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(54) Title: POWER CONTROL FOR A MOBILE TERMINAL IN A SATELLITE COMMUNICATION SYSTEM

(57) Abstract

A method for controlling the transmit power level of a mobile terminal in a satellite communication system includes both a closed–loop element and an open–loop element. For the closed–loop element, the base station calculates the mobile terminal's power setting based on the strength of the signals received from the mobile terminal. The base station takes into account the propagation delays of the satellite system in determining the mobile terminal's transmit power setting. The open–loop element of the power control method allows the mobile terminal to adjust its own transmit power level from frame to frame based on the strength of the received signals from the base station. The strength of the signal received from the base station in each frame is compared to the strength of the signal received in the previous frame. The transmit power level of the mobile terminal is then adjusted inversely in accordance with variations in the observed signal strength.

POWER CONTROL FOR A MOBILE TERMINAL
IN A SATELLITE COMMUNICATION SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to the field of mobile satellite communication systems, and more particularly, to a power control method for controlling the transmit power of a mobile terminal in a satellite communication system.

BACKGROUND OF THE INVENTION

Satellite systems are playing an increasing role in mobile communications by providing coverage in zones where land-based infrastructures are unable or ineffective to supply mobile services. Satellite systems can, for example, provide coverage in large, sparsely-populated areas where it is not cost effective to implement network infrastructures. Satellite systems can also make services available to airborne and sea-based users. Another use of satellite systems is to back-up or supplement a land-based network. Satellite systems can continue to provide services to users when segments of the network infrastructure are down, can carry additional traffic during peak transmission periods when the land-based network is overloaded, and can fill-in holes in the coverage area of a land-based system caused by man-made or natural obstacles.

Satellite communication systems are typically a derivative of GSM, which is adapted for use in a satellites system. The GSM technical specifications are published by the European Telecommunications Standard Institute (ETSI) and are incorporated in their entirety by reference herein. In GSM, the mobile

terminal's power level is controlled by the base station. The algorithm used by the base station is quite complex. To put it simply, the base station takes two measurements, called RXQUAL and RXLEV, based on the received signal. These measurements are used to determine the transmit power level for the mobile terminal. RXQUAL is based on bit error rates (BER) and RXLEV is based on the strength of the received signal. These measurements are generally taken over one complete SACCH period. Once the base station determines the appropriate power level for the mobile terminal, it sends a signaling message to the mobile terminal to tell it to adjust its transmit power level. The mobile unit has no part in deciding its transmit power level. While this method of power control works well in land-based cellular systems for which GSM was developed, it has shortcomings when applied in a mobile satellite communication system.

In a land-based cellular system, the propagation time for the transmission of a signal is relatively short. In a satellite system, the signal travels great distances before reaching its intended receiver. Consequently, there is a substantial propagation delay in satellite communications. The power control method used in GSM does not take into account these propagation delays. If, for example, the base station sends a message to the mobile terminal telling it to increase its power, the mobile station will not receive the message until approximately four SACCH cycles later. By that time the mobile station might be out of its disadvantaged location. The mobile unit would then transmit at a power level that is greater than the minimum needed to assure a desired signal quality which will result in an unnecessary drain on the mobile units battery.

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Conversely, if the base station commands the mobile terminal to reduce its

transmit power because of favorable conditions, the designated transmit power

level might be too low to maintain the desired signal quality by the time the

mobile terminal receives the command.

Accordingly, there is a need for a new power control method that is

specifically designed for use in a satellite system and takes into account the long

propagation delays of a satellite system.

SUMMARY OF THE INVENTION

The present invention is a method for controlling the transmit power in a

mobile radio communication device in a satellite communication system. The

power control method of the present invention comprises both a closed-loop

element and an open-loop element. For the closed-loop element, the base

station calculates a power control constant for the mobile terminal based on the

strength of signals received from the mobile terminal. The base station takes

into account the propagation delays of the satellite system in determining the

mobile terminal's transmit power level. The mobile terminal uses the power

control constant to calculate its transmit power so that changing the power

control constant causes a corresponding increase or decrease in the mobile

terminal's transmit power.

The open-loop element of the power control method allows the mobile

terminal to adjust its own transmit power level based on the strength of signals

received from the base station while it waits for a new transmit power setting

from the base station. It is assumed that the path loss on the uplink will be the

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same as the path loss on the downlink. If the power of the received signal

diminishes on the down-link without any change in the transmit power level, it is

assumed that the path loss is increasing. The mobile unit monitors the signal

received from the base station and varies its transmit power level inversely in

accordance with observed variations in the signal strength of signals received in

the previous frame.

When discontinuous transmission (DTX) is employed in order to conserve

power, transmissions are silenced in the direction not currently speaking.

According to one aspect of the invention, one frame in every 13 TDMA frames

always contains an active transmission of SACCH information even when DTX is

used. The SACCH information is preferably transmitted at a constant power

level to provide a stable signal strength reference point. The SACCH occurring

one frame in thirteen does not allow fast control of the uplink power level since

the 12 intervening frames receive no separate power control information.

According to another aspect of the invention, the mobile terminal may receive a

SACCH signal in a timeslot other than its allocated timeslot in order to determine

if the path loss is varying. The alternate slot used for this purpose is preferably

as close as possible in time to the mobile terminal's assigned transmit slot

without causing difficulty in switching from receive to transmit sufficiently rapidly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is an illustration showing the major elements in a satellite communication system.

FIGURE 2 is an illustration showing a TDMA frame used in the satellite system of the present invention.

FIGURE 3 is an illustration showing the propagation delays in a satellite communication system.

FIGURE 4 is a block diagram illustrating the components of a mobile terminal.

FIGURE 5 is a flow diagram illustrating the closed-loop portion of the power control method.

FIGURE 6 is a flow diagram illustrating the open-loop portion of the power control method.

FIGURE 7 is a graph comparing the combined closed-loop/open-loop power control method of the present invention with a closed-loop only power control method.

FIGURE 8 is an illustration of a TDMA frame.

FIGURE 9 is an illustration showing the relative frame timing on different channels in a TDMA system.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, the power control method for controlling the transmit power of a mobile terminal in a satellite communication system will be described. A mobile satellite communication system which utilizes the power

control method of the present invention is shown in Figure 1 and is indicated

generally by the numeral 10. The satellite system 10 includes a space-based

satellite 12 having an antenna 14 which projects one or more spot beams onto

the surface of the earth to provide a communication medium for communications

between earth stations. The earth stations in a satellite communication system

include both mobile stations 16 and at least one base station 18. The base

station 18 includes a mobile switching center (MSC) 22 which provides a

connection to the public switched telephone network (PSTN) 28, or other

terrestrial network. The MSC 22 includes a control processor 24 and memory

devices 26 to control its operation and to handle signaling as will be hereinafter

described. Since the basic architecture of satellite communication systems is

well known to those skilled in the art, further discussion of the same is omitted.

Figure 2 illustrates a TDMA transmission format employed in the satellite

system of the present invention. In the satellite application, the GSM frame

structure is modified to comprise 13 frames of 16 slots in which every 13th frame

is an SACCH frame. A multiframe, indicated generally at 50, comprises 26 TDMA

frames 52. In each multiframe 50, the first 12 frames 52 carry traffic information.

The fourteenth through twenty-fifth frames 52 also carry traffic information. The

thirteenth and twenty-sixth frames 52 each carry one eighth of a Slow Associated

Control Channel message (SACCH). Four multiframes 50 are required to

complete delivery of one SACCH message, while each multiframe 50 delivers

sixteen, 20 mS speech vocoder datablocks. Each 20 mS block of coded data

representing a segment of the speech waveform is spread over three

consecutive TDMA frames 52 in a process known as block-diagonal interleaving.
Each TDMA 52 frame can be transmitted on a different frequency using
frequency hopping to obtain the benefit known as interference averaging or
interferer diversity.

