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(54) Title: A TIME DIVERSITY METHOD AND APPARATUS FOR IMPROVING TRANSMISSION BIT RATE IN A MULTI-CARRIER SYSTEM

(57) Abstract: A method that increases an effective signal-to-noise ratio (SNR) of a carrier signal that has an SNR that precludes transmitting a complete information bit of an input bit stream at a bit-error rate during a single symbol period is described. The increasing of the SNR of the carrier signal includes modulating a same information bit of the input bit stream during successive symbol periods. The modulating of the same information bit during successive symbols achieves the bit-error rate for the carrier signal. The carrier signal is demodulated for successive symbol periods to obtain partial information regarding the information bit. The partial information is combined to produce a complete information bit.

A Time Diversity Method and Apparatus for Improving Transmission Bit Rate in a Multicarrier System

Related Application

This application claims the benefit of the filing date of co-pending U.S. Provisional Application, Serial No. 60/164,543, filed November 10, 1999, entitled "Time Diversity Method to Improve Data Rate in Multicarrier Systems," the entirety of which provisional application is incorporated by reference herein.

Field of the Invention

This invention relates to communication systems using multicarrier modulation. More particularly, the invention relates to a method and apparatus for improving the transmission bit rate in a multicarrier modulation system.

Background of the Invention

In a conventional multicarrier communications system, transceivers communicate over a communication channel using multicarrier modulation, such as discrete multitone modulation (DMT). A DMT transmitter, such as a DMT modem, receives an input bit stream comprising information bits and modulates the information bits onto carrier signals (carriers) or sub-channels spaced within a usable frequency band of the communication channel. The modulation occurs at a symbol transmission rate of the system. The DMT transmitter typically modulates the phase characteristic (or phase) and amplitude of the carrier signals using an Inverse Fast Fourier Transform (IFFT) to generate a time domain signal (or transmission signal) that is a linear combination of the carrier signals. The DMT transmitter transmits the transmission signal to a DMT receiver over the communication channel. The receiver demodulates the received carrier signals using a Fast Fourier Transform.

The number of information bits that each carrier signal carries during a single DMT symbol depends on the signal-to-noise ratio (SNR) of that carrier signal and the associated bit-error rate (BER) requirement of the communication channel. Typically, DSL communication systems operate with a BER of 1 x 10^{-7} (i.e., one bit in ten million is received in error on average). Different carriers can have different SNR and therefore may carry a different number of bits at the same BER. For conventional multicarrier communications systems, however, if a carrier signal has a SNR for a given BER that is less than a minimum SNR needed to modulate a complete information bit, the DMT transmitter does not use that particular carrier signal. For example, to carry at least one complete information bit at a BER of 1 x 10^{-7}, a carrier signals needs a minimum uncoded SNR of 11.34 dB. Any carrier signal with an SNR less than 11.34 dB is not used and consequently, in noisy multicarrier communication systems, many carrier signals can remain unused.

Thus, there remains a need for a system and method that can use previously unused carrier signals that have a SNR that is less than the minimum SNR needed to transmit one information bit at a specified BER.

Summary of the Invention

One objective of the invention is to increase the transmission bit rate of multicarrier modulation transceivers by using carrier signals with an signal-to-noise ratio (SNR) that precludes transmitting one information bit at a specified BER during a single DMT symbol period. In one aspect, the invention features a method in a multicarrier modulation system including two transceivers in communication with each other using a transmission signal having a plurality of carrier signals for modulating an input bit stream. One of the carrier signals has a signal-to-noise ratio (SNR) that precludes transmitting at a bit-error rate a complete information bit of the input bit stream on that one carrier signal during a single symbol period. The same information bit of the input bit stream is modulated during multiple symbol periods on this carrier signal, to increase the effective SNR of that carrier signal and achieve the specified bit-error rate. The multiple symbol periods can be successive in order. At least one bit is allocated to the carrier signal having the SNR that precludes transmitting a complete information bit at the bit-error rate. In one embodiment, a transmission bit rate is determined, and the modulating of the same information bit occurs when the transmission bit rate is less than a minimum transmission bit rate. In another embodiment, the modulating of the same information bit occurs if the modulating will improve the transmission bit rate by at least a predefined threshold percentage.

