

APPARATUS AND METHOD FOR OBTAINING FREQUENCY AGILITY
IN TIME DIVISION MULTIPLE ACCESS SYSTEMS

The present invention relates to wireless communication systems wherein a base station is in communication with one or more subscriber stations connected thereto by RF channels in a manner to permit simultaneous communications with the subscriber stations over two or more channels having multiple sequentially repetitive time slots, with particular time slots being assigned to particular subscriber stations.

The present invention provides

means to automatically change either the frequency or the time slot configurations, or both, in the event of the entrance of additional subscriber units which have gone off-hook or in the event of deterioration of transmission quality due to modulation change, frequency channel interference, equipment failure, or the like. The change means includes a remote-connection processing unit and an exchange unit, preferably in the form of a concentrator, which includes a switch that responds to a control signal

from the remote-connection processing unit by physically connecting a selected port in a communication circuit to a selected slot. The control signals are supplied in response to status messages received by the remote-connection processing unit.

The present invention is utilizable in a system such as disclosed in United States Patent Application Serial No. 713,925, filed March 20, 1985 now issued as Patent No. 4,675,863, dated June 23, 1987. Such a system comprises a base station and a plurality of subscriber stations connected thereto by RF channels. It provides for communication between the subscriber stations and an external communication network having a plurality of ports. The base station includes a communication circuit for enabling simultaneous communications between a plurality of the ports and the subscriber stations over two or more communication channels of different frequencies having multiple sequentially repetitive time slots, with predetermined time slots being assigned respectively to predetermined subscriber stations. The system includes a central office terminal (COT) in which is provided a remote-connection radio processing unit (RPU) for directing

communications between the time slot assigned to a given subscriber station and a given port and an exchange for connecting the communication circuit to the ports. The exchange, which is preferably a concentrator of a type
5 hereinafter more fully described, includes a switch which responds to a control signal from the RPU by physically connecting a selected port to a selected communication channel time slot assigned to a given subscriber station.

The communication circuit includes a plurality of
10 channel control units (CCUs) for coupling the assigned communication channel time slot to the corresponding subscriber station in response to a command signal communicated by the RPU to the CCU's over a baseband control channel (BCC). These command signals are in response to status
15 messages provided over the BCC to the RPU to indicate the usage status of the communication channel time slots and the subscriber stations. The assigned communication channel time slot is coupled to the corresponding subscriber station by an assigned time slot in an assigned radio frequency (RF)
20 channel. The BCC is provided over lines separately connected from the RPU to each of the CCU's. Control commands and status messages are communicated between the CCUs and the subscriber stations over a radio control channel (RCC) assigned to a predetermined time slot of a
25 predetermined RF channel.

A primary aim of the present invention is to provide frequency and slot agility to overcome any difficulties in transmissions between the base station and its

associated subscriber units. Another aim of the present invention is to provide the aforesaid agility in a relatively simple and inexpensive manner.

According to the present invention there is provided a
5 communication system for communicating between a base station and one or more subscriber stations, comprising:

one or more subscriber stations in RF communication with a base station;

the base station having two or more RF channels of
10 different frequencies for establishing RF communication between the base station and the one or more subscriber stations, each RF channel having multiple sequentially repetitive time slots;

a time slot assignor capable of assigning a time slot
15 in a different one of said RF channels to a subscriber station already in communication with the base station in response to either the coming on line of an additional subscriber or a deterioration in the transmission between the base station and a subscriber station.

20 The various other aims and attendant advantages of the present invention will be readily apparent from the following detailed description when read in conjunction with the following drawings wherein:

Fig. 1 is a block diagram of a base station utilized in
25 the present invention, the connected subscriber stations being generally indicated.

Fig. 2 is a block diagram of a single subscriber unit embodying the present invention.

Fig. 3 is a block diagram of a dual subscriber unit embodying the present invention.

Fig. 4 is a block diagram of a multiple single-subscriber unit embodying the present invention.

Fig. 5 is a block diagram of a multiple dual-subscriber unit embodying the present invention.

Fig. 6 is illustrative of a radio processing unit matrix embodying the present invention.

Fig. 7 is a block diagram showing the details of a channel module utilized in the present invention.

