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United States Patent	**6,490,270**
Krishnamoorthy , et al.	**December 3, 2002**

Modulation method for transmitter

Abstract

In a wireless communication system, the constellation mapping scheme employed may be changed on a per-time-slot basis, i.e., from time slot to time slot, so that the constellation used to encode the symbols of each time slot may be different for each time slot within a single frame and may be different for a particular time slot in different consecutive frames. In other words, several constellation mapping schemes are available, with each providing the ability to transmit a different number of bits per symbol, and the particular constellation mapping scheme employed for any time slot need be selected for that time slot only. The ability to use any particular constellation mapping scheme is dependent on the current channel quality. The particular constellation mapping used for the user data of the time slot may be indicated in the preamble of the time slot. To this end, each time slot may have its own preamble that is mapped with a constellation mapping scheme which is a) known a priori, b) may be the same for all time slots, and c) may be different from the constellation mapping scheme used to encode user data in the time slot. A receiver can determine the constellation mapping used for each time slot from solely from the preamble of the time slot.

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Claims

What is claimed is:

1. A method for use in selecting a constellation mapping scheme for mapping user data to symbols in a system employing time slots arranged into frames, the method comprising the steps of:

determining a channel quality that is available for a particular one of said time slots; and

selecting a constellation mapping scheme for use in mapping user data transmitted on said particular one of said time slots as a function of said determined channel quality;

wherein said determining and selecting are repeated at least once while said particular one of said time slots is assigned to a particular user and wherein each time said selecting step is executed said selected constellation mapping scheme for said particular one of said time slots is identified in a preamble of an instantiation of said particular one of said time slots.

2. The invention as defined in claim 1 further including the steps of:

mapping user data for transmission in at least one of said time slots using a first constellation mapping scheme selected during a first execution of said selecting step; and

mapping user data for transmission in at least another one of said time slots using a second constellation mapping scheme selected during a second execution of said selecting step.

3. The invention as defined in claim 1 wherein said identification in said preamble is mapped using a different constellation mapping scheme than said selected constellation mapping scheme.

4. The invention as defined in claim 1 wherein said identification in said preamble is mapped using the same constellation mapping scheme as said selected constellation mapping scheme.

5. The invention as defined in claim 1 wherein said identification in said preamble is mapped using a constellation mapping scheme that is the same for all of said time slots.

6. The invention as defined in claim 1 wherein said identification in said preamble is mapped with an constellation mapping scheme which is known a priori to an intended receiver of said user data.

7. The invention as defined in claim 1 further including the step of monitoring said channel, results of said monitoring being used in said determining step to determine said channel quality.

8. The invention as defined in claim 1 wherein determining said channel quality is a function of at least one effect from the group of effects consisting of: properties of said channel, interference caused on said channel by other sources, and noise.

9. A method for use in selecting a constellation mapping scheme for mapping user data to symbols, the method comprising the steps of:

determining a channel quality that can be achieved for each time slot of a frame that is in use; and

selecting a constellation mapping scheme that has been determined to be employed for said determined channel quality of said each time slot of a frame that is in use;

wherein said constellation mapping scheme selected for each of said time slots is identified in a preamble of said each time slot of a frame that is in use.

10. The invention as defined in claim 9 wherein said determining and selecting steps are performed for each frame.

11. The invention as defined in claim 9 further including the step of mapping user data using said selected constellation mapping scheme.

12. The invention as defined in claim 9 wherein said preamble uses a constellation mapping scheme different from said selected constellation mapping scheme.

13. The invention as defined in claim 9 wherein said preamble uses a constellation mapping scheme that is the same as said selected constellation mapping scheme.

14. A method for use in selecting a constellation mapping scheme for mapping user data to symbols, the method comprising the steps of:

determining a channel quality that can be achieved for each time slot that is in use of a frame of time slots; and

selecting a constellation mapping scheme for use in encoding user information to be carried in said each time slot as a function of said determined channel quality of said each time slot of a frame that is in use;

wherein said constellation mapping scheme selected for each of said time slots is identified in a preamble of said each time slot of a frame that is in use.