The SACCH message facility is used to transmit power control information
to and from the mobile terminal. In a typical GSM system, the base station
determines the appropriate transmit power level for the mobile terminal based on
the average received signal strength over one entire SACCH period and sends a
SACCH message to the mobile terminal to command the mobile terminal to set
its transmit power level to the specified level. The timing diagram shown in
Figure 3 illustrates the delays involved when this method of power control is
used in a satellite system. It takes approximately 960 mS to transmit the SACCH
message and 240 mS for the signal to propagate. Once the base station
receives the SACCH signals, it needs some time to calculate the new power
setting for the mobile terminal based on the signal strength of the received
SACCH signals. The base station begins transmitting a SACCH message
containing the new power setting on the next SACCH cycle. It takes another 960
mS to transmit the SACCH message and 240 mS for the signal to propagate
before it is received by the mobile terminal. The mobile terminal begins
transmitting at the new power level at the beginning of the next transmit slot.

By the time the mobile station receives its transmit power setting from the
base station, the conditions may have changed substantially from the conditions
that existed when the original SACCH signals on which the power setting is

based were transmitted from the mobile terminal to the base station. Because of

the delay, the adjustment may no longer be needed by the time that the new

power setting is received by the mobile terminal. For example, assume that the

base station notices a substantial drop in the RSSI from the mobile terminal

reflecting an increase in the path loss between the mobile terminal and the base

station. The base station calculates a new power setting based on the average

RSSI over one SACCH period and then sends a message to the mobile terminal

telling it to increase its transmit power. By the time the mobile terminal receives

the new power setting it may already be out of its disadvantaged location. This

would cause the mobile terminal to transmit at a power level greater than what is

needed to maintain the minimum desired signal quality thus wasting power.

Moreover, the excessive power increases the amount of co-channel interference

that will be experienced by other users in the system. Conversely, if the base

station notices an increase in the RSSI from the mobile terminal resulting from

favorable conditions, it will instruct the mobile terminal to reduce its transmit

power level. If the favorable conditions no longer exist when the new power

setting is received at the mobile terminal, then the mobile terminal may transmit

at a power that is insufficient to maintain the minimum desired signal quality.

To avoid the power control problems resulting from the long delays in

satellite communications systems, the present invention uses a dual method of

power control including both a closed-loop element and an open-loop element.

Closed loop power control is a function of the base station. The base station

sends power control messages to the mobile terminal which causes the mobile

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terminal to either raise or lower its transmit power. Open loop control is carried out by the mobile terminal. The mobile terminal is allowed to vary its own transmit power based on variations in the strength of the signal received from the base station. It is assumed that the path loss on the uplink will be the same as the path loss on the downlink. If the mobile terminal sees a drop in the strength of the received signal (indicating an increase in the path loss between the base station and the mobile terminal), it will increase its transmit power. Conversely, if the mobile terminal sees an increase in the strength of the received signal (indicating a decrease in the path loss between the base station and the mobile terminal), it will lower its transmit power accordingly.

In the closed-loop element of the power control method, the base station determines the value of a power control constant for the mobile terminal based on the quality of the signals received from the mobile terminal. The base station transmits the power control constant to the mobile terminal using the SACCH message facility. The mobile terminal receives a new power control constant once every SACCH cycle and uses the power control constant to calculate its transmit power setting according to the following equation:

TX POWER LEVEL = CONSTANT – RECEIVED SIGNAL LEVEL

where quantities are expressed on a logarithmic scale (e.g. decibels). This equation indicates that the mobile terminal will vary its own transmit power inversely in accordance with observed variations in received signal strength to provide open loop control over the transmit power. This equation also indicates that a change in the power control constant will result in a corresponding change

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in the transmit power of the mobile terminal for all values of received signal strength.

The RECEIVED SIGNAL LEVEL is measured by the mobile terminal by averaging over each received timeslot, and these slot averages may be subject to further averaging depending on a time constant which may also be modified by a SACCH command from the base station.

The open-loop control element allows the mobile terminal to vary its own transmit power during the period between receipt of two complete SACCH messages from the base station (which is approximately one second).

Description of Mobile Terminal

Referring now to Figure 4, there is shown a schematic diagram of a mobile terminal which utilizes the power control method of the present invention. The mobile terminal is indicated generally by the numeral 100. The mobile terminal 100 includes a burst receiver 102 to receive transmitted signals and a burst transmitter 104 for transmitting signals. A signal processing unit 106 processes signals passed to it by the receiver 102 and prepares signals for transmission by the transmitter 104. The signal processing unit 106 includes a received signal processor 108, a transmit signal processor 114, and a channel codec 110. The received signal processor 108 includes a demodulator and demultiplexer (indicated collectively by the numeral 108) to extract the transmitted bit stream from a received burst and to sort the received information from the different time slots and frames into their appropriate logical channels.

The received signal processor also includes a power measurement circuit to measure the strength of the received signal , and a bit error determination circuit to determine received information quality. The power and quality measurements are passed to the control and signaling unit 112. A channel codec 110 decodes the bit sequence coming from the received signal processor 108. If the decoded bit stream is a speech frame, then the channel codec passes it to the speech codec 118. If the decoded bit stream is a signaling frame, it is passed to the control and signaling unit 112.

The control and signaling unit performs all of the control functions of the mobile terminal. These functions include power control, and channel selection. To perform its control functions, the control and signaling unit 112 exchanges signaling messages with the base station or network. These signaling messages are prepared or processed in the control and signaling unit 112 and are passed to or received from the channel codec 110.

The burst building unit, multiplexer and modulator (indicated generally by the numeral 114) prepare signals for transmission. The burst building unit places coded bit sequences received from the channel codec 110 in the appropriate burst structure and then adds the necessary training sequence bits, tail bits, and stealing flag. The multiplexer assigns each individual burst to a timeslot in a numbered frame. After the bit sequence is sorted and ordered the modulator impresses the bit sequence on the carrier frequency for transmission by the transmitter 104.

The frequency synthesizer 116 provides the internal timing references for the bit and frame clock as well as for the RF sources in the receiver and transmitter. A voltage controlled oscillator assumes a stable operating frequency as commanded by the control and signaling unit 112.

The control and signaling unit 112, as previously mentioned, performs the power control functions for the mobile terminal. The power control functions are performed by a software routine within the control and signaling unit 112. As will be apparent to those skilled in the art, the power control function may be performed in a time-shared processor performing other functions at different times. The power control algorithm processes the signaling messages together with the received signal strength and quality measurements to determine a power level for transmitting the next signal burst.

Description of Power Control Algorithm

Referring now to Figure 5, a flow diagram is shown illustrating the closed-loop element of the power control method. The base station receives a signal from the mobile terminal 100 (block 200) and measures the RSSI of the signal (block 202). After one full SACCH period (block 204), the base station averages the RSSI values of the signals received over the SACCH period (block 206). The base station calculates the difference (designed as γ) between the average RSSI value of the received signals and the desired receive power p (block 208). This difference is referred to herein as the power deviation value. The power deviation value γ is compared to a predetermined threshold power differential

(designed as c) (block 210). If the absolute value of the power deviation value γ

exceeds c, then the base station calculates a new power control constant for the

mobile terminals (blocks 212 and 214) and transmits the new power control

constant to the mobile terminal using the SACCH message facility (block 216).

To obtain the new power constant, the base station divides the power deviation

value γ by a predetermined delay factor k (block 212) and adds the resulting

value to the previous power control constant for the mobile terminal (block 214).

The delay factor k will usually be a small integer such as 4. The value of the

delay factor k can be left to the discretion of the system operator and may, for

example, be set according to step size.

Because of the delay factor, the base station will not attempt to correct

large swings in received power in one step. If there is a sudden drop in receive

power at the base station due to shadowing, the base station will increase the

transmit power level in increments while the effects of shadowing are

experienced. This incremental increase prevents large swings in the transmit

power over short intervals of time and thus prevents the base station from

overreacting to transitory changes in signal strength.