Fig. 8 is a block diagram of a radio processing unit and its connecting elements embodying the present invention.

Fig. 9 is a functional illustration showing the layers of communication between the base station and a subscriber station.

GLOSSARY OF ACRONYMS

BCC	baseband control channel
BER	bit error rate
CCT	channel control task
CCU	channel control unit
CO	central office
COT	central office terminal
CRC	cyclic redundancy check
DBM	data base module
LQ	link quality
MF	malfunction
MPM	message processing module
MTU	master timing unit
MUX	multiplexer
PCM	pulse code modulation
RCC	radio control channel
RF	radio frequency
RPU	radio processing unit
RRT	remote radio terminal
SCT	subscriber control task
SDLC	synchronous data link control
SM	scheduler module
VCU	voice codec unit

Referring to the drawings wherein similar reference characters refer to similar parts, there is shown in Fig. 1 a base station, generally designated 10 which includes a central office terminal (COT), generally designated 12 and a remote radio terminal (RRT), generally

designated 14. The COT 12 includes a radio processing unit (RPU) 16 coupled through an interface 18 to an exchange unit 20. The exchange is preferably in the form of a concentrator such as "Model 1218C" digital image concentrator provided with a switch, which is presently available from
5 ITT corporation, New York, New York, U.S.A.

The exchange 20 is in circuit with the central office (CO) 22 over a plurality of two-wire appearance lines 24 and is also in circuit, via echo cancellers 26 and a
10 plurality of span trunks 28, with a plurality of multiplexers (MUX's) 30 coupled to a master timing unit (MTU) 32 in the remote radio terminal 14. Each of the span trunks 28 carries a plurality of multiplexed time slots provided by its respective MUX 30. A baseband control channel (BCC) 34,
15 which occupies one of the time slots on one of the span trunks 28, provides communication between the MUX's 30 and the channel modules 36.

Each MUX 30 is embodied in a modular card that is capable of handling up to 24 pulse code modulation (PCM) simultaneous circuits or 23 PCM simultaneous circuits plus
20 the BCC. The MUX's act to extract the data from the trunks 28 and to distribute it to the channel modules 36 that are in circuit with the transmitter receiver network 38 via power amplifier 40.

25 The RPU 16 has ultimate control of both the exchange (concentrator) 20 and the RRT 14 and acts to process subscribers' requests to set up the required transmission path between the subscriber stations, indicated generally at 42, and the central office (CO) 22.

The subscriber stations 42 may each comprise either a single subscriber unit, a dual subscriber unit or a multiple subscriber unit. Fig. 2 shows a single subscriber unit that comprises a transceiver 50 coupled between an antenna 52 and modem 54 that is in circuit with a codec 56 for encoding or decoding signals to and from a subscriber set 58. In Fig. 3, the same general type of unit is shown except that it comprises a dual subscriber unit in which the antenna 60, transceiver 62, modem 64 and codec 66 are in circuit through buffers 68 and 70 with separate subscriber sets 72 and 74.

In the dual subscriber unit of Fig. 3, if two conversations are transmitted and received in one slot, the transceiver, modem and codec may be single reversible elements that only have to perform one set of operations at a time, e.g. transmit or receive over each line. Furthermore, since the unit is never receiving and transmitting at the same time, no duplexer is required since the only duplication that takes place is through the buffers 68 and 70 which are connected to interface circuitry (not shown) for the subscriber sets.

In Fig. 4 there is shown a multiple system of single subscribers that comprises a combining, deploying and duplexing network, generally indicated at 80, coupled to an antenna 82 and to a multiplicity of single subscriber units 84a, 84b, 84n. Each subscriber unit is coupled to a respective subscriber set indicated at 86a, 86b and 86n.

Fig. 5 shows the same type of multiple system as in Fig. 4 except that the network 88 is coupled to dual

subscriber units 90, 92, 94, etc., each of the type shown in Fig. 3 and each being coupled to respective dual subscriber sets, as at 96 and 98, for unit 90, at 100 and 102, for unit 92 and at 104 and 106 for unit 94.

5 During a conversation, some problems may arise due to various factors which may generally be classified as follows: (a) multisubscriber configuration, (b) modulation change (c) interference avoidance and (d) equipment failure of an individual channel.