In another aspect, the invention features a method for communicating over a communication channel. During a symbol period, one or more information bits of an input bit stream are transmitted on one or more carrier signals at a first bit-error rate. During successive symbol periods, a same information bit of the input bit stream is transmitted on one of the carrier signals at a second bit-error rate. In one embodiment, the second bit-error rate is higher than the first bit-error rate. The successive symbol periods can include the symbol period during which one or more information bits of the input bit stream are transmitted on one or more carriers at the first bit-error rate. The number of bits transmitted per symbol period and the transmission bit rate at the first bit-error rate are thereby increased.

In another aspect, the invention features a method wherein a carrier signal having an SNR that precludes transmitting a complete information bit at a bit-error rate during a single symbol period is demodulated. The carrier is demodulated for successive symbol periods to obtain partial information regarding an information bit during each of the successive symbol periods. The partial information is combined to produce a complete information bit.

In another aspect, the invention features a method wherein a same information bit is received during successive symbol periods on a previously unusable carrier signal at a second bit-error rate. The previously unusable carrier signal was unusable because the carrier signal was unable to carry bits at a first bit-error rate. The second bit-error rate is higher than the first bit-error rate, thereby increasing the transmission bit rate at the first bit-error rate.

Description of the Drawings

The invention is pointed out with particularity in the appended claims. The advantages of the invention described above, as well as further advantages of the invention, may be better understood by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a block diagram of an embodiment of a digital subscriber line (DSL) communications system including a discrete multitone modulation (DMT) transceiver in communication with a remote transceiver; and

Fig. 2 is a flow diagram of an embodiment of a process for increasing the transmission bit rate of the communication system.

Detailed Description

Fig. 1 shows a digital subscriber line (DSL) communication system 2 including a discrete multitone modulation (DMT) transceiver 10 in communication with a remote transceiver 14 over a communication channel 18 using a transmission signal 38 having a plurality of carrier signals. The DMT transceiver 10 includes a DMT transmitter 22 and a DMT receiver 26 and the remote transceiver 14 includes a transmitter 30 and a receiver 34. Although described with respect to discrete multitone modulation, the principles of the invention apply also to other types of multicarrier modulation, such as, but not limited to, orthogonally multiplexed quadrature amplitude modulation (OQAM), discrete wavelet multitone (DWMT) modulation, and orthogonal frequency division multiplexing (OFDM).

The communication channel 18 provides a downstream transmission path from the DMT transmitter 22 to the receiver 34, and an upstream transmission path from the transmitter 30 to the

DMT receiver 26. In one embodiment, the communication channel 18 is a pair of twisted wires of a telephone subscriber line. In other embodiments, the communication channel 18 is a fiber optic wire, a quad cable, consisting of two pairs of twisted wires, or a quad cable that is one of a star quad cable, a Dieselhorst-Martin quad cable, and the like. In a wireless communication system wherein the transceivers 10, 14 are wireless modems, the communication channel 18 is the air through which the transmission signal 38 travels between the transceivers 10, 14.

As shown in Fig. 1, the DMT transmitter 22 includes a QAM encoder 42, a bit allocation table (BAT) 44, and a modulator 46. The transmitter 30 of the remote transceiver 14 comprises equivalent components as the DMT transmitter 22. Although this embodiment specifies a detailed description of the DMT transmitter 22, the inventive concepts apply also to the receivers 34, 36, which have similar components to that of the DMT transmitter 22, but perform inverse functions in a reverse order.

The QAM encoder 42 maps an input serial data bit stream 54, which consists of information bits, into N parallel QAM symbols 58, where N represents the number of carrier signals generated by the modulator 46. The modulator 46 uses an inverse fast Fourier transform (IFFT) to change the QAM symbols 58 into a transmission signal 38 comprised of a sequence of DMT symbols 70. Each carrier signal of the transmission signal 38 is modulated with a different QAM symbol 58. In one embodiment, a pilot tone is included in the transmission signal 38 to provide a reference signal for coherent demodulation of the carrier signals at the receiver 34 during reception of the transmission signal 38.

In general, the modulator 46 modulates information bits on carrier signals on a DMT symbol by DMT symbol basis. Each DMT symbol period is approximately 250 ms, which corresponds to a 4 kHz DMT symbol rate. The number of bits modulated on a particular carrier signal during a DMT symbol period depends on the signal-to-noise ratio (SNR) of that carrier signal at a specified BER.