15. The invention as defined in claim 14 wherein said selecting step is further a function of a quality of service for each respective user of said each time slot.

16. The invention as defined in claim 14 wherein said selecting step selects for each said time slot a constellation mapping scheme that yields a highest bit rate.

17. The invention as defined in claim 14 wherein said selecting step selects for at least one of said each time slot a constellation mapping scheme that yields a bit rate for said for at least one of said each time slot that at least meets a quality of service required for said at least one of said each time slot but is less than a bit rate that can be achieved using a different constellation mapping scheme given said determined channel quality for said at least one of said each time slot.

18. A method for use in transmitting user information in a system employing time slots arranged into frames, the method comprising the steps of:

determining a channel quality that is available for a particular one of said time slots; and

modulating said user information using constellation mapping scheme that is selected as a function of said determined channel quality;

identifying said constellation mapping scheme in a preamble of said one of said time slots;

repeating said determining, modulating, and identifying steps at least once while said particular one of said time slots is assigned to the same particular user.

19. Apparatus for use in selecting a constellation mapping scheme for mapping user data to symbols in a system employing time slots arranged into frames, the apparatus comprising:

a per-time-slot channel quality determiner; and

a constellation mapper that modulates user data for a time slot using a constellation mapping scheme that determined as a function of a quality determined by said per-time-slot channel quality determiner for said particular time slot and places an indication of said constellation mapping scheme used into a preamble of said particular time slot;

said constellation mapper being adapted to change said constellation mapping scheme even while a time slot remains assigned to a particular user.

20. The invention as defined in claim 19 wherein said indication is mapped with a constellation mapping scheme that is different from said constellation mapping scheme used to modulate said user data.

21. The invention as defined in claim 19 wherein said indication is mapped with a constellation mapping scheme that is the same as said constellation mapping scheme used to modulate said user data.

22. Apparatus for use in transmitting user information in a system employing time slots arranged into frames, the apparatus comprising:

means for determining a channel quality that is available for a particular one of said time slots;

means for modulating said user information using a constellation mapping scheme that is selected as a function of said determined channel quality; and

means for identifying in a preamble of an instantiation of said particular one of said time slots said constellation mapping scheme used by said means for modulating;

wherein said means for determining, said means for modulating and said means for identifying perform their respective functions at least twice while said particular one of said time slots is assigned to the same particular user.

23. The invention as defined in claim 22 wherein said means for determining determines an initial channel quality when said particular one of said time slots is initially assigned to said particular user.

24. Software in computer readable form for use in mapping user data to symbols using a constellation

mapping scheme, the software comprising modules for:

determining a channel quality that can be achieved for each time slot that is in use of a frame of time slots;

selecting a constellation mapping scheme for use in encoding user information to be carried in said each time slot as a function of said determined channel quality of said each time slot of a frame that is in use; and

identifying in a preamble of said each time slot said selected constellation mapping scheme used to encode said user information carried in said each time slot.

Description

TECHNICAL FIELD

This invention relates to the art of allocating available data rate to users of a wireless communication system, and in particular, to allocating available data rate to users of fixed wireless loop, or so-called "wireless local loop" systems.

BACKGROUND OF THE INVENTION

Typical prior art wireless systems employ a fixed data rate allocation per user. Once a user is assigned a modulation scheme, i.e., a constellation for mapping the user's bits into symbols, the user's data rate is fixed unless the user is assigned further, e.g., an additional one or more, time slots. Such systems are unable to take advantage of improvements in channel quality, and suffer in the event of channel quality degradation.

