

METHOD AND APPARATUS FOR MOBILE STATION-TO-MOBILE STATION CALLS IN A MOBILE SATELLITE COMMUNICATIONS SYSTEM WITH ON-BOARD TDMA FORMAT CONVERSION.

FIELD OF THE INVENTION

The present invention relates to time division multiple access (TDMA) communication systems and, more specifically, to TDMA communication systems with asymmetrical TDMA frame structures.

BACKGROUND OF THE INVENTION

Cellular telecommunications is one of the fastest growing and most demanding telecommunication applications ever. Today it represents a large and continuously increasing percentage of all new telephone subscriptions around the world.

In Europe and in North America, there are several large analog cellular systems operating such as NMT (Nordic Mobile Telephone) in the Nordic countries, TACS (Total Access Communication System) in the United Kingdom, and AMPS (Advanced Mobile Phone System) in the United States. Quality, capacity and area of coverage vary widely, but demand has outstripped estimates almost universally. To address the capacity limitations of the existing analog cellular systems, many operators are migrating to digital cellular systems. Digital cellular systems are generally classified as either TDMA, CDMA (Code-Division Multiple Access), or hybrids thereof. TDMA systems, such as the pan-European GSM (Groupe Spécial Mobile, or Global System for Mobile communication) system and D-AMPS (Digital Advanced Mobile Phone System) in the United States, provide increased capacity by dividing each frequency band into time slots, multiple users being allocated a different timeslot on the same frequency. CDMA systems, on the other hand, provide increased capacity by allowing multiple users to operate simultaneously across the same frequency range through the use of orthogonal spreading codes. In the long-term perspective, cellular systems using some form of digital technology will become the universal way of communication.

TDMA systems, such as GSM and D-AMPS, are currently the most widely deployed digital cellular systems. In GSM, for example, each frequency is divided into 8 timeslots. As shown in Figure 1, base station 100 broadcasts a signal on frequency F1 to mobile station

120a on timeslot 2 and to mobile station 120b on timeslot 5. Up to eight mobile stations may be accommodated on a single frequency. Signals transmitted from base station 100 to the mobile stations 120a, 120b, are called the downlink signals, or more simply, the downlink. For two-way communication, there must also be a corresponding set of frequencies and timeslots in the opposite direction which are called the uplink signals, or more simply, the uplink. Generally, TDMA systems employ a symmetrical frame format, that is, the TDMA frame structure (i.e., bandwidth, number of timeslots, data rates, etc.) is the same on the uplink as it is on the downlink.

Recently, there have been proposals to construct a mobile satellite communication system employing orbiting satellites in place of, or to supplement coverage from, terrestrial base stations. Generally, mobile satellite communication systems employ a satellite which is in low earth orbit (LEO), intermediate circular orbit (ICO), or geostationary earth orbit (GEO). A ground station serves as the gateway between the satellite and the public switched telephone system (PSTN), or a terrestrial cellular system. Ideally, the satellite functions as a "bent pipe", that is, the satellite is a transponder, relaying signals received from a mobile station down to a ground station and, similarly, relaying signals received from the ground station to the mobile station. Often, a frequency translation in the satellite is required as communications between the ground station and the satellite occur across a different frequency range (e.g. C-band, Ku-band) than do the communications between the satellite and the mobile stations (e.g. L-band). It is generally desirable to design the system such that the satellite has a simple architecture.

TDMA may be used to increase the capacity of communications between the satellite and the mobile stations. As mentioned, TDMA formats are generally symmetrical, that is, the uplink and the downlink have the same TDMA timeslot structure. However, for reasons of performance, the uplink TDMA structure could be different than that of the downlink TDMA structure, that is, the bandwidth, number of timeslots, and data rates may differ significantly between the uplink and downlink.

Where mobile station to mobile station communications are required, passing through the ground station to effect the mapping between asymmetric TDMA formats results in unacceptable time delays. Normally, in an ICO system, the time delay experienced in a connection between the PSTN, or terrestrial cellular network, and a mobile station in communication with the satellite is on the order of 400 milliseconds, which is perceptible to the users, but not quite a hinderance to normal conversation. Where a link between two

mobile stations is effected through the ground station, the delay can be as much as 1.2 seconds which results in an unacceptable hinderance to normal conversation.

SUMMARY OF THE INVENTION

The aforementioned problem of reducing the time delay in a mobile satellite communications system is solved in accordance with the present invention.

A method is presented in which a satellite is conditioned to map uplink signals having a first TDMA format which are received from a mobile station to downlink signals having a second TDMA format for transmission to another mobile station.

