addresses different than the terminal's address. The detected control-packets are sent to a control-data processing unit 307 and the detected data-packets are sent to an internet browser/audio/video terminal 316.

Referring to Figure 5a and 5b, in the direction of up-link (from one of the terminals to the base-station), the terminal-transmitter 5 of each terminal packs data from the browser/audio/video terminal 501 into an uplink packet stream which is channel-encoded at 502. The downlink control messages sent by the base transmitter 2 to the terminal are received and processed at 307 which controls the bandwidth (data rate) available to this terminal's uplink. The downlink control messages are used at 503 to check the bandwidth (data rate) available to the terminal.

Referring to Figure 5a, in one embodiment of the terminal-transmitter 5, the uplink uses a spread spectrum approach. The uplink-data packets are passed through a data-rate-control and demultiplex unit 504 which generates M_k $(k=1,\ldots N)$ uplink frames. The uplink frames are passed through an orthogonal/PN-code spreading unit 505 which generates uplink spread frames. Each unique PN-code with a plurality of M_k $(k=1,...N)$ orthogonal codes represents an uplink channel which is used by terminal. The orthogonal-code may be, for example, a Walsh code. Each PN-code is unique for each terminal and may be a truncation of a long-period PN-code different than other terminals' truncations or a time-shifted copy of the same PN-code different than other terminals' time-shift. Each chip of the long-period PN-code may be a binary number (either 0,1 pair or 1,-1 pair) or a complex number with its real and imaginary components to be binary chips of binary long-period PN-codes. The uplink data rate is controlled by 503 and 504. The available bandwidth (data rate) for this terminal is checked at 503 and the uplink data rate is changed accordingly by changing the number (M_k, $k=1,...N$) of orthogonal-code frames used. It is noted that one of the uplink data frames may be multiplexed with pilot symbols which are known to both the terminals and the base-station and are used for channel estimation, frequency estimation and other receiving processing. Finally the uplink spread frames are passed through a baseband/RF transmit processing unit 506 and sent to the air through the antenna 507.

The detailed design principle of the orthogonal/PN-code spreading unit 505 is identical to that of the base orthogonal/PN-code spreading unit 204 except that the number M_k $(k=1,...N)$ of orthogonal-code frames used in 505 is changing according to the uplink data rate. For example, suppose the orthogonal code is a 64-bit Walsh code. Then $M_k \leq 64$ $(k=1,...N)$. Suppose each orthogonal-code frame can carry 8kbps data rate, then the uplink data rate can be 8, 8*2, 8*3, ..., 8*64 kbps respectively by choosing M_k=1,2,3,...,64 $(k=1,...N)$ respectively. In addition, the PN-code used for the terminal is unique for the terminal and is different than other terminals' PN-code.

Referring to Figure 5b, in another embodiment of the terminal-transmitter 5, the uplink data rate is controlled by 503 and 504 changing the number of channels used for the terminal's uplink. The uplink packets are passed through a baseband modulation unit 515 which generates a modulated uplink signal without spread spectrum. The modulated uplink signal is passed through an RF transmit processing unit 516 and sent to the air through the antenna 507.

The RF-processed uplink signals from all the terminal-transmitters 5, 5' etc. are received by the base-station receiver 4.

Referring to Figure 4a, in one embodiment of the base-station receiver 4, the RF-processed uplink signals are passed through an RF/baseband-receive processing unit 402 which generates received uplink spread frames. The received uplink spread frames is a composite signal of uplink spread frames from all terminals. The received uplink spread frames are sent to an orthogonal/PN-code despreading unit 404. The orthogonal/PN-code despreading unit 404 has a plurality of despreading processing units 8, each of which performs despreading processing of the received uplink frames from one terminal. The used orthogonal-codes and the used PN-code are the same as the codes used in one of the terminal-transmitters. The orthogonal/PN-code despreading unit 404 generates received uplink-packets for all terminals 120, 130 etc. The received uplink packets are passed through a channel-decoder 406. Then the uplink packets are reordered/multiplexed and sent to the network 100.

The despreading processing unit 8, which detects the uplink frames for one of the terminals and is a part of the base orthogonal/PN-code despreading unit 404, is illustrated in Figure 8. The received RF-processed uplink spread frames are passed through an RF/baseband receive processing unit 402 which generates a composite signal of M_k $(k=1,...N)$ received uplink spread frames from one terminal plus interference signals from other terminals. The received composite signal is passed through the despreading processing unit 800 by using the orthogonal/PN-codes identical to the orthogonal/PN-codes used in one of the terminal-transmitters 5, 5' etc. The despreading processing unit 800 then generates received uplink frames which are de-multiplexed and channel-decoded into a received uplink packet stream. The received uplink packet stream would be identical to the transmitted uplink packet stream in the terminal-transmitter 5,5' etc. if the receiving error rate is zero.