10 Fig. 6 illustrates an example of an RPU matrix where the various subscribers are designated by the letters A through G, the horizontal rows representing frequencies and the vertical columns representing slots. The number "1" represents "in use" and "0" represents "not in use". In
15 this matrix only the transmit slots need to be stored (as shown) since receive slots are always offset by 2 slots.

 During operation, it frequently occurs that all four slots of a particular frequency are occupied by various subscribers. Assume, for example, that there is one dual
20 subscriber unit while the others are single subscriber units. In the case of the dual subscriber unit it is necessary that the two dual subscribers thereof be in adjacent slots. If one of the two dual subscribers is occupying a particular frequency and slot while the other slots in that
25 frequency are occupied by other single subscribers, and if the other of the two dual subscribers requires a connection because he has either gone off-hook to make a call or an incoming call is to be routed to him from the central office, either the single subscriber in the adjacent slot of

that frequency must be moved to another frequency and/or slot to make room for the second of the two dual subscribers or the first dual subscriber occupying the particular frequency and slot must be moved to another frequency where an adjacent slot is available. The RPU, in this situation, acts to set up the current connections and store them in its memory and it can, therefore, determine where within the matrix a transfer can be effected.

The above type of transfer is accomplished in the following manner: Assume, for example, that the first of the dual subscribers is currently engaged in a conversation on frequency D in transmit slot 1 (receive slot 3). When the second of the dual subscribers goes off-hook, an alert signal (one bit) is sent back to the base station as part of the control bits transmitted in addition to the conversation. The alert bit is detected in the channel module 36 which then sends a message back to the RPU 16 via the MUX 30, span trunk 28, exchange 20 and interface 18, either along with the reverse conversation path or along a separate path. Conversely, an incoming signal from the control office (CO) 22 is routed through the exchange 20 and interface 18 to the RPU 16.

In the event of the occurrence of either signal, e.g. from the off-hook set or from the central office, a slot must be made available for the second of the dual subscribers to connect to the base station in a slot adjacent to the slot already in use by the first of the dual subscribers. While it would be possible to move the first dual subscriber from frequency channel D to G, that would be

the less preferable move since two empty adjacent slots on the same frequency are not often available. It is, in any event, at least as easy to move the adjacent single subscriber unit from frequency D, slot 2 to a different frequency. In the example shown, the adjacent subscriber could be moved to any one of the eight open slots. Since the single subscriber being moved does not require adjacent slots for transmission and reception, if the move is made in frequency only (e.g. from channel D to B or G) it can be accomplished while the slot is unused and is, therefore, glitchless. If a change is made in both slot and frequency, then one slot's worth of transmission data is either duplicated or lost.

The analagous situation exists with multiple single unit subscribers, such as in Fig. 4. Since each unit has a complete set of elements, more than one unit is capable of transmitting at one time. It is, in fact, preferable to have all transmit simultaneously and receive simultaneously in order to prevent receiver front-end overload. Therefore, in the matrix of Fig. 6, if two subscribers are occupying slot 1 on frequencies B and D and a call set-up is required for a third subscriber, then the RPU 16 must assign the third subscriber to slot 1 on either frequency F or G.

Where the system is that of Fig. 5, where there are multiple dual subscriber units, the first subscribers of each pair of dual subscribers must be in the same slot but on different frequencies while the second of each pair must be in adjacent slots on the same frequencies as their respective first subscribers.

The RPU, in the above situations, acts to set up the current connections at each interval of time and stores them in its memory. It can, therefore determine, at any time, where within the matrix a transfer can be effected.

5 In all of the above situations where the concern is with the assignment of slots and frequencies in multi-subscriber situations, the stimulus for change originates outside the base station (either from the central office or the subscriber set). In the following situations which involve modulation change due to fading, or interference avoidance or change due to equipment failure, the stimulus originates or is detected in the base station itself.

15 In the base station, each channel module 36, as shown in Fig. 7, includes a channel control unit (CCU) 110 and a modem 112, each being coupled to a voice codec unit (VCU) 114 by respective compressed data link 116 and control status link 118. The VCU is interfaced to the MUX 30 by pulse code modulation (PCM) data channels 120, while the CCU is interfaced with to the MUX 30 by synchronous data link control (SDLC) 122.

