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(54) **METHOD AND APPARATUS FOR PILOT SIGNAL TRANSMISSION**

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H04J 11/00 (2006.01)

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(58) **Field of Classification Search** 370/203, 370/252, 310, 331, 332, 334, 335, 342, 350; 375/134, 137, 140, 142, 143, 144, 145, 148, 375/149, 299
See application file for complete search history.

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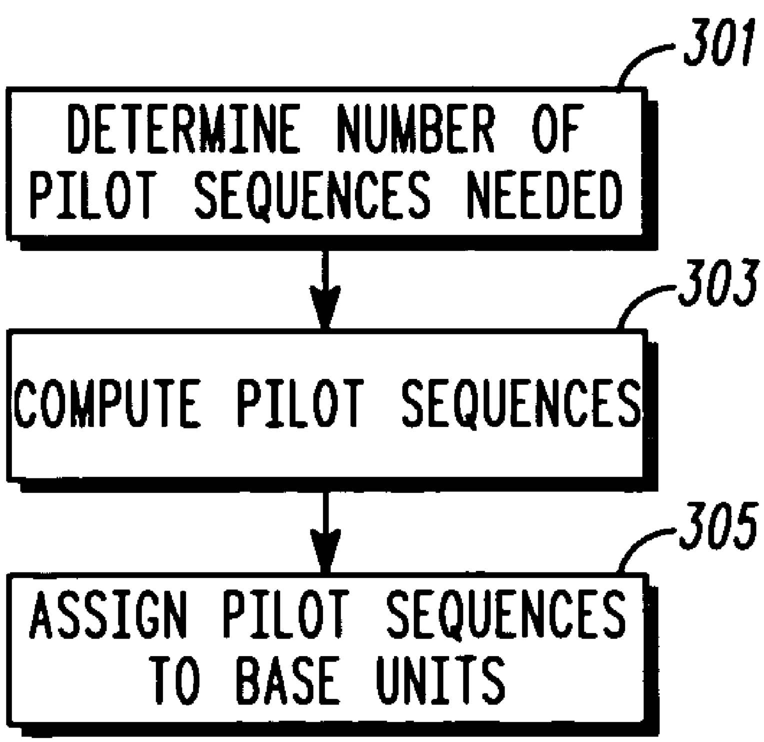
(57) **ABSTRACT**

Pilot sequences are constructed from distinct "classes" of chirp sequences that have an optimal cross correlation property. Utilization of chirp sequences for pilot sequences results in pilot sequences that have optimal or nearly-optimal cross correlation and auto-correlation properties.