The detailed design principle of the despreading processing unit 800 is identical to that of the terminal orthogonal/PN-code despreading unit 304 except that the number M_k $(k=1,...N)$ of the orthogonal-code (frames used in 800 is changing according to the uplink data rate. For example, suppose the orthogonal code is a 64-bit Walsh code. Then $M_k \leq 64$ $(k=1,...N)$. Suppose each orthogonal-code frame can carry 8kbps data rate, then the uplink data rate can be 8, 8*2, 8*3, ..., 8*64 kbps respectively by choosing M_k=1,2,3,...,64 $(k=1,...N)$ respectively. In addition, the PN-code used for each terminal is unique for the terminal and is different than other terminals' PN-codes.

Referring to Figure 4b, in another embodiment of the base-station receiver, the RF-processed signals are passed through an RF-receive processing unit 412 which generates received modulated uplink signal. The received modulated uplink signal is a composite signal of modulated uplink signals from all terminals. The received modulated uplink signal is sent to a baseband demodulation unit 413, which generates received uplink-packets for all terminals 120, 130 etc. The received uplink packets are passed through a channel-decoder 414. Then the uplink packets are reordered/multiplexed and sent to the network 100.

It should be noted that the method of using truncated long-period PN-codes to avoid using complicated timing circuits can be also applied to any other spread-spectrum communication systems. The truncated long-period PN-codes have a low cross-correlation since the cross-correlation among the truncated long-period PN-codes is close to the auto-correlation of the original long-period PN-code no matter what the relative timing is. Particularly when the truncation length is much larger than the correlation length, the cross-correlation among the truncated long-period PN-codes is almost equal to the auto-correlation of the original long-period PN-code no matter what the relative timing is.

Comparing to the existing wireless communication systems, the invented system has several advantages.

First, the invented system can utilize the downlink bandwidth most efficiently while maintaining a very low complexity. As is shown in Figures 2a and 3a, the downlink data for all users are transmitted/received through one baseband/RF circuit which does not need a complicated variable-processing-gain approach used in the existing CDMA wireless systems. The design of all users' data sharing the same frequency-band/hardware also enables a bursty high-data-rate user, such as an internet user downloading a picture, to secure a very-high-data rate when needed and release the bandwidth to other needed users once his downloading is completed.

Second, the invented system can utilize the uplink bandwidth most efficiently while maintaining a very low complexity. As is shown in Figures 4a and 5a, the uplink data for each user are transmitted/received through a baseband/RF circuit which does not need a complicated variable-processing-gain approach used in the existing CDMA wireless systems. The design of changing the number of orthogonal-code frames to change the data-rate also enables a bursty high-data-rate user, such as an internet user sending a large email file, to secure a high-data rate when needed and release the bandwidth to other needed users once his/her email-sending is completed.

Third, the invented CDMA wireless communication system does not need complicated timing circuits needed in existing CDMA systems. As is shown in Figures 2a, 3a, 4a and 5a, each base-station or terminal is distinguished from each other by using a unique truncation of a long-period PN-code. The truncated PN-codes guarantee that the cross-correlation between them is minimized independent of their timing. On the contrary, the existing CDMA systems require either global-positioning-system (GPS) circuits or complicated protocols to control the timing of different base-stations and terminals.

Forth, the number of users in the invented system is not limited by the number of available orthogonal codes and can accommodate much more users than the existing CDMA systems can.

While considerable emphasis has been herein on the preferred embodiment illustrated and described hereinabove, it will be appreciated that other embodiments of the invention can be made and that changes can be made in the preferred embodiment without departing from the principals of the present invention. Accordingly, it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the invention and not as a limitation.

What is claimed is:

1. A wireless communication system comprising:

a communication network;

a plurality of terminals;

at least one base-station

receiving downlink packets from said communication network,

processing said downlink packets and sending said downlink packets to each of said terminals through an electromagnetic-wave modulation circuit;

wherein each of said terminals

has a distinctive terminal address,

receives said downlink packets,

separates said downlink packets into a first group of detected downlink packets having a distinctive destination address which is the same as said distinctive terminal address, and a second group of disregarded downlink packets having destination addresses which are different than said distinctive terminal address,

further processes said first group of detected downlink packets and disregards said second group of disregarded downlink packets.

2. The wireless communication system as defined in claim 1 wherein:

said downlink packets comprise data packets from said communication network and downlink control packets generated by a control-packet generator.

3. The wireless communication system as defined in claim 1 wherein:

said base-station further comprises a base-transmitter comprising:

a base-transmit-processing unit which reorders said downlink packets and forms a plurality of downlink frames from said downlink packets,

a spreading unit which uses spreading codes to spread said downlink frames into downlink spread frames.

4. The wireless communication system as defined in claim 3 wherein:

said spreading codes comprise orthogonal codes and a pseudo-noise code,

each of said orthogonal codes is used to spread a distinctive downlink frame of said downlink frames,

said PN-code is used to spread each of said downlink frames.

5. The wireless communication system as defined in claim 4 wherein:

said pseudo-noise code is a truncation of a long-period pseudo-noise code.