The base station also receives reports from the mobile terminal of the

quality of the signal received by the mobile terminal from the base station. If the

quality is too low, the base station will increase the power it transmits to that

mobile terminal for the whole of the next SACCH period. Then, in recognition

that the mobile terminal's open loop power control system will reduce the mobile

terminal's transmit power when it detects an increase in signal level from the

base station, the base station must adjust the power control constant it transmits

to the mobile station by the same amount in order to avoid unwanted interaction

between the downlink power (base transmit power) control loop and the uplink

power (mobile transmit power) control loop.

If discontinuous transmission (DTX) is employed, the mobile terminal 100

will continue to transmit SACCH signals at a power level (e.g. maximum power

level) in one out of every thirteen frames. The base station can measure the

RSSI of the SACCH signals and use these measurements to calculate the path

loss from the mobile terminal as the SACCH is transmitted with known power.

The path loss can be used to compute the appropriate power level for the mobile

to transmit the traffic channels when not in DTX mode. Of course, this can be

done directly without necessarily consulting an intermediate value equal to the

path loss, which was mentioned as an aid to understanding the physical system.

The open-loop element of the power control method is shown in Figure 6.

The mobile terminal 100 receives signals on the down-link from the base station

(block 300). If the signal completes a SACCH message (block 302) then the

mobile terminal sets a power control constant accordingly (block 304). The

mobile terminal 100 then calculates the RSSI of the down-link transmissions

(block 306) and smoothes the RSSI values of the down-link signal (block 308).

The smoothing algorithm gives more weight to the most recently received signal

on the down-link than earlier signals. The smoothed value based on the RSSI of

the received signals (called RX_NEW) is then used to calculate the new transmit

power level in block 310. RX_NEW is subtracted from the desired receive power
P to obtain a power correction value Pcor. The power correction value Pcor is
then added to the power control constant provided by the base to obtain the
transmit power for the next transmit slot. In block 312, the mobile transmits
using the transmit power level calculated in block 310. The power setting is
adjusted in this manner from frame to frame using the previously received power
control constant until a new power control constant is received from the base
station. The result is that the transmit power will vary inversely with the RSSI of
the received signal. If the RSSI of the received signal decreases, then the
transmit power of the mobile terminal is increased by a corresponding amount.
Conversely, if the RSSI of the received signal increases, then the transmit power
of the mobile terminal is decreased by a corresponding amount.

The open-loop element of the control method allows the mobile terminal to
respond in more timely fashion to variations in path loss which are attributable to
shadowing. Although shadowing effects are relatively slow, the delays inherent in
a satellite system make timely response by the base station impossible. Figure 7
is a graph showing a simulation of a computer comparing the transmit power
level of a mobile terminal using only closed-loop power control with a mobile
terminal using both closed-loop and open-loop power control. As shown in the
graph, a drop in receive power occurred in the 49th SACCH cycle of the
simulation. The mobile terminal using only closed-loop power control did not
react until the 53rd SACCH cycle. The mobile terminal using both open-loop
control and closed-loop power control reacted almost immediately to the drop in

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power. It is apparent, therefore, that the open-loop element makes the mobile terminal better able to respond to variations in path loss caused by shadowing.

If the base station detects a lack of correlation between signal quality reported by the mobile and signal level received from the mobile, this may be indicative of uncorrelated up and down link fading. When this is detected, the base station can send another SACCH command to change the smoothing algorithm at block 310 to use a longer smoothing time constant. Otherwise, the base station may send an SACCH message to reduce the time constant used in block 310 when it estimates that up and downlink fading are more correlated, in order to speed up the open-loop part of the power control algorithm.

In the discussion thus far, it has been assumed that the base station transmits a signal continuously to the mobile station. This assumption may not always be correct. When discontinuous transmission is employed, transmissions are silenced in the direction not talking. The reason for using discontinuous transmission is to conserve power when it is not needed. The power control method of the present invention can be adapted for DTX mode.

To enable open-loop power control in DTX mode, one frame in every thirteen TDMA frames always contains an active transmission of slow associated control channel information. The SACCH signals are transmitted at a known power level to provide a signal strength reference point. The SACCH information may, for example, be transmitted at a constant level which is known to the mobile terminal, which may also be an upper-level for transmissions of SACCH's. Alternatively, a down link power report can be sent to the mobile terminal as part

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of a SACCH message to inform the mobile terminal of the transmit power level used by the base for SACCH transmissions. When the base transmit power level is known, the mobile may compute the path loss from the base station or satellite and then use the path loss to compute an appropriate level for transmitting traffic information. Of course, this may also be calculated without necessarily computing an intermediate value equal to the path loss.

The SACCH occurring one frame in every thirteen does not allow fast control of the transmit power level for the mobile terminal since the twelve intervening frames receive no separate power control information. Therefore, the mobile terminal may choose to receive a signal in a timeslot other than its own allocated receive timeslot in order to determine if the path loss is varying. This timeslot switching is illustrated in Figure 8.

As shown in Figure 8, the mobile station is allocated the first slot in each frame to receive transmissions from the base station (i.e., down-link communications). If the base station does not transmit information during the mobile terminal's allocated receive slot because the user at the other end is not talking, then the mobile terminal can switch to an alternate slot (for example, slot 4) which is a receive slot allocated to some other mobile terminal. Since other timeslots contain information that is of no interest to the mobile terminal in question, the signal does not have to be completely demodulated. It is sufficient to make an RSSI measurement of the signal strength received in the alternate slot. The slot used for this purpose is preferably a slot as close as possible in

time to the mobile station's transmit slot while leaving sufficient time to switch from receive to transmit mode.

The signal in the alternative timeslot is transmitted with unknown power. Therefore, the first frame received in the alternative timeslot does not provide sufficient information on which to make power adjustments. Data from at least two frames, preferably consecutive, are needed to determine whether the path loss is varying. As an alternative to receiving another timeslot on the same carrier frequency, the mobile can use its frequency agile synthesizer to receive a slot on a different carrier frequency on which unrelated calls are taking place. The carrier frequencies available in a particular cell or satellite beam would have been previously read from the system's broadest control channel. In particular, the mobile can choose the carrier frequency, from among those available, which another call's SACCH slot coincides with, or is close in time to, the mobile's own reception timeslot. The likelihood of finding such an SACCH slot is enhanced by deliberately staggering the frame on which the SACCH is transmitted as between different carriers, which is in any case desirable to avoid all SACCH transmissions coinciding, with consequent high peak power demand from the satellite transponder. Thus, when a cell or beam contains 13 carrier frequencies, one carrier is always carrying an SACCH transmission to some mobile terminal and preferably at a known power level.

In one embodiment, the RSSI value of the first frame received in the alternate slot is compared with the immediately preceding SACCH burst in the mobile terminal's own timeslot and the difference is determined and stored as a

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calibration of the power level of the alternate slot relative to the known SACCH power level. The RSSI measurement on each succeeding frame in the alternative slot is then corrected using this difference. The corrected RSSI value of each succeeding frame is compared to the immediately preceding frame to determine if the path loss if varying. The transmit power of the mobile terminal is varied inversely according to the adjusted RSSI of the signal on the alternate channel. The mobile terminal only needs to measure RSSI, and not decode, the alternate slot, and can thus conserve its decoding resources for continuing to process signals in its own slot in order to detect when DTX ceases and transmission of speech or data resumes.

As an alternative, it may be sufficient to observe whether the alternative slots RSSI has increased or decreased from frame to frame, and to apply the same increase or decrease, appropriately inverted, to the transmit power level without first correcting the RSSI value as previously described. An accumulation of such delta changes has a tendency to slowly drift away from a correct absolute value, but the absolute power value may be corrected every time a SACCH burst of known reference power is received thus limiting the drift to thirteen frames or 120 milliseconds. Thus, the drift is insignificant.

Another method which might be employed when discontinuous transmission is used would be to allow the mobile unit to hop to a different carrier frequency on each of the 12 intervening frames to receive a SACCH signal in each of the 12 intervening frames. If the SACCH signals are transmitted at a

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constant power, then the mobile terminal can determine the path and thus determine if it has varied.