The modulator 46 can modulate several information bits on each carrier signal when the communication channel 18 has low noise (i.e., a high SNR on each carrier signal) and thus achieves a high system transmission bit rate. If the conditions of the communication channel 18 are poor (i.e., noisy), the SNR can be low and the number of information bits modulated on each carrier signal few, resulting in a low system transmission bit rate. For example, Table 1 below shows the required uncoded SNR at a 1×10^{-7} BER for modulating one through eight information bits on a carrier signal during one DMT symbol period using QAM.

TABLE 1: Required Uncoded SNR on a Carrier During One Symbol Period for BER = 1×10^{-7}

Bits per carrier	Required SNR for BER = 1×10^{-7}
1	11.34 dB
2	14.32 dB
3	19.11 dB
4	21.31 dB
5	24.46 dB
6	27.54 dB
7	30.59 dB
8	33.61 dB

Typically, in a DMT system with many carrier signals, the SNR of one or more carrier signals is too low to carry a full information bit at the specified bit-error rate. For example, when the SNR of a carrier signal is less than 11.34 dB, such a SNR precludes the transmission of a complete bit of information on that carrier signal at a BER of 1×10^{-7}. In accordance with the principles of the invention, the transceivers 10, 14 make use of these carrier signals that might otherwise remain unused for conveying information over the communication channel 18. Hereafter, such carrier signals are referred to as recovered carrier signals. As described further below, the transmitter 22 transmits one or more information bits on the recovered carrier signal for successive DMT symbol periods at a higher BER than the specified BER. The effect of transmitting an information bit on a recovered carrier signal for successive DMT symbol periods at the higher BER, although that carrier signal cannot transmit a complete information bit at the specified BER, is to increase the effective

SNR of the recovered carrier signal and achieve the specified BER.

For example, if the SNR of a recovered carrier signal is substantially equivalent to 8.34 dB and the SNR required to modulate one information bit during one DMT symbol period is approximately 11.34 dB to achieve a 1×10^{-7} BER, the modulator 46 modulates one information bit over two successive DMT symbols 70. Table 2 below illustrates an embodiment of the required SNR to modulate an information bit in a DMT communication system 2 with a BER of 1×10^{-7}. As shown in column 2, another way of expressing the transmission of one bit over successive DMT symbol periods is as a fraction of a bit being transmitted on a carrier in a single DMT symbol period.

TABLE 2: Required SNR on a carrier during one symbol period for BER = 1×10^{-7}

Number of DMT Symbols for 1 bit transmission	Bits per carrier signal per one DMT symbol period	Required SNR for BER = 1×10^{-7}
2	½	8.34 dB
4	¼	5.34 dB
8	1/8	2.34 dB

In other embodiments, the transmitter 22 transmits one or more information bits on the recovered carrier signal during non-successive DMT symbol periods at a higher BER than the specified BER. For example, the transmitter 22 can transmit the same information bit on a recovered carrier signal during every other DMT symbol period (e.g., during the first and third DMT symbol periods). Other examples include transmitting the same information bit over every third, fourth, fifth DMT symbol period, and so on. Thus, the transmitter 22 can transmit the complete information bit on a recovered carrier signal using non-successive DMT symbol periods as long as the receiver 34 knows which DMT symbol periods the transmitter 22 is using to transmit that information bit.

In yet other embodiments, the transmitter 22 can transmit more than one bit on a recovered carrier signal during a single DMT symbol period. For such embodiments, the BER at which the multiple bits are transmitted is higher than if only one information bit was transmitted on that recovered carrier signal. Further, the transmitter 22 transmits the same information bits on the recovered carrier signal for a greater number of successive DMT symbols than needed for transmitting one information bit. For example, if the SNR is 8.34 dB, the recovered carrier signal can carry two bits over four successive DMT symbols 70 to achieve a BER of 1×10^{-7}.

The BAT 44 is in communication with the modulator 46 to specify the number of bits carried by each carrier signal. For recovered carrier signals, the BAT 44 in one embodiment allocates one bit and specifies additional information that indicates the number of DMT symbol periods needed to convey the complete information bit. Thus, the BATs 44, 44' identify which carrier signals are being used to convey information bits over more than one DMT symbol period and the number of DMT symbol periods required to transmit information bits on that carrier signal. In another embodiment, the BAT specifies fractions of bits to indicate the number of DMT symbol periods needed to convey the complete information bit.