6. The wireless communication system as defined in claim 4 wherein:

said pseudo-noise code is a stream of complex numbers which has a real part comprising a first truncation of a long-period pseudo-noise code and has an imaginary part comprising a second trunction of said long-period pseudo-noise code.

7. The wireless communication system as defined in claim 3 wherein:

at least one of said downlink frames is a pilot frame comprising pilot symbols which are known to both said base-station and said terminals.

8. The wireless communication system as defined in claim 3 wherein:

said terminal further comprises a terminal-receiver comprising:

a despreading unit which uses said spreading codes to despread said downlink spread frames into received downlink frames,

said spreading codes comprise orthogonal codes and a pseudo-noise code,

each of said orthogonal codes is used to despread a distinctive downlink spread frame of said downlink spread frames,

said PN-code is used to despread each of said downlink spread frames.

9. The wireless communication system as defined in claim 1 wherein:

said base-station further comprises a base-transmitter comprising:

a baseband modulation unit which modulates said downlink packets into a modulated downlink signal.

10. The wireless communication system as defined in claim 9 wherein:

said baseband modulation unit is a phase-shift-keying modulator.

11. The wireless communication system as defined in claim 9 wherein:

said baseband modulation unit is a quadrature-amplitude modulator.

12. The wireless communication system as defined in claim 9 wherein:

said baseband modulation unit is a multi-carrier modulator.

13. A wireless communication system comprising:

a communication network;

a plurality of terminals with each of said terminals transmitting a plurality of uplink packets through an electromagnetic-wave modulation circuit;

at least one base-station

receiving said uplink packets from said terminals,

sending said uplink packets to said communication network;

wherein each of said terminals

comprises a terminal-transmit-processing unit which reorders said uplink packets and forms a plurality of uplink frames from said uplink packets,

has a variable uplink data rate which is controlled by using a variable number of said uplink frames according to a control message from said base-station.

14. The wireless communication system as defined in claim 13 wherein:

each of said terminals further comprises a terminal-transmitter comprising:

a spreading unit which uses spreading codes to spread said uplink frames into uplink spread frames.

15. The wireless communication system as defined in claim 13 wherein:

each of said terminals

uses a distinctive pseudo-noise code to spread each of said uplink frames,

uses a plurality of orthogonal codes to spread said uplink frames with each of said orthogonal codes to be used to spread a distinctive uplink frame of said uplink frames.

16. The wireless communication system as defined in claim 14 wherein:

said base-station has a plurality of despreading units wherein

each of said despreading units uses said spreading codes to despread said uplink spread frames from a distinctive terminal of said terminals,

said spreading codes comprise orthogonal codes and a pseudo-noise code,

each of said orthogonal codes is used to despread a distinctive uplink spread frame of said uplink spread frames from said distinctive terminal,

said PN-code is used to despread each of said downlink spread frames from said distinctive terminal.

17. The wireless communication system as defined in claim 13 wherein:

at least one of said uplink frames is a pilot frame comprising pilot symbols which are known to both said base-station and said terminal.

18. A communication system comprising:

a transmitter comprising a spreading unit using a spreading code wherein

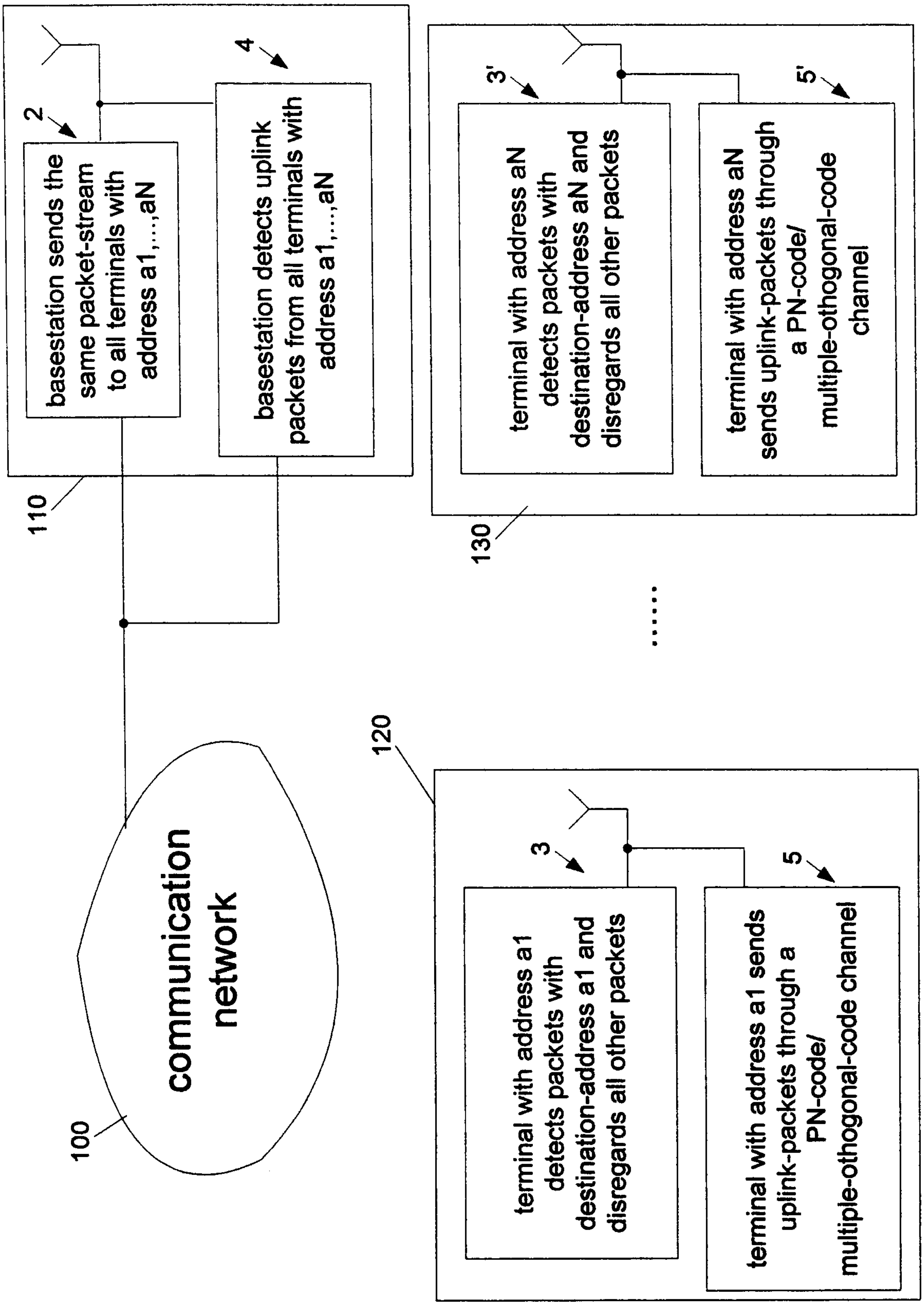
said spreading code is a pseudo-noise code which is a truncation of a long-period pseudo-noise code.