SUMMARY OF THE INVENTION

In accordance with the principles of the invention, the constellation mapping scheme employed may be changed on a per-time-slot basis, i.e., from time slot to time slot, so that the constellation used to encode the symbols of each time slot may be different for each time slot within a single frame and may be different for a particular time slot in different consecutive frames. In other words, several constellation mapping schemes are available, with each providing the ability to transmit a different number of bits per symbol, and the particular constellation mapping scheme employed for any time slot need be selected for that time slot only. The ability to use any particular constellation mapping scheme is dependent on the current channel quality.

In accordance with an aspect of the invention, the particular constellation mapping used for the user data of the time slot may be indicated in the preamble of the time slot. To this end, each time slot may have its own preamble that is mapped with a constellation mapping scheme which is a) known a priori, b) may be the same for all time slots, and c) may be different from the constellation mapping scheme used to encode user data in the time slot.

In accordance with another aspect of the invention, a receiver can determine the constellation mapping used for each time slot from the preamble of the time slot.

Advantageously, by having the ability to change the constellation mapping scheme employed on a per-

time-slot basis the user's data rate may be rapidly changed, i.e., increased or decreased, to correspond to the data rate that has the highest throughput under current channel conditions and the user's specified QoS. Since the constellation mapping scheme that may be employed is a function of the channel quality, which may change over time, it is necessary to monitor the channel quality to determine which constellation mapping is appropriate to use for each time slot.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 shows exemplary steerable beam TDMA wireless communication system arranged in accordance with the principles of the invention;

FIG. 2 shows an exemplary frame structure for use in the steerable beam wireless communication system shown in FIG. 1;

FIG. 3 shows an exemplary process, in flow chart form, for determining the modulation scheme used to modulate the payload portion of a time slot and identifying a received training sequence; and

FIG. 4 shows, in flow chart form, an exemplary process employed by a transmitter to transmit data when various modulation schemes are available for modulating the data on a per-time slot basis.

DETAILED DESCRIPTION

The following merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples and conditional language recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

Thus, for example, it will be appreciated by those skilled in the art that the block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudocode, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

The functions of the various elements shown in the FIGS., including functional blocks labeled as "processors" may be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, explicit use of the term "processor" or "controller" should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, read-only memory (ROM) for storing software, random access memory (RAM), and non-volatile storage.

Other hardware, conventional and/or custom, may also be included. Similarly, any switches shown in the FIGS. are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the implementor as more specifically understood from the context.

In the claims hereof any element expressed as a means for performing a specified function is intended to encompass any way of performing that function including, for example, a) a combination of circuit elements which performs that function or b) software in any form, including, therefore, firmware, microcode or the like, combined with appropriate circuitry for executing that software to perform the function. The invention as defined by such claims resides in the fact that the functionalities provided by the various recited means are combined and brought together in the manner which the claims call for. Applicant thus regards any means which can provide those functionalities as equivalent as those shown herein.

Note that as used herein channel quality includes effects from channel properties, such as multipath; interference from other sources, such as other radio sources of the same or other systems as well as cosmic sources; and noise, such as thermal noise within the receiver itself.

Note that a "user" as referred to herein may be reflective of a particular person, a particular terminal, or particular applications or instantiations thereof, depending on the implementor. Those of ordinary skill in the art will readily be able to design from the description herein systems that accommodate any of these meanings for the "user", and even for any combination of such meanings.

FIG. 1 shows exemplary steerable beam TDMA wireless communication system 100 arranged in accordance with the principles of the invention. Wireless communication system 100 includes base station antenna 101 serving remote terminals 103-1 through 103-N, collectively remote terminals 103, and base station antenna 105 serving remote terminals 107-1 through 107-N, collectively remote terminals 107. The pairing of a remote terminal with a particular base station is determined by the implementor based on the best signal power and least interference that can be achieved for a remote terminal-base station pair.