This frequency hopping scheme is illustrated in Figure 9. As shown in Figure 9, the mobile terminal receives a SACCH signal in its own allocated receive slot in frame 13. If a transmission is not received in frame 14, then the mobile terminal switches to an alternate channel (in this case channel 2) to receive a SACCH signal in the alternate channel. The mobile terminal switches to a third channel on frame 15 if it does not receive a signal in its own allocated timeslot. The mobile terminal can hop from channel to channel in this manner to receive a SACCH signal on each visited channel. If the SACCH signals on all channels are transmitted at a constant power setting, then the mobile terminal can determine whether the path loss is varying by comparing the SACCH signal received in each frame to the SACCH signal received in the previous frame even though the SACCH signals are received on different channels. In order to employ this method, the mobile terminal would preferably obtain information from the broadcast control channel giving the relative timing stagger of SACCH transmissions on different carrier frequencies.

The invention may also be adapted advantageously to determine transmit power levels for mobile radios in a landmobile radio system of the type known as trunked radio. Trunked landmobile radio differs from conventional landmobile radio in that the users do not receive a permanent frequency allocation. Instead, a number of users or user groups pool a smaller number of frequencies. Typically, each pooled frequency is actually a pair of frequencies, one for

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transmitting in the base to mobile (downlink) direction and the other for

transmitting in the mobile to base (uplink) direction; this arrangement is called

"two-frequency simplex."

One of the shared downlink frequencies is used to broadcast control

messages to the mobile radios, and one of the pooled uplink frequencies is used

to receive control messages from the mobile radios. When a particular user

wishes to talk, he depresses the pressed switch (press-to-talk button) on the

radio and the radio automatically transmits a channel request message on the

uplink control channel, and then temporarily reverts to the receive state. The

base station receives the message and immediately replies by transmitting an

access grant message on the downlink control channel, the message indicating

to the mobile radio the channel number of the next free channel that it shall use

for the duration of that "over." The mobile radio then resumes the transmit state

using the indicated channel number until the user releases the press-to-talk

switch.

One problem that arises in prior art landmobile radio systems is that

mobile radios can lie at large or small distances from the base station and thus

may be received very strongly or very weakly. A very strongly received mobile

signal can interfere with reception of a weaker one, particularly when the weaker

one is using an adjacent frequency channel. The customary solution to this

problem is either to design expensive radios with very high adjacent channel

rejection, or else not to use adjacent channels within the same base station.

Neither solution is favorable at the present state of the art and a better solution is

to implement power control of the mobile transmit power so that signals are received by the base station at around a desired strength and not excessively strong.

According to the invention, a method is provided for determining the appropriate transmit power for a mobile radio to use.

In a trunked radio system, all mobiles listen to the downlink control channel in idle mode. If a member of their group becomes an active transmitter, the whole group receives the access grant message allocating a free channel to the transmitter. The rest of the group (i.e., the non-transmitting radios of the group) then tune to the downlink channel of the allocated channel pair in order to receive the message relayed from the transmitting radio by the base station.

Upon initiation of transmission, the transmitting radio remembers the signal strength (RSSI(o)) it was receiving on the control channel just before it went to transmit; an access request message is then transmitted by the mobile radio at a known power level P(o).

The base station measures the signal strength of the received access request and determines if it is too strong or too weak. The base station then sends an access grant message to the mobile radio comprising the number of a free channel it shall use and also an indication of the amount DELTA by which the received access request signal was too strong or too weak.

The mobile radio then makes the following computation:

$$CONSTANT(o) = P(o) - RSSI(o) + DELTA$$

in order to determine an initial power control constant CONSTANT(o). It then

transmits on the assigned channel using a power given by:

$$P = CONSTANT\ (o) - RSSI$$

where RSSI is any of RSSI(o), or the signal strength at which the access grant

message was received, or any subsequent measurement of signal strength

received from the base station. In a TDMA landmobile radio system, mobile

radios transmit in bursts occupying less than 100% of the time available and are

able to momentarily revert to receive between transmit bursts to receive

information from the base station. The information received can include timing

information to maintain synchronism of the transmit bursts, frequency error

information that can be used to maintain an accurate transmit frequency, and

signal strength information which can be used according to this invention to

update the power level P that shall be used for the next transmit burst.

Periodically reverting to receive also provides the useful facility of PRIORITY

INTERRUPT, where a radio nominally on transmit can be commanded to revert

to receive in order to allow the user to receive a more urgent message. Even

non-TDMA radios can advantageously be caused momentarily to revert to

receive for a few milliseconds in order to determine if a more urgent

communication is needed, which interruption causes negligible loss of voice

quality while providing the opportunity to make a signal strength measurement

with which to update the transmit power upon resumption of transmission.

IN THE CLAIMS

What Is Claimed Is:

1. In a TDMA system wherein a mobile station communicates with a base station using timeslots in a repetitive TDMA frame period, an open loop power control method for controlling the transmit power of said mobile terminal comprising:

  a) receiving at said mobile terminal a signal transmitted from said base station in a first timeslot of said TDMA frame period;

  b) measuring at said mobile terminal the signal strength of the signal received in said first TDMA frame period;

  c) computing at said mobile terminal a transmit power setting for the mobile terminal based on said measurement of said received signal strength; and

  d) transmitting a signal from said mobile terminal at said computed transmit power setting to said base station in a second timeslot in said TDMA frame period.

2. The method of claim 1 further including decoding said signal received in said first timeslot in order to recover information.

3. The method of claim 1 further including receiving a signal at said second station from said first station in a third timeslot of said TDMA frame and decoding it in order to recover information.

4.   The method of claim 1 in which said first timeslot contains information transmitted from said first station to a third station.

5.   A closed-loop power control method for controlling the transmit power level of a mobile terminal in a mobile radio communication system, said method comprising:

a)   receiving at a base station a transmitted signal from said mobile terminal;

b)   measuring the signal strength of the received signal at said base station;

c)   calculating a power deviation value based on the difference between the measured signal strength of said received signal and a predetermined reference power;

d)   computing at said base station a transmit power setting for said mobile terminal based on said power deviation value and a predetermined delay factor;

e)   transmitting the power setting from said base station to said mobile terminal; and

f)   adjusting the transmit power of said mobile terminal in response to the receipt of said transmit power setting from said base station.

6.   The closed-loop power control method according to claim 5 wherein said transmit power setting is computed by dividing the power deviation value by said delay factor and adding the result to a previous transmit power setting.

7.   The closed-loop power control method according to claim 5 further including the step of comparing said power deviation value to a predetermined power differential threshold and if said power deviation value exceeds said power differential threshold, determining a new transmit power setting for said mobile terminal.

8.   The closed-loop power control method according to claim 5 wherein the signal strength of the received signal is measured over a plurality of frames and wherein the average value of the received signal strength over said plurality of frames is used to calculate the power deviation value.

9.   The closed-loop power control method according to claim 8 wherein the average of the received signal strength is computed over a period of traffic information reception bounded by periods of signaling information transmission.

10.   The closed loop power control method of claim 5 wherein the power setting for the mobile terminal is a power control constant and wherein the transmit power level for the mobile terminal is determined by subtracting the received signal strength from said power control constant.

11.   The closed-loop power control method according to claim 5 further including the steps of receiving a transmitted signal at said mobile terminal, measuring the signal strength of the received signal, calculating at said mobile terminal an adjusted transmit power setting based on said measured receive signal strength and said transmit power setting received from said base station,

and transmitting a signal from said mobile terminal at said adjusted transmit

power setting.

12.   The closed-loop power control method according to claim 11

wherein the signal received at said mobile terminal is transmitted by said base

station in an allocated received timeslot for said mobile terminal.

13.   The closed-loop power control method according to claim 11

wherein the signal received at said mobile terminal is transmitted by said base

station in a timeslot other than the mobile terminal's own allocated receive

timeslot.