19. The wireless communication system as defined in claim 18 wherein:

Each chip of said long-period pseudo-noise code is a binary number.

20. The wireless communication system as defined in claim 18 wherein:

Each chip of said long-period pseudo-noise code is a complex number.



100
communication network
110
2
basestation sends the same packet-stream to all terminals with address a1,...,aN
4
basestation detects uplink packets from all terminals with address a1,...,aN
120
3
terminal with address a1 detects packets with destination-address a1 and disregards all other packets
5
terminal with address a1 sends uplink-packets through a PN-code/ multiple-othogonal-code channel
130
3'
terminal with address aN detects packets with destination-address aN and disregards all other packets
5'
terminal with address aN sends uplink-packets through a PN-code/ multiple-othogonal-code channel
......

Figure 1

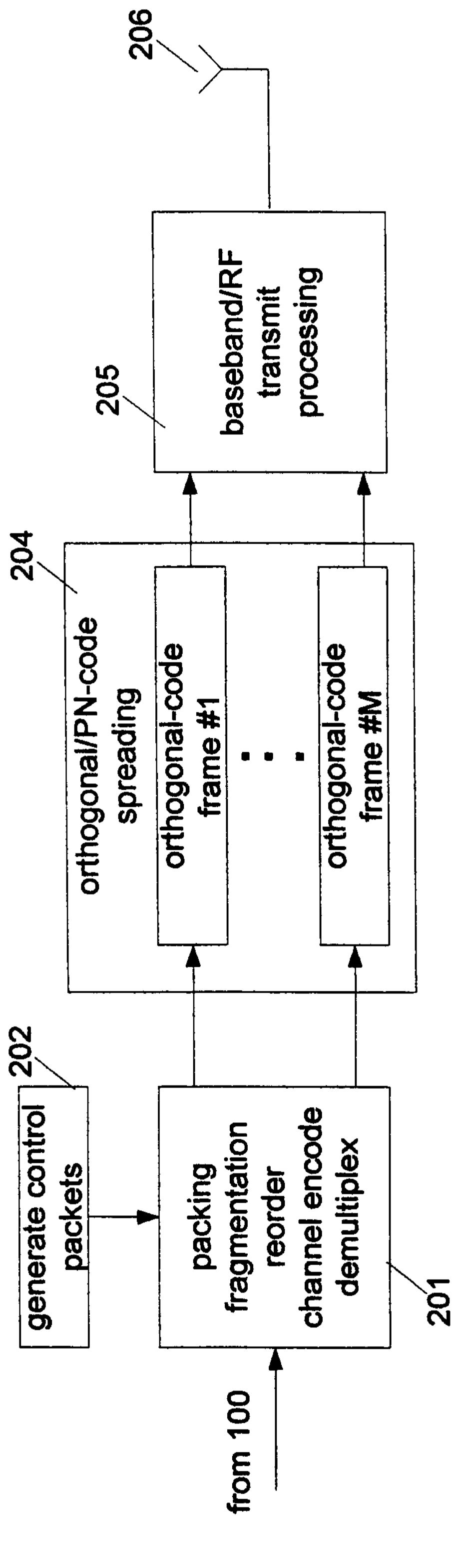


Figure 2a

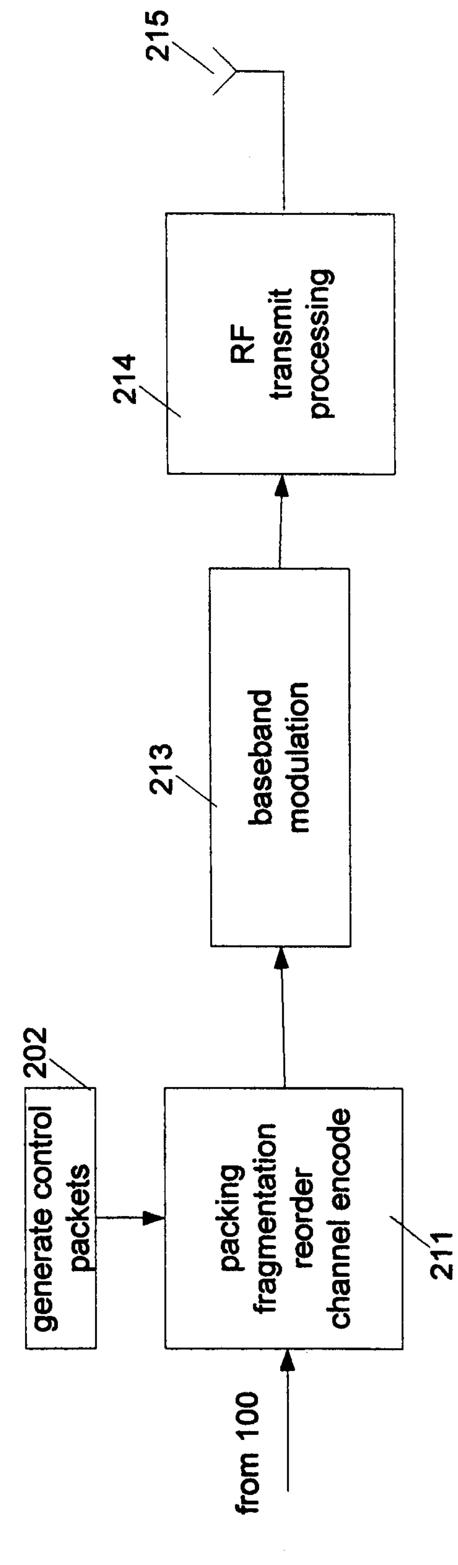


Figure 2b

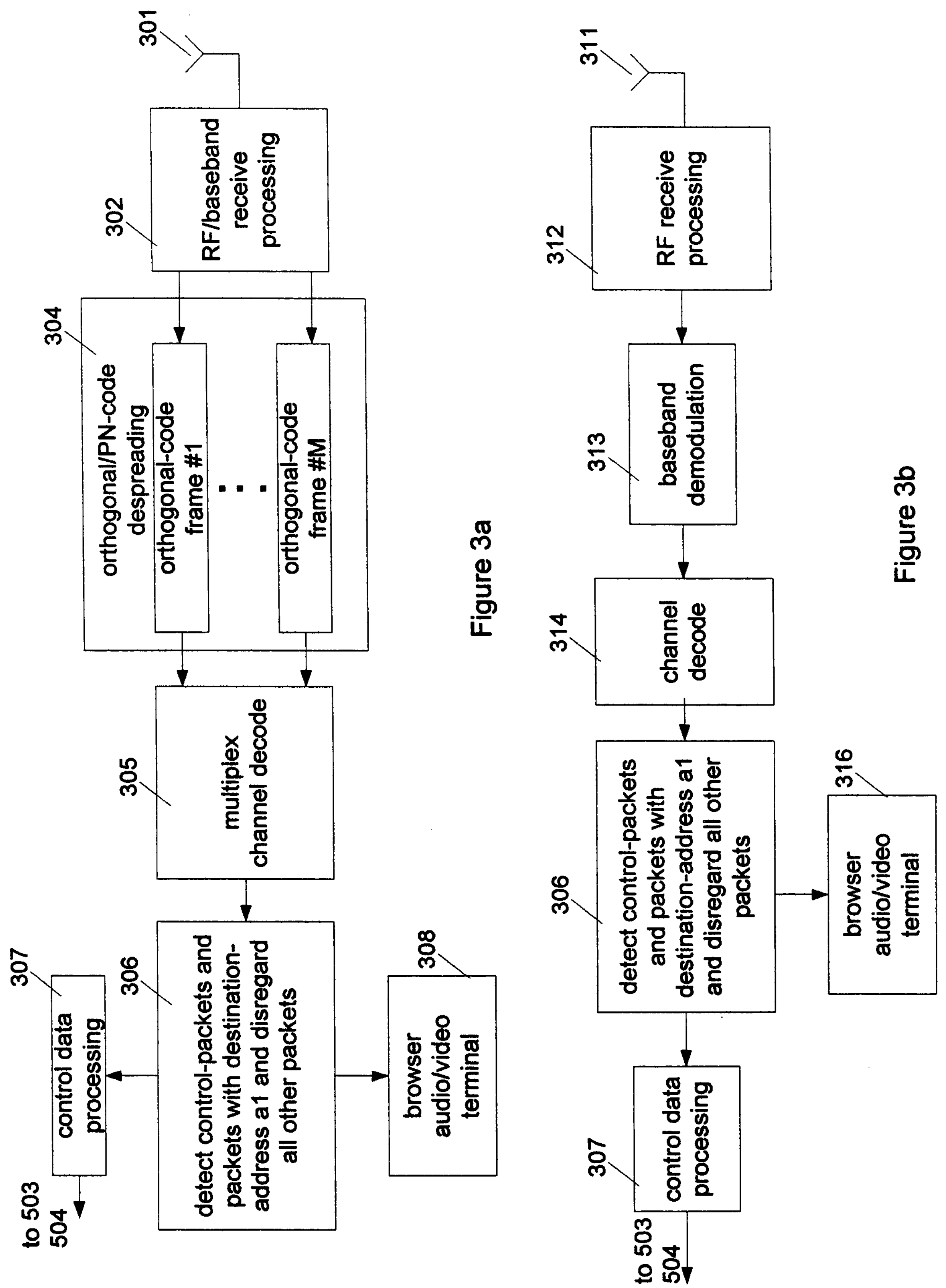


Figure 3a

Figure 3b

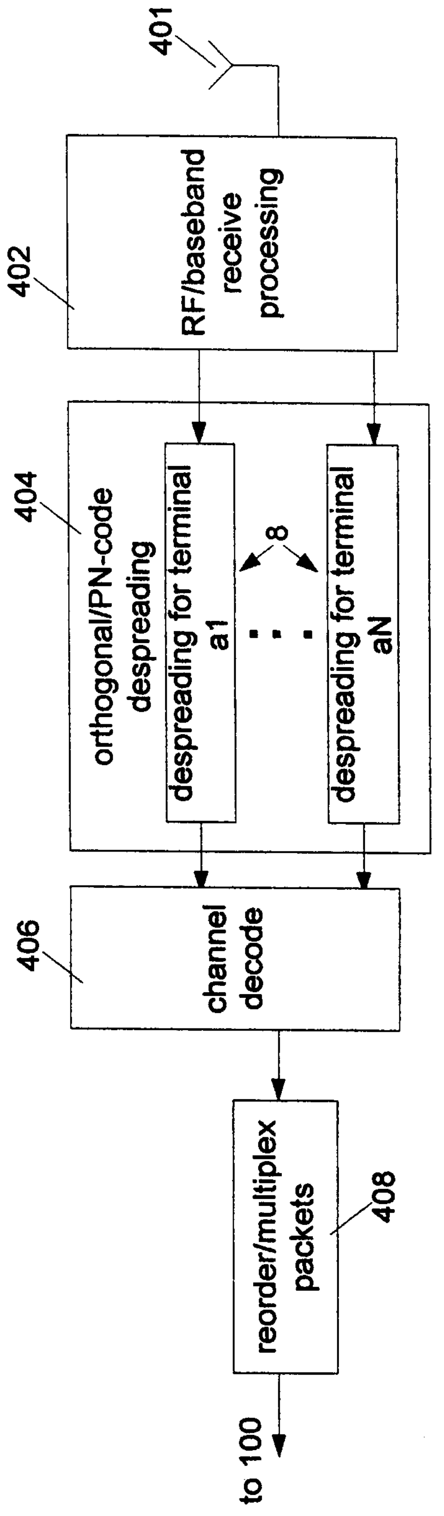


Figure 4a

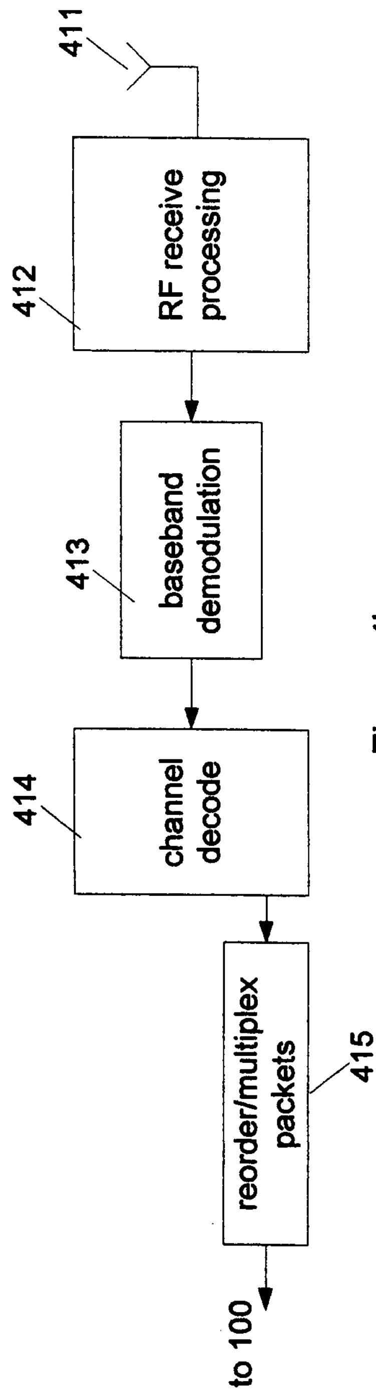


Figure 4b