20 A number of buffers (not shown) are associated with the various elements. In this respect, each channel module contains an AGC buffer for each slot as well as a link quality (LQ) buffer that measures the differential of received phase error. In addition, the VCU is provided with a bit error rate (BER) buffer. A cyclic redundancy check (CRC) is transmitted as part of each conversation encoded burst which provides a BER count to the BER buffer.

For the present purposes, a high AGC level means that a high signal level is being received and the receiver gain is small. Conversely, a low AGC level indicates a low received signal level and a large receiver gain. This AGC level is used to indicate whether a deterioration of signals is due to fading of the signal or whether there is interference. Interference is indicated by a higher AGC level because the AGC level is based on the sum of the transmitted signals plus any interfering signals. In either instance correction can be made by modulation change. In this respect, as more fully described hereinafter, each channel module 36 contains a modem that is capable of transmitting and receiving on voice slots with either 16 or 4 phase modulation. There are only half as many bits passed per symbol in 4 phase modulation as there are in 16 phase modulation, but the bit rate is the same. Therefore, when 4 phase modulation is used, two adjacent slots, as shown in the matrix of Fig. 6, are combined into one elongated slot containing the same number of bits per elongated slot as would occur in a slot during 16 phase operation.

When, for example, a dual subscriber system is in operation, if either the BER increases beyond a certain threshold (e.g. 0.1%) or the LQ decreases below a certain threshold (e.g. 6 degrees) the contents of the corresponding buffers are reported to the RPU via the MUX-span-exchange(concentrator)-interface link. The RPU thereupon sends a control signal back via the same linkage to the control module to change from 16 to 4 phase operation. At the same time, if two subscribers are currently in operation in adjacent slots on the same frequency, one of the sub-

scribers is changed to another frequency in the manner described above.

5 If, after the modulation level has been changed in the above manner, the AGC level is still high for that particular subscriber, it is assumed that the reason for the poor BER and LQ is interference rather than transmission fade. The outputs of all the AGC buffers are reported to the RPU which determines which frequencies (if any) have a low AGC level and the RPU then initiates a change in frequency for that subscriber from the frequency with a high AGC level to one having a low AGC level. This acts to eliminate the interference if it is present.

15 The base station is also provided with malfunction (MF) buffers which provide the operational status of each link in the base station chain including the exchange (concentrator), span trunk, MUX, channel module, power amplifier, transmitter and receiver. If the MF buffer senses a malfunction or equipment failure, a signal is sent to the RPU indicating which frequency is involved. On receipt of this MF signal, the RPU initiates a frequency (and, if necessary, a slot) change for each conversation (if any) currently taking place on the affected channel.

20 The RPU 18 is a primary element in controlling the assignment of frequency channels and slots and its general structure is shown in Fig. 8. It comprises a message processing module (MPM) 130 coupled to a data base module (DBM) 132 and a scheduler module (SM) 134. The MPM manages all interface between the SM and DBM within the RPU as well as with the channel control unit (CCU) 110 and a subscriber

control task (SCT) 136 situated outside the RPU. The CCU is located within the channel module 36, as shown in Fig. 7, while the SCT is in circuit with the subscriber stations.

In operation, if, for example, during a call, the link quality (LQ) goes down below a predetermined level, the RPU is actuated to send a message to the SCT 128, which, thereupon, communicates with the MPM 122. The MPM then (a) sends a signal to the DM 124 to identify an available channel, and (b) checks with the scheduler module 126 for schedule control and timing (the scheduler module serving to arrange the messages received by it in the order that they are received). If there is an available channel, the MPM sends a message back to the SCT to reconfigure the matrix to move the call to the available channel. If there is no available channel, the call is retained in the same channel.