14.   An open-loop power control method for controlling the transmit

power level of a mobile terminal in a TDMA communication system, said method

comprising:

g)   receiving signals transmitted from a base station to said mobile

terminal in an allocated receive timeslot of a repetitive TDMA frame

period for said mobile terminal;

h)   when no signal is received in the mobile terminal's allocated

receive timeslot, switching to an alternate timeslot and receiving

signals in said alternate timeslot transmitted from said base station;

i)   measuring the signal strength of the signals received in the mobile

terminal's allocated timeslot and in the alternate timeslot;

j)   adjusting the transmit power level of said mobile terminal based on

the measured signal strength of the signal received in the mobile

terminal's own allocated receive timeslot when a signal is received

therein; and

k)   adjusting the transmit power level of said mobile terminal based on

the measured signal strength of the signal received in the alternate

timeslot when no signal is received in the mobile unit's own

allocated receive timeslot.

15.   The open-loop power control method of claim 14 further including

the step of receiving a first signal in said alternate timeslot, receiving a said

second signal in said alternate timeslot, determining the change in signal

strength between said first and second receive signals in said alternate timeslot,

and adjusting the transmit power level of said mobile terminal based on the

change in signal strength between said first and second signals.

16.   The open-loop power control method of claim 15 wherein said first

signal is compared to a signal of known reference power to obtain a correction

value based on the difference in the signal strength of the two signals, and

applying the correction value to said first and second signals prior to determining

the change in signal strength between the first and second signals.

17.   The open-loop power control method of claim 16 wherein the signal

of known reference power is transmitted on the slow associated control channel.

18.   A method for controlling the transmit power of a mobile terminal in

a trunked radio system comprising:

a)   transmitting an access request message from said mobile terminal

to said base station;

b) receiving said access request message at said base station;

c) transmitting an access grant message from said base station to said mobile terminal, wherein said access grant message includes a channel allocation;

d) transmitting power control information from said base station to said mobile terminal as part of said access grant message;

e) receiving said access grant message and said power control information at said mobile terminal;

f) computing the transmit power level of said mobile terminal based on said power control information transmitted to said mobile terminal by said base station; and

g) transmitting a signal from said mobile terminal to said base station at said computed transmit power level.

19. The method of claim 18 further including the step of:

a) measuring at said mobile terminal to strength of a signal received from said base station; and

b) computing the transmit power level based on the received signal strength measurement.

20. The method according to claim 19 wherein the transmit power level is computed by subtracting the receival signal strength measurement from a power control constant stored in said mobile terminal.

21.   The method according to claim 20 wherein said power control

information is used by said mobile station to adjust the value of said power

control constant.

FIGURE 1

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A TDMA FRAME $\left(\dfrac{240}{26}\text{ mS}=9.23\text{ mS}\right)$