In steerable beam wireless communication system 100, the beam pattern formed at the remote terminal location may be of any arbitrary width. The particular width of the beam is a function of the directionality of the antenna design and often it is a wide beam. Typically the same beam pattern is used for both transmitting and receiving. For example, an antenna at the remote terminal location having a 30.degree. angle has been employed in one embodiment of the invention, although any other angle may be used.

The base station has the ability to controllably form beam patterns of substantially arbitrary width, so as to listen and transmit on either a wide beam or on a narrow beam, depending on the situation. Initially, e.g., during call setup, communication between a base station and a remote terminal is carried out by having the base station use a wide beam. However, once a communication channel is established between a base station and a remote terminal, i.e., a so-called "traffic" channel, the base station typically uses a narrow beam. When using a narrow beam, the base station directs the beam in the direction of the remote terminal at the time communication is to take place between the base station and the remote terminal. Communication may be simultaneously bidirectional between the base station and the remote terminal, e.g., one frequency is used for transmission from the base station to the remote terminal while a second frequency is used for transmission from the remote terminal to the base station.

Steerable beam wireless communication system 100 of FIG. 1 is a time division multiple access

(TDMA) system. Such systems employ a repeating frame structure, within each frame there being time slots. FIG. 2 shows an exemplary frame structure 201 for use in steerable beam wireless communication system 100. Frame structure 201 is 2.5 ms long and contains within it 64 time slots 203, including time slots 203-1 through 203-64. Each of time slots 203 includes a data part (DP) 205 and a guard interval (G) part 207. For example, each of time slots 203 is 2.5/64 ms, which is 39.0625 .mu.s. Each guard interval 207 is 2 .mu.s leaving each data part 205 as being 37.0625 .mu.s. The same frame structure is used for both the uplink, i.e., from the remote terminal to the base station, and for the downlink, i.e., from the base station to the remote terminal.

More specifically, each time slot 203 is divided into symbols, the number of which is determined by the implementor based on bandwidth and the time slot period. For example, as noted above, a 39.0625 .mu.s time slot period with a guard interval of 2 .mu.s leaves a data part of 37.0625 .mu.s. If the channel bandwidth is 5 MHz, and the useful bandwidth 3.9936 MHz, then there are 148 symbols, each of length approximately 250.04 ns.

The number of bits per symbol, i.e., the constellation size, determines the number of bits that are transmitted in each time slot. In accordance with an aspect of the invention, the number of bits per symbol may be changed on a per-time slot basis regardless of the position of the data that is to be placed in time slot within the data stream of the user, i.e., regardless of the state of the segmentation algorithm which is dividing the user data into radio link packets for transmission in time slot-sized units. For example, in one embodiment of the invention, five different modulation schemes are employed, namely, a) quadrature phase shift keying (QPSK), b) 8-ary phase shift keying (8-PSK), c) 16 quadrature amplitude modulation (16-QAM), d) 32 quadrature amplitude modulation (32-QAM), d) 64 quadrature amplitude modulation (64-QAM). For a time slot with 148 symbols, these modulation schemes enable the transmission therein of a) 296, b) 444, c) 592, d) 740, and e) 888 raw bits, respectively. Note that the actual bits available for user data in a time slot will often be less than the number of raw bits due to the use of raw bits for training sequences, headers, error detection and/or correction codes, and the like.

In accordance with an aspect of the invention, the constellation mapping scheme employed may be changed on a per time slot basis. Advantageously, by changing the constellation mapping scheme employed per-time-slot and the number of time slots employed by a user the user's data rate may be rapidly changed, i.e., increased or decreased.

Although simply changing the modulation scheme employed is easy, doing so in a manner that a receiver can respond appropriately to such a change is not. Therefore, in accordance with the principles of the invention, one or more specific training sequences are incorporated into the preamble of each time slot for use in both identifying the type of modulation used for the remainder of the time slot and for use in performing conventional training functions such as timing recovery, carrier recovery, and channel equalization, in a high quality fashion. In accordance with an aspect of the invention, correlation is used in the receiver to identify which particular training sequence has been received.