Fig. 2 shows embodiments of a process used by the DMT transceiver 10 and the remote transceiver 14 for communicating over the communication channel 18. During initialization of the transceivers 10, 14, the remote receiver 34 determines (step 204) the number of bits to be carried by each carrier signal. For each carrier signal, the remote receiver 34 measures the SNR for a specified bit-error rate. The measured SNR limits the number of bits that the carrier signal can carry and achieve the specified bit-error rate. For example, Table 1 described above shows the SNR required for a carrier signal to convey one through eight bits at a bit-error rate of 1×10^{-7}.

The receiver 34 then determines (step 206) from the measured SNR of the recovered carrier signal how many DMT symbol periods are needed to convey the information bit completely at the specified BER. For example, when the measured SNR is 8.34 dB, the receiver 34 determines that two DMT symbol periods are needed to carry the complete information bit at the specified bit-error rate of 1×10^{-7}. Approximately one-half of the bit information can be conveyed during each of the two symbol periods; in effect, during each symbol period the carrier signal conveys partial information or a fraction of the information bit. If, for example, the measured SNR is instead 5.34 dB, then the receiver determines that four DMT symbol periods are needed to convey the complete information bit.

The remote receiver 34 then communicates (step 208) the number of bits allocated to each carrier signal to the transmitter 22. For carrier signals with an SNR that precludes conveying a complete bit during a single symbol period, the remote receiver 34 can specify the number of DMT symbol periods needed to convey the complete information bit or the fraction of the information bit conveyed during each DMT symbol period.

The transmitter 22 and remote receiver 34 each create (step 212) its copy of the bit allocation table 44, 44', which specify the number of bits allocated to each carrier signal, in accordance with the information determined by the receiver 34 and communicated to the transmitter 22. For recovered carrier signals, the BAT 44 in one embodiment allocates one bit and specifies additional information that indicates the number of DMT symbol periods needed to convey the complete information bit. In another embodiment, the BAT specifies the fraction of the information bit conveyed during each DMT symbol period for recovered carrier signals.

In one embodiment, shown in phantom, the transmitter 22 determines (step 216) whether to use recovered carrier signals to carry information bits based on one or a combination of the following factors: (1) the transmission bit rate of the communication system; or (2) the amount of improvement in the transmission bit rate gained by using recovered carrier signals for carrying information bits. With respect to the first factor, the transceiver 10 compares the transmission bit rate of the DSL communication system 2 to a minimum transmission bit rate (e.g., 256 kilobits per second (kb/s)). If the transmission bit rate of the DSL communication system 2 is greater than or equal to the minimum transmission bit rate, the transmitter 22 does not use (step 218) recovered carrier signals to carry information bits. If, instead, the transmission bit rate is less than the minimum bit rate, the transmitter 22 can modulate information bits on recovered carrier signals. With respect to the second factor, the transmitter 22 can modulate information bits on recovered carrier signals if using of such recovered carrier signals will increase the transmission bit rate of the DSL communication system 2 by a predetermined amount. For example, if the increase in the transmission bit rate is equal to or exceeds a predefined threshold percentage (e.g., 10%), the transmitter 22 then uses recovered carrier signals for transmitting information bits.

When using recovered carrier signals to convey information, the transmitter 22 modulates (step 226) the same information bit(s) on the recovered carrier signals for two or more successive DMT symbols. The number of successive DMT symbols over which the same information bit is transmitted is based on the SNR of the recovered carrier signal and the BER at which the modulated bits are transmitted. Thus, some carrier signals carry information bits that are transmitted completely in a single DMT symbol period at a first BER, and one or more recovered carrier signals carry information bits over two or more successive DMT symbols 70 at a second BER (per single DMT period) that is greater than the first BER. By combining within a single DMT symbol period information bits on recovered carrier signals with information bits on the other carrier signals, the transmitter 22 achieves an increase in the transmission bit rate at the first BER.