240 mS

1   13   26

S A C C H

| TAIL | 57 DATA | F | 26 BITS SYNCWORD | F | 57 DATA | TAIL |
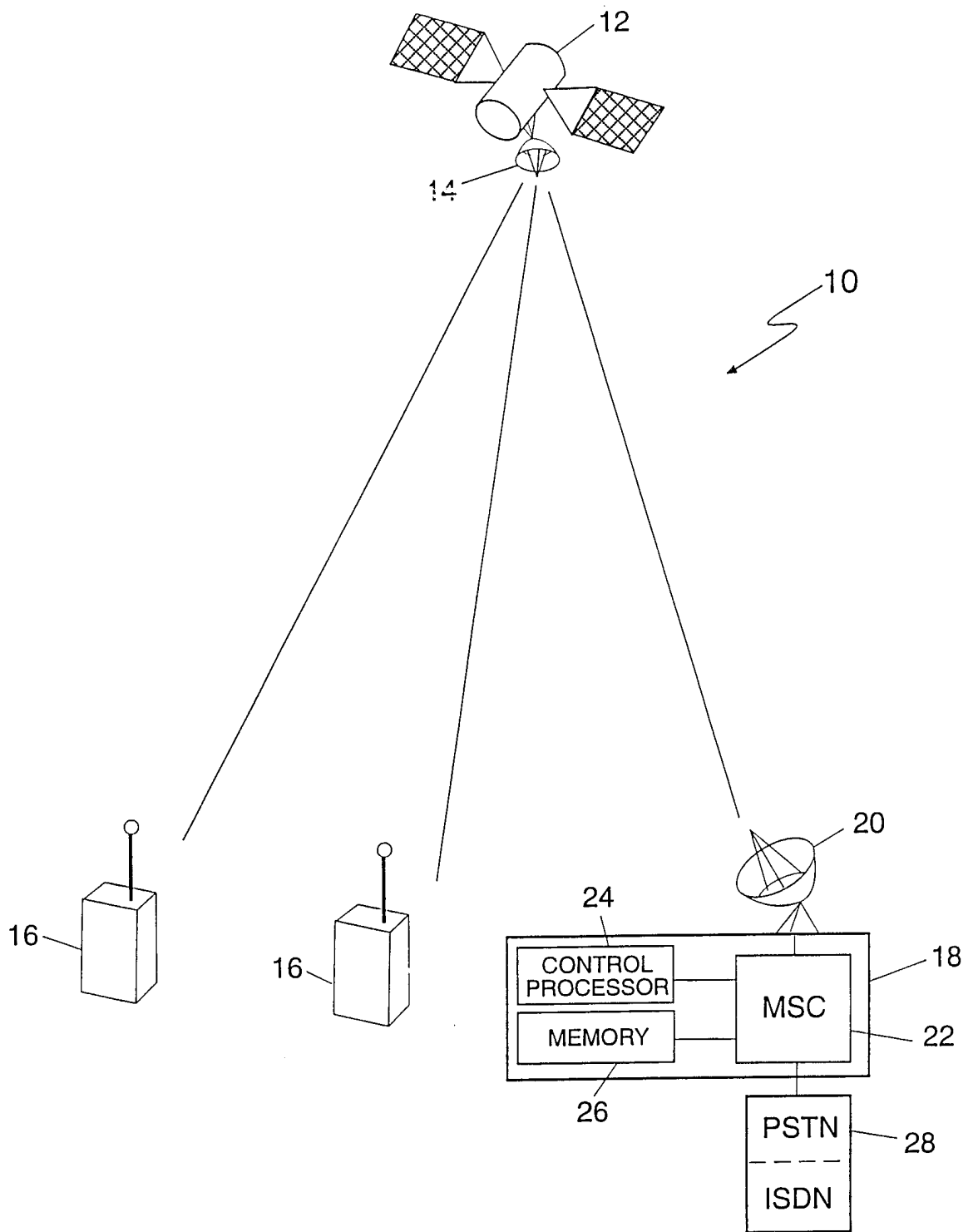
FIGURE 2

FIGURE 3

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FIGURE 4

FIGURE 5
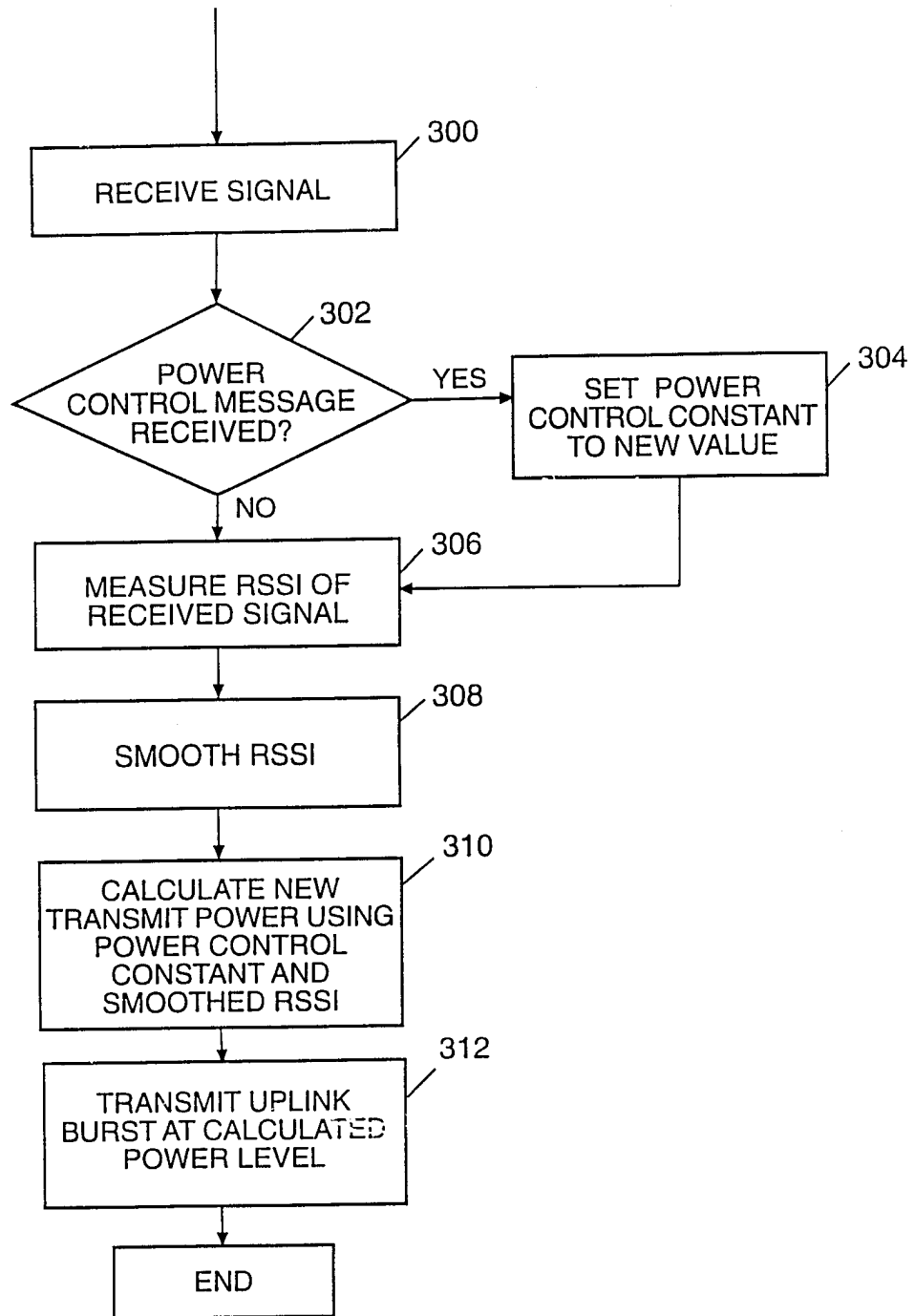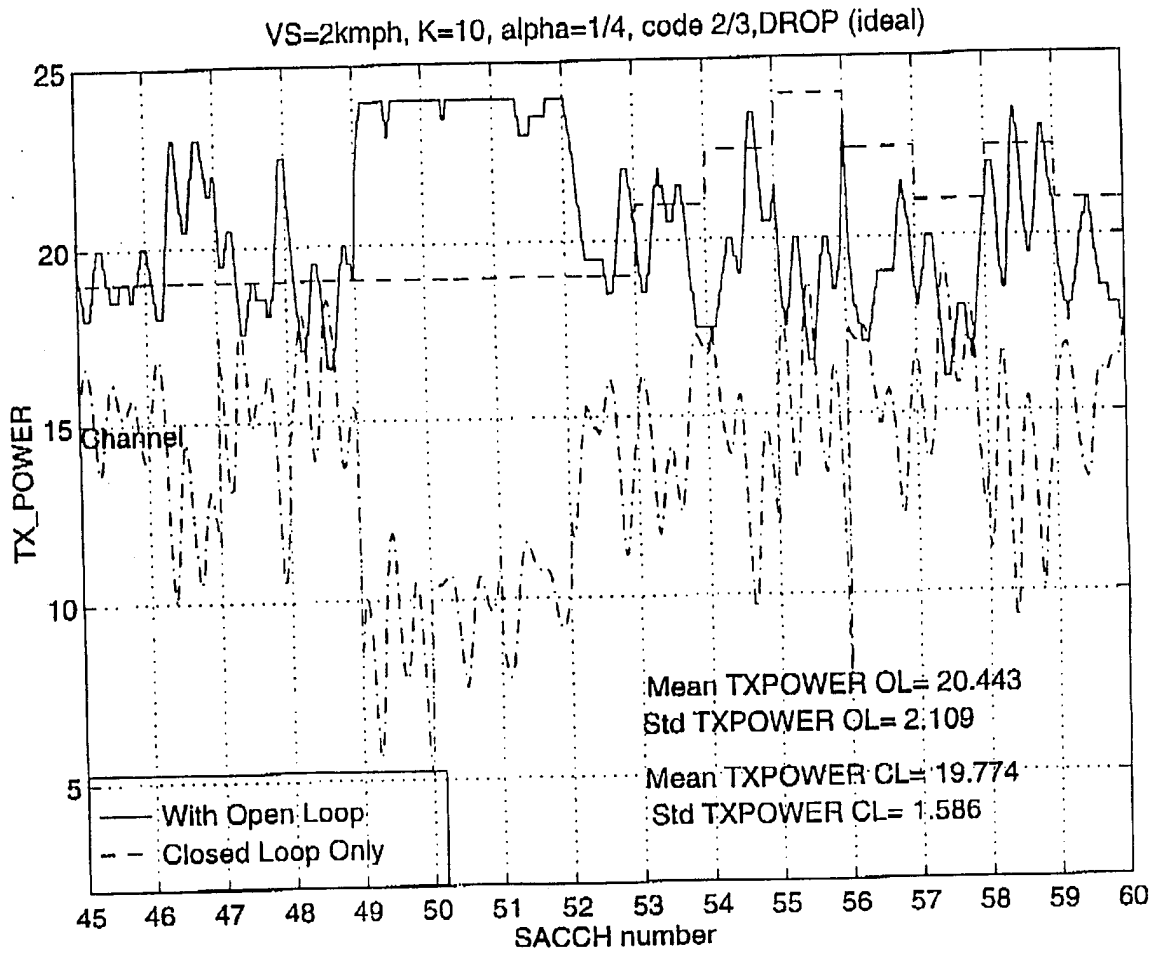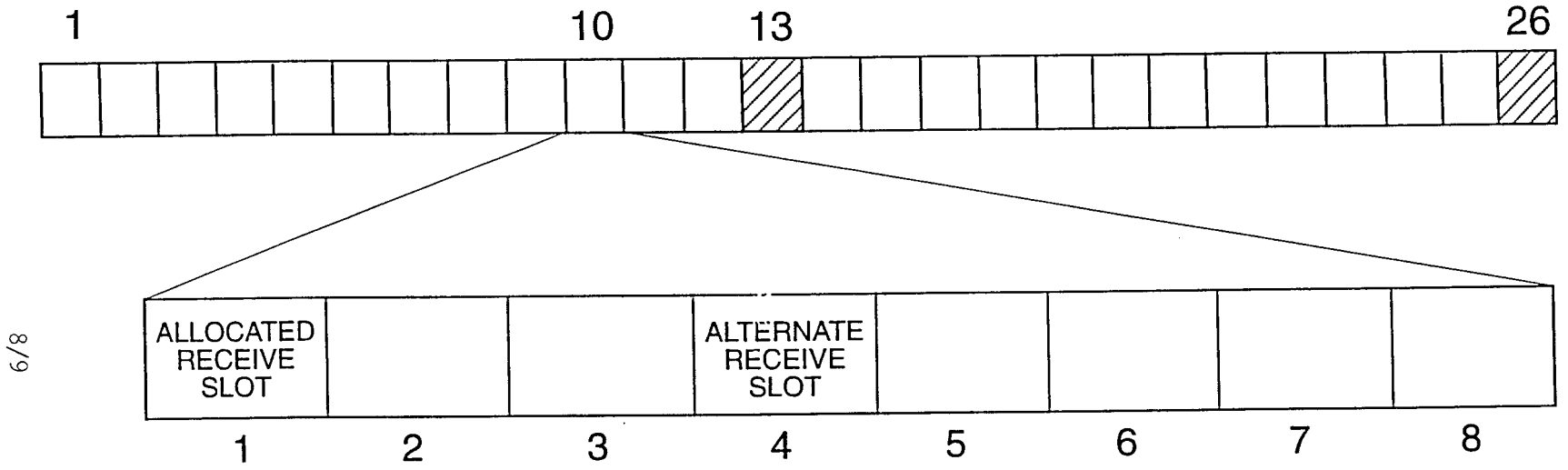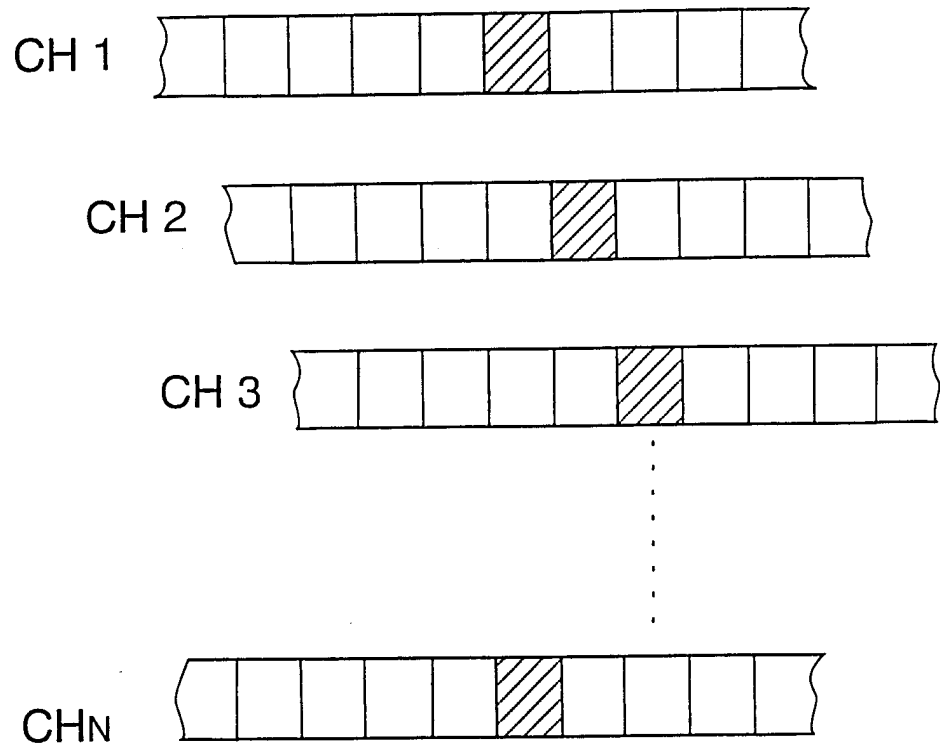
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```
                    ┌─────────────────────┐  ╱ 300
                    │   RECEIVE SIGNAL    │
                    └─────────────────────┘
                              │
                              ▼
                        ╱ 302
                    ╱─────────────╲
                   ╱    POWER       ╲      YES    ┌───────────────────┐ ╱ 304
                  ╱ CONTROL MESSAGE  ╲──────────▶│   SET  POWER      │
                   ╲   RECEIVED?    ╱            │CONTROL CONSTANT    │
                    ╲─────────────╱              │  TO NEW VALUE     │
                         │                       └───────────────────┘
                         │ NO                              │
                         ▼                                 │
                 ┌────────────────────┐ ╱ 306              │
                 │ MEASURE RSSI OF     │◀──────────────────┘