A first mobile station transmits a first signal to a satellite, the first signal having a first TDMA format. The satellite receives the first signal and downconverts the first signal to produce a first IF signal having a first bandwidth, BW. The first IF signal is sampled by an analog to digital converter at a rate of $N \times BW$ where N is an integer greater than or equal to 2 to produce an input bitstream. The input bit stream is coupled to a buffer which receives and stores the input bit stream. The buffer clocks a bit stream out at a rate $M \times N \times BW$, where M is an integer value greater than 1 to produce an output bitstream with a bandwidth equal to $M \times BW$ and a second TDMA format. The output bitstream is coupled to a low pass filter, upconverted and rebroadcast as a second signal, having a second TDMA format, to a second mobile station.

These and other features and advantages of the present invention will be readily apparent to one of ordinary skill in the art from the following written description when read in conjunction with the drawings in which like reference numerals refer to like elements.

Brief Description of the Drawings

An exemplifying embodiment of the invention will now be described in more detail with reference to the accompanying drawings, in which:

Figure 1 illustrates the downlink of a terrestrial TDMA cellular communications system;

Figure 2 illustrates a mobile satellite communication system in which the present invention may be advantageously employed;



Figure 3 illustrates a mobile station-to-mobile station communications link in a mobile satellite communications system;

Figure 4 is a block diagram of satellite 200 illustrating in detail the circuits for for converting a first TDMA format to a second TDMA format; and

Figure 5 is a block diagram illustrating in greater detail the function of the elastic buffer.

DESCRIPTION OF THE INVENTION

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular circuits, circuit components, techniques, etc. in order to provide a thorough understanding of the invention. However it will be apparent to one of ordinary skill in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods, devices, and circuits are omitted so as not to obscure the description of the present invention with unnecessary detail.

In Figure 2 is shown a mobile satellite communications system. In the present invention, satellite 200 is situated in an intermediate circular orbit (ICO) (*i.e.*, approximately 10,000 kilometers above the earth.) Feeder links 205a and 205b are transmitted to, or received from, satellite 200 via dish antenna 215 which is part of ground station 220. Ground station 220 functions as a gateway between satellite 200 and the public switched telephone network (PSTN) 225, or mobile telephone switching office (MTSO) 235. Access to MTSO 235 may be effected through PSTN 225 or directly to ground station 220 through a dedicated link 240. PSTN 225 routes calls to the landline telephone network in the usual manner and calls to cellular telephones are effected through MTSO 235 in the usual manner.

Satellite 200 is intended to provide coverage to mobile users 120 who are located beyond the coverage area of the terrestrial cellular network 100. Mobile station 120 may be a car-mounted cellular telephone as shown in Figure 2, a hand-held cellular telephone, a wireless modem installed in a laptop computer, or generally any radio communications device.

In the following, telephone calls, communication links, calls, data links, links and conversations, all refer to the establishment of a communications link over which voice, data, video, or any other information may be exchanged. The originator of a call refers to the device from which a call is initiated, and the receiver of a call refers to the device with which the originator wishes to communicate. With regard to the flow of information during a call, the forward uplink refers to the uplink to the satellite from the originator of the call; the forward downlink refers to the downlink from the satellite to the receiver of the call; the reverse uplink refers to the uplink back to the satellite from the receiver of the call; and reverse downlink refers to the downlink from the satellite back to the originator of the call.

Telephone calls which originate from PSTN 225 or MTSO 235 are routed to ground station 220 where they are processed and subsequently transmitted to satellite 200 via forward uplink 205a according to known techniques. Satellite 200 receives forward uplink 205a and frequency translates the forward uplink to another frequency/format which is then transmitted to mobile station 120 over forward downlink 210b. Frequency translation is usually required because the forward uplink and forward downlink usually operate in different frequency ranges. In this embodiment, for example, forward uplink 205a is transmitted to satellite 200 in C-band; forward downlink 210b is transmitted from satellite 200 in L-band; reverse uplink 210a is transmitted from mobile station 120 in L-band; and reverse downlink 205b is transmitted from satellite 200 in C-band. Signals transmitted from mobile station 120 over reverse uplink 210a are received by satellite 200 which, as before, frequency translates and re-formats the reverse uplink signal for transmission to ground station 220 over reverse downlink 205b. With an ICO satellite, the propagation delay between ground station 220 and mobile station 120 (and vice-versa) is on the order of 400 milliseconds. It is obvious to one skilled in the art that a mobile satellite communications system as illustrated in Figure 3 may comprise several ground stations 220, more than one satellite 200, and hundreds, or thousands, of mobile stations 120.