For example, one embodiment of the BAT 44 can allocate one bit to carrier signal #1, one bit to carrier signals #2 and #3, and three bits to carrier signals #4 and #5. Further, the BAT 44 can identify carrier signal #1 as a recovered carrier signal that carries the same information bit for two successive DMT symbols. Thus, carrier signals #2, #3, #4, and #5 carry new information bits during each of the two successive DMT symbols 70 at the first BER, while the recovered carrier signal #1 carries the same information bit over both of the two successive DMT symbols 70 at the second BER.

In another embodiment, the second of the two successive DMT symbol periods can be used to carry only the information bits on the recovered carrier signals (e.g., carrier signals #2, #3, #4, and #5 are unused). In still other embodiments, the transmitter 22 transmits the information bits at the first BER during one DMT symbol 70, and subsequently transmits the information bits on the recovered carrier signals at the second BER during the two successive DMT symbol periods. Although each of such embodiments may provide little or no transmission bit rate improvement, such embodiments may simplify the design of the transmitter 22 or receiver 34.

The DMT transmitter 22 then transmits (step 228) the transmission signal 38 to the receiver 34. The receiver 34 demodulates (step 230) the transmission signal 38 for successive DMT symbol periods to obtain partial information about the information bit during each of the successive DMT symbol periods. The receiver 34 then linearly combines (step 232) the partial information of the information bit to generate the complete information bit.

In one embodiment, the receiver 34 uses the first DMT symbol period in the series of successive DMT symbol periods to determine whether the same information bit is modulated over the successive DMT symbol periods. For example, if the receiver 34 determines that the phase of the carrier signal is approximately 90°, the receiver 34 anticipates that the information bit has a value that is equal to one. The receiver 34 therefore does not need to wait for the following DMT symbol(s) to bring additional partial bit information so that the receiver 34 can generate the complete information bit. Thus, in this embodiment receiving an information bit over multiple DMT symbols does not increase the delay of demodulating that information bit. If, however, the phase of the carrier signal is less than 90°, such as 45°, the receiver 34 may need additional information provided by subsequent DMT symbol(s) to determine the value of the information bit. For instance, the 45° phase might correspond to a bit value of one or might be the result of noise. In such cases, the receiver 34 can still decide from this phase that the information bit has a value of 1 and then use error checking to determine later if the decision was erroneous.

During the operation of the communications system 2, the conditions of the communication change may change to affect the SNRs of one or more carrier signals. In one embodiment, the receiver 34 and the transmitter 22 dynamically exchange bit allocation information corresponding to the new communication channel 18 conditions. For carrier signals with SNRs that have fallen below the minimum SNR for the specified BER, and for recovered carrier signals with SNRs that change but remain below the minimum SNR, such exchanged information may include the number of DMT symbol periods needed to transmit a complete information bit, as described above. The exchange of the information can occur at the boundary of complete information bit (e.g., after the second DMT symbol 70 conveying an information bit that is completely transmitted in two DMT symbols).

While the invention has been shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the following claims. For example, although the specification uses DSL to describe the invention, it is to be understood that various other forms of DSL can be used, i.e., ADSL, VDSL, SDSL, HDSL, HDSL2, or SHDSL. It is also to be understood that the principles of the invention apply to various types of applications transported over DSL systems (e.g., telecommuting, video conferencing, high speed Internet access, video-on demand).

What is claimed is:

Claims

1. In a multicarrier modulation system including two transceivers in communication with each other using a transmission signal having a plurality of carrier signals for modulating an input bit stream, one of the carrier signals having a signal-to-noise ratio (SNR) that precludes transmitting at a bit-error rate a complete information bit of the input bit stream on that one carrier signal during a single symbol period, a method for increasing the effective SNR of the carrier signal comprising:

modulating during multiple symbol periods a same information bit of the input bit stream on the carrier signal having the SNR that precludes transmitting a complete information bit at the bit-error rate, to increase the effective SNR of that carrier signal and achieve the bit-error rate.

2. The method of claim 1 wherein the multiple symbol periods are in successive order.

3. The method of claim 1 further comprising determining the number of symbol periods for carrying the same information bit.

4. The method of claim 1 further comprising allocating at least one bit to the carrier signal having the SNR that precludes transmitting a complete information bit at the bit-error rate.

5. The method of claim 1 further comprising determining a transmission bit rate, and wherein the modulating of the same information bit occurs when the transmission bit rate is less than a minimum transmission bit rate.

6. The method of claim 1 wherein the modulating of the same information bit occurs if the modulating will improve a transmission bit rate by at least a predefined threshold percentage.