                 │ RECEIVED SIGNAL     │
                 └────────────────────┘
                         │
                         ▼
                 ┌────────────────────┐ ╱ 308
                 │    SMOOTH RSSI     │
                 └────────────────────┘
                         │
                         ▼
                 ┌────────────────────┐ ╱ 310
                 │ CALCULATE NEW       │
                 │TRANSMIT POWER USING │
                 │ POWER CONTROL       │
                 │ CONSTANT AND        │
                 │ SMOOTHED RSSI       │
                 └────────────────────┘
                         │
                         ▼
                 ┌────────────────────┐ ╱ 312
                 │ TRANSMIT UPLINK     │
                 │BURST AT CALCULATED  │
                 │  POWER LEVEL        │
                 └────────────────────┘
                         │
                         ▼
                    ┌─────────┐
                    │   END   │
                    └─────────┘
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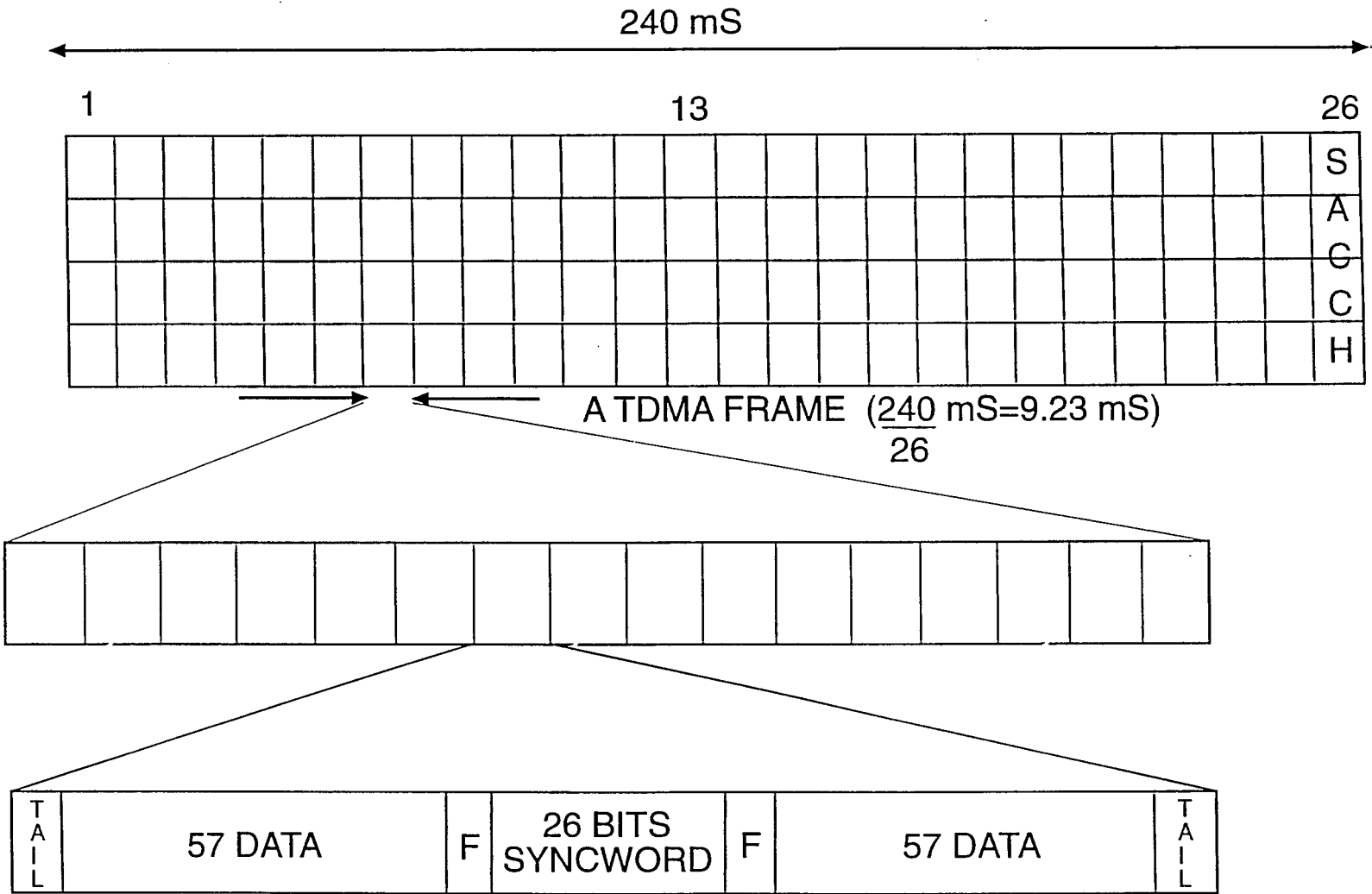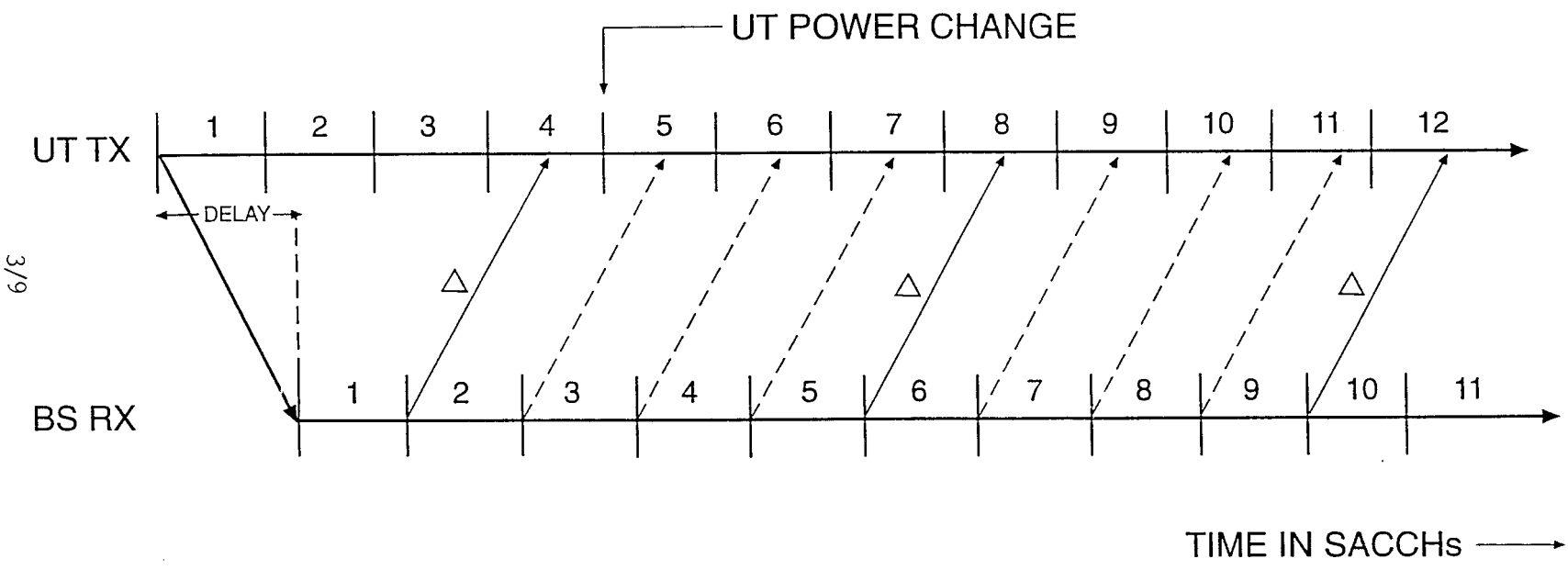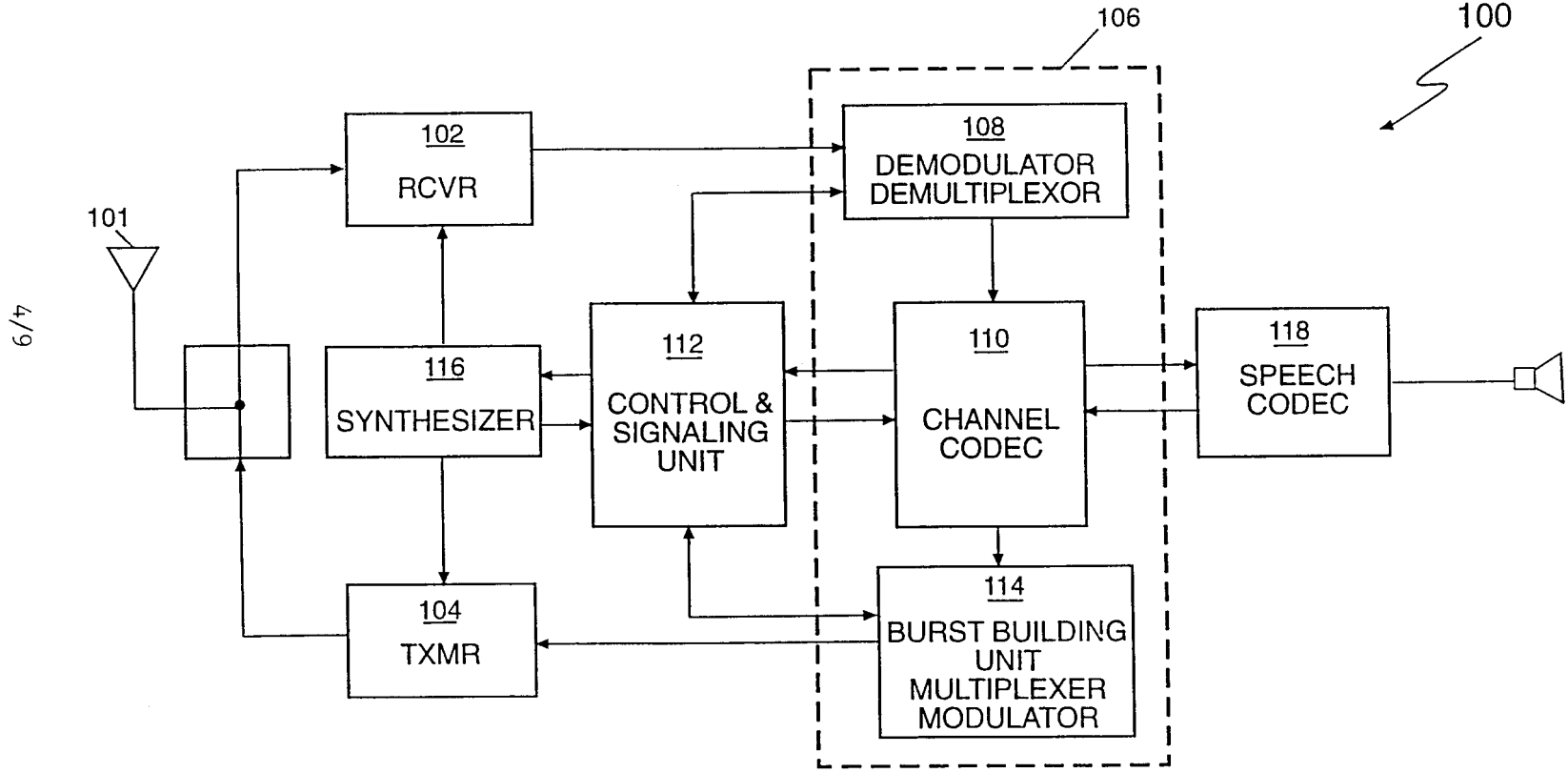
FIGURE 6

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VS=2kmph, K=10, alpha=1/4, code 2/3,DROP (ideal)

Mean TXPOWER OL= 20.443
Std TXPOWER OL= 2.109

Mean TXPOWER CL= 19.774
Std TXPOWER CL= 1.586

FIGURE 7

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ALLOCATED RECEIVE SLOT			ALTERNATE RECEIVE SLOT				
1	2	3	4	5	6	7	8

FIGURE 8

FIGURE 9

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INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04B7/005   H04B7/185   H04Q7/28

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)
IPC 6   H04B   H04Q

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of box C.	[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 September 1998	15/09/1998

Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Dejonghe, O

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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X A	US 5 299 199 A (WILSON TIMOTHY J ET AL) 29 March 1994 see abstract see column 1, line 13-44 see column 1, line 58-68 see column 2, line 37-54 see column 3, line 27-38 see column 3, line 65 - column 4, line 32 see column 4, line 64 - column 5, line 39 see figure 2 see claims ---	18 19-21
A	EP 0 717 508 A (NIPPON TELEGRAPH & TELEPHONE) 19 June 1996 see abstract see column 2, line 16 - column 4, line 35 see figure 3 see claims -----	5,6

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