In one embodiment of the invention, the training sequences are all modulated using a binary phase shift keying (BPSK) modulation scheme, essentially one of simplest known modulation schemes. Such a simple scheme is employed so as to maximize the likelihood of the information being properly received. Furthermore, because the length of the training sequence to get good performance varies as a function of the modulation scheme employed, an initial determination is performed using a first number of symbols, e.g., 13, as to whether the modulation scheme employed is QPSK or one of the other modulation schemes.

If QPSK is detected then no more symbols need be employed than those used for the initial determination, and so those symbols remain available to carry additional payload in QPSK modulated

time slots. This is beneficial because QPSK has the lowest throughput of the modulation schemes listed above that are employed in this exemplary embodiment. Also, by having an initial separation into QPSK and other modulation schemes the correlation results are more likely to be accurate than if there was a need to detect each modulation scheme separately initially.

If QPSK is detected by the correlator in the receiver, the remainder of the time slot is demodulated using QPSK demodulation. Furthermore, once the particular training sequence for QPSK is recognized, the samples that make up the training sequence can be used for conventional training, as the value of the training sequence is now known.

If QPSK is not detected by the correlator in the receiver, then clearly the modulation scheme employed is one of the other modulation schemes. Furthermore, the training sequence is recognized as being that sequence of symbols that indicates that a modulation scheme other than QPSK is being employed. Once this particular training sequence is recognized, the samples that make up this "other" training sequence can be used for conventional training, as the value of the training sequence is now known. However, preferably, training is deferred until a second training sequence, that is transmitted within the same timeslot but after the first training sequence and that identifies which particular modulation scheme other than QPSK is being employed, is determined. To this end, once the "other" training sequence is recognized the symbols at a second location within the time slot that make up a second training sequence are compared using correlation to one or more of a set of respective training sequences, each member of the set respectively identifying the modulation scheme of the time slot as being one of 8-PSK, 16-QAM, 32-QAM, or 64-QAM. The modulation scheme corresponding to the one of the known training sequences that correlates most highly with the symbols at a second location within the time slot at which the second training sequence are to be found is determined to be the modulation scheme employed for use in demodulating the remainder of the time slot. Furthermore, once the particular training sequence is recognized, the samples that make up the training sequence and the samples that make up the original "other" training sequence can be used for conventional training, as the value of the entire training sequence is now known.

FIG. 3 shows an exemplary process, in flow chart form, for determining in a receiver the modulation scheme that had been used to modulate the payload portion of a time slot. The process is entered in step 301 when a new time slot is received via the air interface. Next, in step 303, the first N1 symbols, which are in the positions at which the training sequence is expected, are correlated with two possible training sequences, P1 and P2. For example, P1 and P2 may each be 13 symbols and P1 indicates that the time slot payload is QPSK modulated while P2 indicates that some modulation scheme other than QPSK is employed for the time slot payload. Conditional branch point 305 tests to determine if the result of the correlations performed in step 303 is such that the output corresponding to P1 is greater than the output corresponding to P2. If the test result in step 305 is YES, indicating that the received training sequence is that for QPSK, control passes to step 307, and the packet is processed as if it is modulated using QPSK. To this end, the training is performed using the QPSK training sequence and data demodulation is performed for QPSK data. The process then exits in step 327.

If the test result in step 307 is NO, indicating the time slot is not QPSK modulated, control passes to step 309 in which the next N2 symbols, which are to correspond to the second training sequence, are correlated as a sequence against training sequences P3, P4, P5 and P6 that correspond to 8-PSK, 16-QAM, 32-QAM, or 64-QAM, respectively. Conditional branch point 311 tests to determine if the output of the correlator that correlated the N2 symbols with P3 has produced the largest output. If the test result in step 311 is YES, control passes to step 313 and the packet is processed as if it is modulated using 8-PSK. To this end, the training is performed using the N1 symbols corresponding to P2 in combination with the 8-PSK training sequence P3, and data demodulation is performed for 8-PSK data. The process then exits in step 327.