7. In a multicarrier modulation system including two transceivers in communication with

each other over a communication channel using a transmission signal having a plurality of carrier signals for modulating an input bit stream, a method for communicating over the communication channel comprising:

transmitting, during a symbol period, one or more information bits of the input bit stream on one or more carrier signals at a first bit-error rate; and

transmitting, during successive symbol periods, a same information bit of the input bit stream on one of the carrier signals at a second bit-error rate.

8. The method of claim 7 wherein the second bit-error rate is higher than the first bit-error rate.

9. The method of claim 7 wherein the successive symbol periods include the symbol period during which one or more information bits of the input bit stream are transmitted on one or more carrier signals at the first bit-error rate, to increase the number of bits transmitted per symbol period and thus the transmission bit rate at the first bit-error rate.

10. The method of claim 7 further comprising identifying one or more carrier signals for transmitting information bits of the input bit stream at the second bit-error rate.

11. In a multicarrier modulation system including two transceivers in communication with each other using a transmission signal having a plurality of carrier signals for modulating an input bit stream, a method for using a carrier signal that is unusable for carrying bits at a first bit-error rate to increase a transmission bit rate at the first bit-error rate comprising:

transmitting during successive symbol periods a same information bit on the unusable carrier signal at a second bit-error rate that is higher than the first bit-error rate, to increase the number of information bits transmitted per symbol period and thus the transmission bit rate at the first bit-error rate.

12. The method of claim 11 further comprising determining the number of symbols for carrying the same information bit.

13. The method of claim 11 further comprising allocating at least one bit to the unusable carrier signal at a second bit-error rate.

14. The method of claim 11 further comprising determining a transmission bit rate, and wherein the modulating of the same information bit occurs when the transmission bit rate is less than a minimum transmission bit rate.

15. The method of claim 11 wherein the modulating of the same information bit occurs if the modulating will improve a transmission bit rate by at least a predefined threshold percentage.

16. In a multicarrier modulation system including two transceivers in communication with each other over a communication channel using a transmission signal having a plurality of carrier signals for modulating an input bit stream, a method for communicating over the communication channel comprising:

receiving, during a symbol period, one or more information bits of the input bit stream on one or more carrier signals at a first bit-error rate; and

receiving, during successive symbol periods, a same information bit of the input bit stream on one of the carrier signals at a second bit-error rate.

17. The method of claim 16 further comprising allocating at least one bit to the one carrier signal on which the same information bit is received during successive symbol periods.

18. The method of claim 16 further comprising measuring the signal-to-noise ratio (SNR) for

the carrier signal.

19. The method of claim 18 further comprising using the SNR to determine a number of successive symbol periods that are needed to convey the information bit completely at the second bit-error rate.

20. In a multicarrier modulation system including two transceivers in communication with each other using a transmission signal having a plurality of carrier signals for modulating an input bit stream, one of the carrier signals having a signal-to-noise ratio (SNR) that precludes transmitting at a bit-error rate a complete information bit of the input bit stream on that one carrier signal during a single symbol period, a method for increasing the effective SNR of the carrier signal comprising:

demodulating, for a plurality of successive symbol periods, a carrier signal having an SNR, that precludes transmitting at a bit-error rate a complete information bit on that carrier signal during a single symbol period, to obtain partial information regarding an information bit during each of the successive symbol periods; and

combining the partial information obtained during the successive symbol periods to produce a complete information bit.

21. The method of claim 20 further comprising determining the number of symbols for receiving the same information bit.

22. The method of claim 20 further comprising allocating at least one bit to the carrier signal having the SNR that precludes transmitting a complete information bit at the bit-error rate.

23. The method of claim 20 further comprising determining a reception bit rate, and wherein the demodulating of the same information bit occurs when the reception bit rate is less than a

minimum reception bit rate.

24. The method of claim 20 wherein the demodulating of the same information bit occurs if the demodulating will improve a reception bit rate by at least a predefined threshold percentage.