The mobile satellite communications system may employ a TDMA format similar to that shown in Figure 1. Indeed, so that existing hardware may be re-used, it is advantageous to employ a TDMA format which is compatible with existing digital cellular systems. Use of a GSM format, for example, on the forward downlink 210b allows mobile station 120 to re-use the existing IF (intermediate frequency) receiver

circuits and A/D (analog to digital) converters with minor modification for communication with satellite 200. For the present invention, a GSM format with 200kHz channel spacings and 32 or 16 timeslots per TDMA frame is employed. By having a variable timeslot architecture, the forward downlink 210b can accommodate two different speech coder rates (i.e., 4 kbps, or half-rate GSM), or alternatively two different channel coding rates (i.e., 1/3, or 2/3).

On the reverse uplink 210a, use of the downlink TDMA format is precluded due to peak transmit power limitations of mobile stations, particularly battery-operated, hand-held mobile stations. For reasons of user safety and to prolong battery life, the peak power transmitted on reverse uplink 210a is desired to be less than 2 Watts with an average power of approximately 250 milliWatts to 500 milliWatts. With a peak power of 2 Watts, the duty cycle needed to achieve the aforementioned average powers is easily calculated to be 0.125 to 0.25 respectively which results in an 8/4 timeslot TDMA frame structure. Therefore, an asymmetrical TDMA format is advantageously used in the present invention. To assist in synchronization between forward downlink 210b and reverse uplink 210a, and to keep the overall system complexity as low as possible, the bandwidth of the reverse uplink 210a is an integer fraction of the bandwidth of the forward downlink 210b. The present invention therefore employs a 50kHz bandwidth on the reverse uplink 210a. In the following the downlink TDMA format refers to 200kHz channels spacings having a 32/16 timeslot TDMA frame, whereas the uplink TDMA format refers to 50kHz channel spacings having a 8/4 timeslot TDMA frame.

In addition to calls originating from, or terminating in, PSTN 225 or MTSO 235, the mobile satellite communication system must also be able to provide mobile station-to-mobile station communications. One method of providing mobile station-to-mobile station communication in a mobile satellite communication system using an asymmetrical TDMA format requires use of ground station 220 to perform the mapping from the uplink TDMA format to the downlink TDMA format. For example, referring to Figure 3, if mobile station 300b is the originator and mobile station 300a the receiver of a call, mobile station 300b transmits over forward uplink 310a using the uplink TDMA format. Satellite 200 frequency translates forward uplink 310a and broadcasts forward downlink 305b. Forward downlink 305b is received by ground station 220 where the uplink TDMA format is mapped to the downlink TDMA format and broadcast back to satellite 200 over reverse uplink 305a. Satellite 200 frequency translates the reverse

uplink 305a and broadcasts reverse downlink 310d to mobile station 300a using the downlink TDMA format. The cumulative propagation delay between mobile station - to satellite - to ground station - back to satellite - and down to mobile station may be as much as 1 second including the processing and propagation delays through ground station 220. Such a lengthy delay is unacceptable for two way voice communication.

In the present invention, the mapping from the uplink TDMA format to the downlink TDMA format is performed in satellite 200. For example, if mobile station 300b is the originator and mobile station 300a the receiver of a call, mobile station 300b broadcasts forward uplink 310a using the uplink TDMA format to satellite 200; satellite 200 processes the forward uplink signal as shown in Figure 4 which converts the uplink TDMA format to the downlink TDMA format and broadcasts forward downlink 310d using the downlink TDMA format to mobile station 300a. Similarly, mobile station 300a broadcasts reverse uplink 310c using the uplink TDMA format to satellite 200, satellite 200 processes the reverse uplink as shown in Figure 4 which converts the uplink TDMA format to the downlink TDMA format and broadcasts reverse downlink 310b using the downlink TDMA format to mobile station 300b. By mapping the uplink TDMA format to the downlink TDMA format in satellite 200, the round trip delay can be more than cut in half over the aforementioned method of providing mobile station-to-mobile station communications via ground station 220.

The apparatus for mapping the uplink TDMA format to the downlink TDMA format is shown in Figure 4 which is a more detailed illustration of satellite 200. Satellite 200 comprises, inter alia, antenna 400 which, in this example is an L-band antenna, and processing circuitry for effecting the conversion from uplink TDMA format to downlink TDMA format. Satellite 200 may also have a separate C-band antenna (not shown) for communicating the ground station 220, attitude control circuitry (not shown), solar panels and/or batteries (not shown), and various other spacecraft management circuits.