If during a call, all four slots are occupied but, because of an interference on a particular frequency, it is necessary to move all the subscribers to another frequency with the same respective slots, the following sequence occurs: The RPU, upon being actuated by the lowering of the link quality, sends a message to the SCT requesting a frequency change. The SCT forwards that message to the channel control task (CCT), located at the subscriber station, for frequency change processing, and also communicates with the MPM at the base station for allocation of an available CCU channel. The MPM sends a signal to the DBM to identify an available channel and also checks with the scheduler module to obtain a time position in the schedule. If there is an available channel, the MPM sends a message back to the SCT

to reconfigure the channel position. If there is no available channel, the SCT sends a busy signal to the RPU and no change is made.

Fig. 9 illustrates the RCC protocol. The RPU 16 is in communication with the CCU 110 and modem 112. At the subscriber station the SCT 136 is in communication with the CCT 138 which is provided with modem 140. The RCC protocol consists of two layers, a data link layer 142 and a packet layer 144. The data link layer is the physical link between the parts while the packet layer comprises the messages being passed over this physical link. The data link layer is responsible for error detection, word synchronization and framing, detection and resolution of collisions (conflicting contention for the same time slot on the same RF channel).

Referring to Fig. 9, an an example, the RPU processes two paths of protocol: In the first protocol, the RPU sends a message to the CCU at the base station to request a modulation change. In the second protocol, the RPU sends a message to the SCT to request a frequency change. In the third protocol, the SCT sends a message back to the RPU to indicate that all channel frequencies are occupied.

In another example, the RPU sends a message protocol to the SCT to request a channel frequency change. This message initiates two functions: First, the message requests that the SCT at the subscriber station obtain a route to another frequency from the RCC. The SCT thereupon communicates with the CCT. The CCT then searches the channels and, when it finds an available slot and frequency, it switches thereto. In the second function, the message

protocol causes the SCT to call the central office to stand by for a connection.

5 If, during a conversation, the link quality falls below a predetermined level, the RPU forwards this information to the CCU and requests a modulation level change. The CCU acknowledges this message through the SCLC link via the MUX to the RPU.



CLAIMS

1. A communication system for communicating between a base station and one or more subscriber stations, comprising:

5 one or more subscriber stations in RF communication with a base station;

the base station having two or more RF channels of different frequencies for establishing RF communication between the base station and the one or more subscriber
10 stations, each RF channel having multiple sequentially repetitive time slots;

a time slot assignor capable of assigning a time slot in a different one of said RF channels to a subscriber station already in communication with the base station in
15 response to either the coming on line of an additional subscriber or a deterioration in the transmission between the base station and a subscriber station.

2. A communication system as claimed in claim 1, wherein:

20 the time slot assignor makes assignments when directed by a control command signal; and

the communication system further includes:

a control command signal generator that generates control command signals in response to status messages that
25 indicate the usage status of the time slots in relation to the one or more subscriber stations; and

a radio control channel that is assigned to a selected time slot in an RF channel for transmitting the control command and status messages from the base station to the one
30 or more subscriber stations.

3. A communication system as claimed in claim 2, wherein the communication system further includes a radio processing unit for transmitting the command control and status
35 messages to the one or more subscriber stations, with the radio processing unit being in communication with a central office and with the base station.



4. A communication system as claimed in claim 1, wherein a deterioration in transmission between the base station and a subscriber station is based on frequency channel interference, or an equipment failure.

5

5. A communication system as claimed in claim 1, wherein one or more single subscriber stations are in RF communication with the base station.

10 6. A communication system as claimed in claim 1, wherein one or more dual subscriber stations are in RF communication with the base station, and the time slot assignor assigns each pair of dual subscriber stations to adjacent time slots.

15

7. A method for forming a communication link between a base station and a plurality of subscriber stations with a communication system as claimed in claim 1, comprising assigning a subscriber station already in communication with
20 the base station to a vacant time slot in a different one of said RF channels according to its adjacency to an occupied time slot in response to an additional subscriber coming on line or to deterioration in the transmission between the base station and a subscriber station or in response both
25 to an additional subscriber coming on line and to deterioration in the transmission between the base station and a subscriber station.

8. A method as claimed in claim 7, wherein deterioration
30 in transmission is based on frequency channel interference, or equipment failure.

9. A method as claimed in claim 7, wherein time slot
35 assigning is carried out during conversations between a subscriber and another entity using an RF channel that establishes communication between a subscriber station and the base station.