If the test result in step 311 is NO, control passes to conditional branch point 315, which tests to determine if the output of the correlator that correlated the N2 symbols with P4 has produced the largest output. If the test result in step 315 is YES, control passes to step 317, and the packet is processed as if it is modulated using 16-QAM. To this end, the training is performed using the N1 symbols corresponding to P2 in combination with the 16-QAM training sequence P4, and data demodulation is performed for 16-QAM data. The process then exits in step 327.

If the test result in step 315 is NO, control passes to conditional branch point 319, which tests to determine if the output of the correlator that correlated the N2 symbols with P5 has produced the largest output. If the test result in step 319 is YES, control passes to step 321, and the packet is processed as if it is modulated using 32-QAM. To this end, the training is performed using the N1 symbols corresponding to P2 in combination with the 32-QAM training sequence P5, and data demodulation is performed for 32-QAM data. The process then exits in step 327.

If the test result in step 319 is NO, control passes to conditional branch point 323, which tests to determine if the output of the correlator that correlated the N2 symbols with P6 has produced the largest output. If the test result in step 323 is YES, control passes to step 325, and the packet is processed as if it is modulated using 64-QAM. To this end, the training is performed using the N1 symbols corresponding to P2 in combination with the 64-QAM training sequence P6, and data demodulation is performed for 64-QAM data. The process then exits in step 327.

In accordance with an aspect of the invention, when performing the correlation in step 309 it is further advantageous to also recorrelate the first N1 symbols with P2 and to take the combined result of the correlations of the first N1 symbols and the next N2 symbols with each respective one of P3, P4, P5, and P6 as a unit for using in steps 311, 315, 319 and 323.

In one embodiment of the invention, the correlation called for herein is performed only after downconversion to baseband has been completed for both the in-phase (I) and quadrature (Q) signals which are carried on the radio link. The I and Q baseband signals are converted to the digital domain, with a new digital value being generated for each symbol period for each of I and Q.

Correlation is then performed between the indicated number of symbols of I and Q and the codeword being tested for, e.g., P1, P2, P3, etc., e.g., using a codeword correlator. Each correlation output is then squared and the sum of the squares is then added. The resulting sum is then used in steps calling for the result of a correlation.

FIG. 4 shows, in flow chart form, an exemplary process employed by a transmitter to transmit data when various modulation schemes are available for modulating the data on a per-time slot basis. The process is entered in step 401, when it is time to prepare data for transmission in an upcoming time slot. Next, in step 403, the channel quality parameters are obtained, from which it is determined, in step 405, the modulation scheme that will be employed to modulate this time slot. The particular mapping of channel quality to modulation scheme is at the discretion of the implementor, as it is a function of the system requirements. Those of ordinary skill in the art will be able to develop such mappings.

Thereafter, in step 407, the appropriate training sequence that corresponds to the selected modulation scheme is placed in the preamble of the time slot. The amount of data that can fit within a time slot when modulated with the selected modulation scheme is obtained in step 409 and so modulated in step 411. The time slot is then transmitted in step 413 and the process exits in step 415.

Those of ordinary skill in the art will recognize that it is not necessary to change modulation scheme on

a per-time-slot basis, although it may be preferable to do so. Instead, the modulation scheme may be changed at known intervals, and the necessary analysis performed only when a modulation scheme change is permitted.

Note that as used herein, within the rubric of the term "frame structure" is included the idea that is sometimes referred to as a superframe, i.e., the frame is defined as being bounded by a known regularly repeating time slot, although other smaller frames may be included therein. Furthermore, the term preamble should not be viewed as limiting the identification of the selected modulation scheme to come before the user data in a time slot, as is most common, but may also include situations in which the identification of the selected modulation scheme comes after the user data in a time slot.

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