Referring to the mobile station-to-mobile station communications link shown in Figure 3 where mobile station 300b is the originator and mobile station 300a the receiver of a call, forward uplink 310a is received at satellite 200 by antenna 400. Forward uplink is, as previously mentioned, an L-band signal having 50kHz (i.e., BW is 50 kHz) channel spacing and 8/4 timeslots. Referring to Figure 4, the received forward uplink signal is coupled to downconverter 405 which filters, amplifies, and mixes the

received signal to produce a first IF signal according to known techniques. The first IF signal is passed through a 50 kHz anti-aliasing low-pass filter 410 and coupled to A/D converter 415 where the first IF is sampled at a sampling rate of $N \times BW$. Preferably, the integer N is greater than 2, so the first IF is being oversampled. The IF samples are coupled to elastic buffer 425 which may be a shift register. The IF samples are then clocked out of elastic buffer 425 as output samples at rate of $N \times M \times BW$, where M is an integer. In the present embodiment $M=4$, which is the ratio between the uplink TDMA format (8/4 timeslots) and the downlink TDMA format (32/16 timeslots). The output samples are coupled to control processor 430 which may add additional overhead bits to the output bit stream to produce the downlink bit stream. The downlink bitstream is coupled to A/D converter 440 and low pass filtered in low pass filter 445 which produces an analog downlink signal. The analog downlink signal is upconverted to L-band in upconverter 450 according to known techniques and broadcast as the forward downlink 310d to mobile station 300a.

The function of elastic buffer 425 is illustrated in greater detail in Figure 5. After downconversion in downconverter 405, the 50kHz signal is coupled to anti-aliasing low pass filter 410 whose output is coupled to A/D converter 415. A/D converter samples the 50 kHz signal at $N \times 50$ kHz, where N is greater than or equal to 2. The time and frequency spectrum of the output of A/D converter 415 is shown in illustration 510. Elastic buffer, which may be a simple shift register, receives the output samples which are stored and clocked out at, for example, 4 times the rate of the input (i.e., $M=4$). The time and frequency spectrum of the output of elastic buffer, shown in illustration 520, is coupled to control processor 430. The control processor allows satellite 200 to add additional information to bitstream such as SACCH messages. The output of control processor 430 is coupled to D/A converter 440, low pass filtered, upconverted, and broadcast by antenna 400. The use of a shift register, or elastic buffer 425, allows satellite 200 to map the uplink TDMA format to the downlink TDMA format without demodulating and re-modulating.

While the present invention has been described with respect to a particular embodiment, those skilled in the art will recognize that the present invention is not limited to the specific embodiments described and illustrated herein. Different TDMA formats, embodiments and adaptations besides those shown and described as well as many variations, modifications and equivalent arrangements will now be reasonably

suggested by the foregoing specification and drawings without departing from the substance or scope of the invention. While the present invention has been described herein in detail in relation to its preferred embodiments, it is to be understood that this disclosure is only illustrative and exemplary of the present invention and is merely for the purposes of providing a full and enabling disclosure of the invention. Accordingly, it is intended that the invention be limited only by the spirit and scope of the claims appended hereto.



What is claimed is:

1. In a mobile satellite communications system, a method for providing communications between a first mobile station and a second mobile station, the method comprising:

transmitting a first signal having a first TDMA format from the first mobile station to a satellite;

receiving, in the satellite, the first signal and downconverting the first signal to a first IF having a first bandwidth, BW;

sampling the first IF at a rate $N \times BW$, where N is an integer greater than or equal to 2 to produce an input bit stream:

storing, in a buffer, the first bitstream and clocking out of the buffer said first bitstream at a rate $M \times N \times BW$, where M is an integer greater than or equal to 2 to produce an output bitstream having a bandwidth $M \times BW$;

filtering said output bitstream to produce a second IF having a second TDMA format;

upconverting said second IF to produce a second signal; and

transmitting said second signal having a second TDMA format to a second mobile station.

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2. A mobile satellite communications system for providing communications between a first mobile station and a second mobile station, comprising:

a first mobile station conditioned to transmit a first signal having a first TDMA format to a satellite;

a receiver in said satellite, for receiving the first signal and downconverting the first signal to a first IF having a first bandwidth, BW;

an analog to digital converter for sampling the first IF at a rate $N \times BW$, where N is an integer greater than or equal to 2 to produce an input bit stream:

a buffer for receiving the first bitstream and clocking out the first bitstream at a rate $M \times N \times BW$, where M is an integer greater than or equal to 2 to produce an output bitstream having a bandwidth $M \times BW$;

a low pass filter for filtering said output bitstream to produce a second IF having a second TDMA format;

an upconverter for upconverting said second IF to produce a second signal: and

a transmitter for transmitting said second signal having said second TDMA format to a second mobile station.

3. The mobile satellite communications system of claim 2, where said buffer is a shift register.

4. The mobile satellite communications system of claim 2, where said second TDMA format is a GSM format.

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