25. In a multicarrier modulation system including two transceivers in communication with each other using a transmission signal having a plurality of carrier signals for modulating an input bit stream, a method for using a carrier signal that is unusable for carrying bits at a first bit-error rate to increase a transmission bit rate at the first bit-error rate comprising:

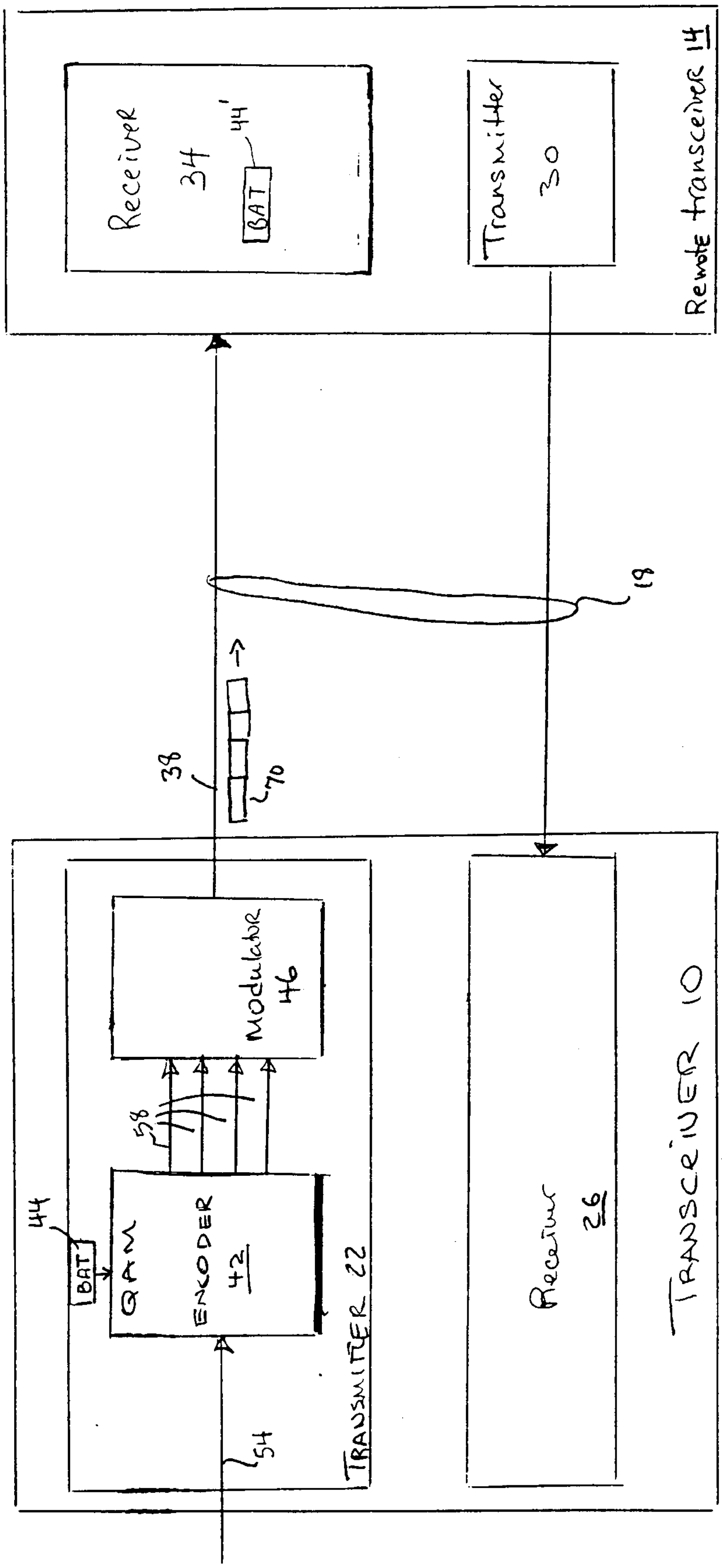
receiving during successive symbol periods a same information bit on the unusable carrier signal at a second bit-error rate that is higher than the first bit-error rate, to increase the number of information bits received per symbol period by using the previously unusable carrier signal and thus to increase the transmission bit rate at the first bit-error rate.

26. The method of claim 25 further comprising determining the number of symbols for receiving the same information bit.

27. The method of claim 25 further comprising allocating at least one bit to the unusable carrier signal at a second bit-error rate.

28. The method of claim 25 further comprising determining a reception bit rate, and wherein the demodulating of the same information bit occurs when the reception bit rate is less than a minimum reception bit rate.