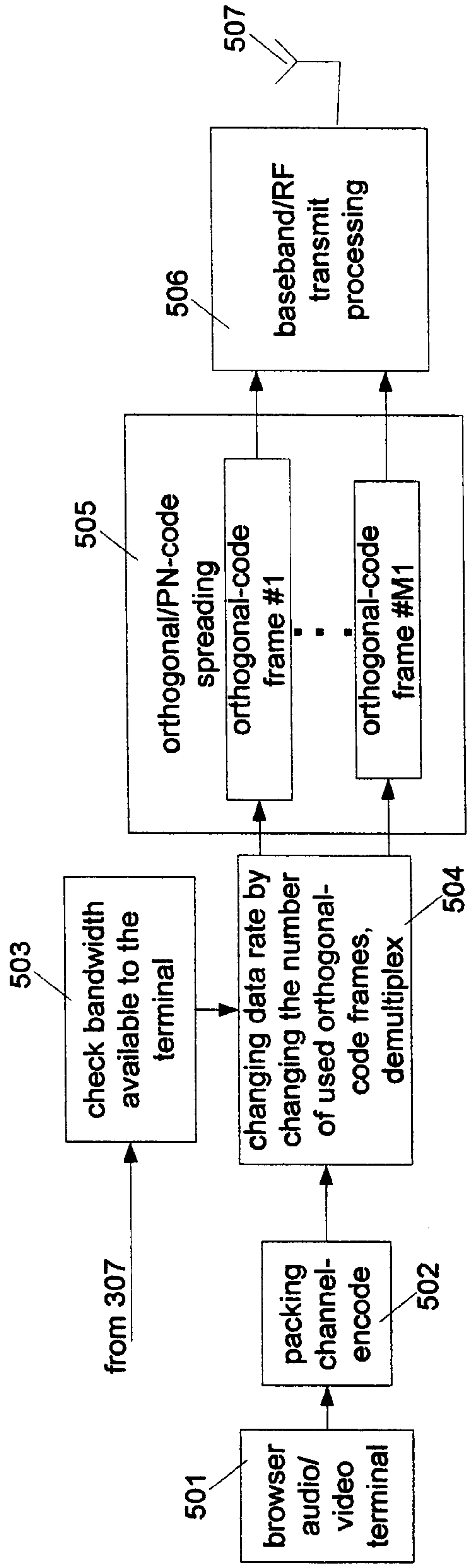


Figure 5a

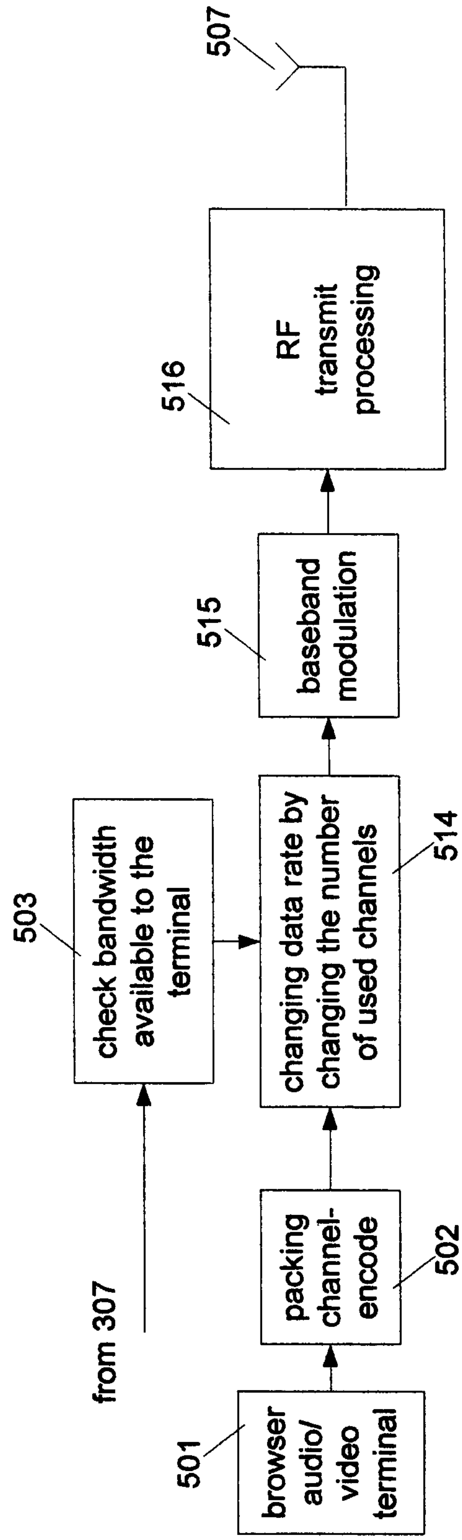


Figure 5b

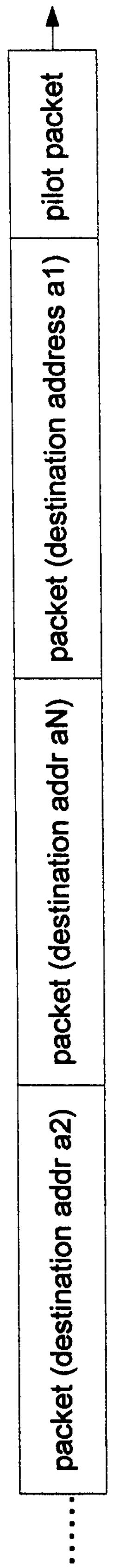


Figure 6

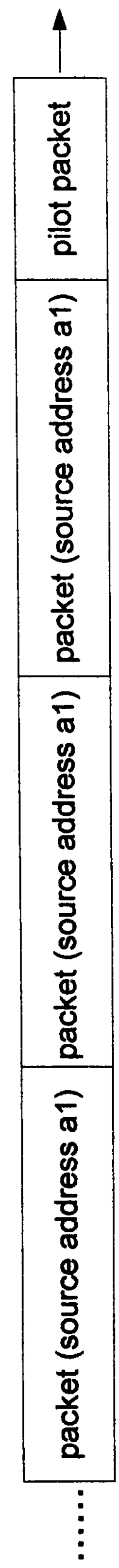


Figure 7

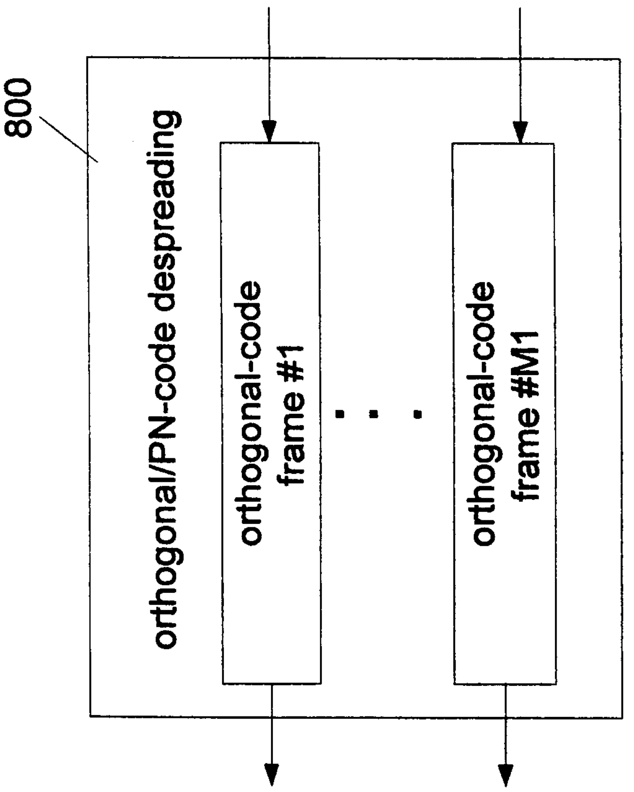

800
orthogonal/PN-code despreading
orthogonal-code frame #1
orthogonal-code frame #M1

Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/18560

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :H04Q 7/24
US CL :370/338
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/338, 310, 312, 314, 334, 335, 336, 337, 338, 341, 342, 347, 349, 339, 328, 326, 329, 498,515; 455/450, 463, 38.1, 517, 550

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ------ Y	US 5,799,010 A (LOMP et al) 25 August 1998, see Figs. 1, 2a-2d, 9-14, 22, and 26, col. 11, lines 1-14 and 31-67, col. 12, lines 1-20, col. 17, lines 15-67, col. 18, lines 1-67, col. 19, lines 1-67, col. 20, lines 1-67, col. 21, lines 1-62, col. 37, lines 14-67, col. 38, lines 1-67, col. 39, lines 1-67, col. 40, lines 1-21, col. 41, lines 62-67, col. 42, lines 1-40, col. 43, lines 54-67, col. 44, lines 1-14, col. 54, lines 17-57 and 60-67, col. 55, lines 1-11 and 22-67, and col. 56, lines 1-44.	18-20 ---------- 1-17

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 NOVEMBER 1999	03 DEC 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHIRIN SAM James R. Matthews Telephone No. (703) 308-9294

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/18560

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,546,420 A (SESHADRI et al) 13 August 1996, see Figs. 1, 3, 5A-5B, and 10-11, col. 1, lines 27-49, col. 5, lines 42-67, col. 6, lines 1-45, col. 9, lines 14-67, col. 10, lines 1-34, col. 12, lines 60-67, and col. 13, lines 1-38.	1-17