29. The method of claim 25 wherein the demodulating of the same information bit occurs if the demodulating will improve a reception bit rate by at least a predefined threshold percentage.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ENCODER
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BAT
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54
Receiver
26
TRANSCEIVER 10

FIG. 1

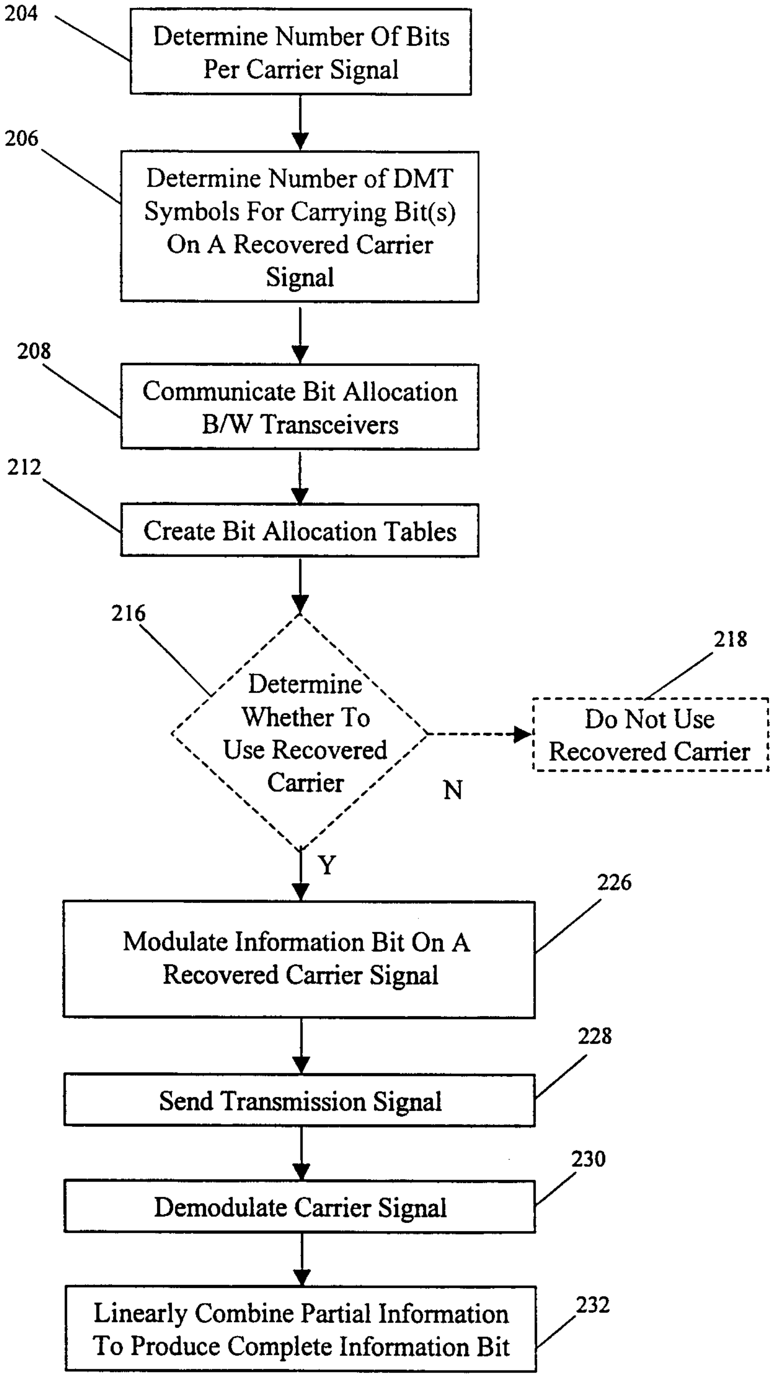
204
Determine Number Of Bits Per Carrier Signal
206
Determine Number of DMT Symbols For Carrying Bit(s) On A Recovered Carrier Signal
208
Communicate Bit Allocation B/W Transceivers
212
Create Bit Allocation Tables
216
Determine Whether To Use Recovered Carrier
218
Do Not Use Recovered Carrier
N
Y
226
Modulate Information Bit On A Recovered Carrier Signal
228
Send Transmission Signal
230
Demodulate Carrier Signal
Linearly Combine Partial Information To Produce Complete Information Bit
232

Fig. 2