28 Claims, 1 Drawing Sheet



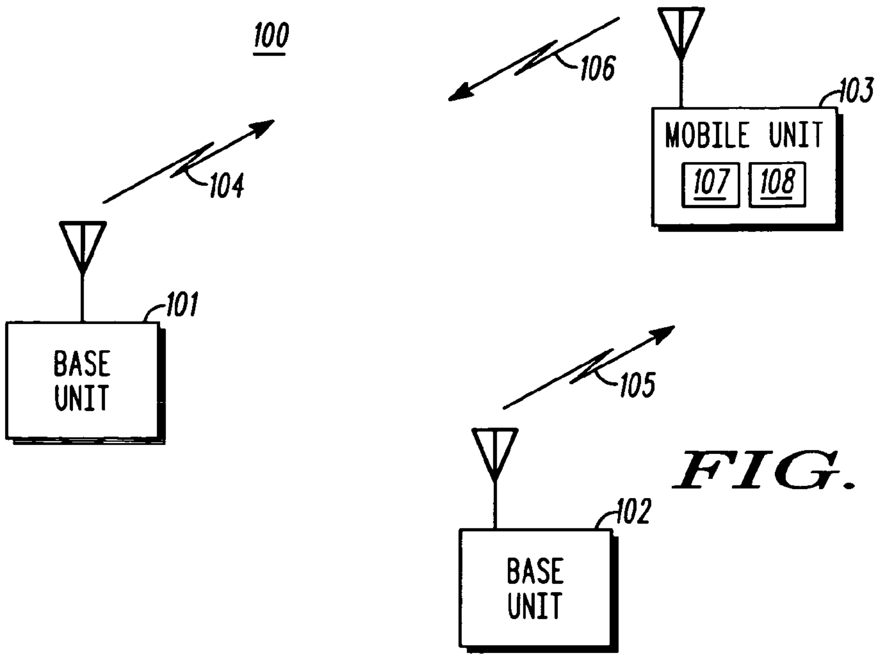


FIG. 1

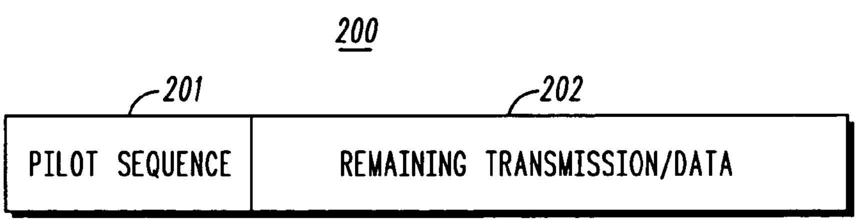


FIG. 2

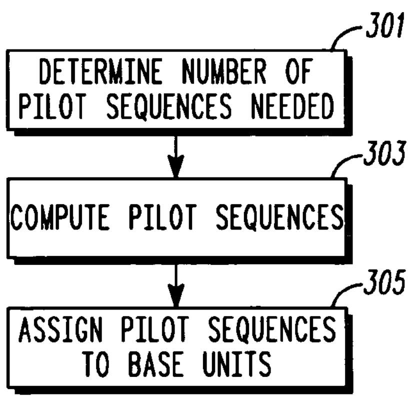


FIG. 3

METHOD AND APPARATUS FOR PILOT SIGNAL TRANSMISSION

FIELD OF THE INVENTION

The present invention relates generally to pilot signal transmission, and in particular to a method and apparatus for pilot signal transmission in a communication system.

BACKGROUND OF THE INVENTION

A pilot signal (or preamble) is commonly used for communication systems to enable the receiver to perform a number of critical functions, including but not limited to, the acquisition and tracking of timing and frequency synchronization, the estimation and tracking of desired channels for subsequent demodulation and decoding of the information data, the estimation and monitoring of the characteristics of other channels for handoff, interference suppression, etc. Several pilot schemes can be utilized by communication systems, and typically comprise the transmission of a known sequence at known time intervals. A receiver, knowing the sequence and time interval in advance, utilizes this information to perform the above-mentioned functions.

Several criteria are important when determining pilot sequences for communication systems. Among these criteria is the ability to have good auto-correlation for each of the pilot sequences utilized, and at the same time the ability to have good cross-correlation between any two different pilot sequences. Auto- and cross-correlation are sequences themselves corresponding to different shifts. Auto-correlation at shift-d is defined as the result of summing over all entries after an element-wise multiplication between the sequence and its conjugated replica after shifting it by d entries (d can be positive or negative for right or left shift). Cross-correlation at shift-d is defined as the result of summing over all entries after an element-wise multiplication between a sequence and another sequence that is conjugated and shifted by d entries with respect to the first sequence. "Good" auto-correlation results in each pilot sequence having a minimal auto-correlation value at all shifts of interest (i.e., a range of d, except for d=0). "Good" cross-correlation results in the pilot sequence having a minimal cross-correlation value at all shifts of interest. When the auto-correlation is zero at all d, except for d=0, it is referred to as "ideal" auto-correlation. Since the cross-correlation of two sequences that have ideal auto-correlation cannot be zero at all d, the minimum of the maximum cross-correlation values at all shifts can be reached only when the cross-correlation at all d is equal in amplitude, which is referred to as having "optimal" cross-correlation.

Since the received signal after propagation consists of replicas of the delayed pilot sequence after some scaling factors, the ideal auto-correlation property of the pilot makes the estimation of the channel scaling factors at different delays possible. The optimal cross-correlation property between any two pilot sequences will minimize the interference effect seen at the receiver that is caused by any pilot sequences other than the desired one (i.e., one that the receiver is tuned to). Good cross-correlation makes the detection of the desired pilot signal and the estimation of the desired channel characteristics more reliable, which enables the receiver to perform synchronization and channel estimation more reliably.

Various techniques have been used in the past to design systems with efficient pilot sequences. For example, in the current CDMA-based cellular system, the pilot sequence in a

sequence for each cell. Channel estimation of the neighboring base stations, when required during a soft handoff, is simply performed by correlating the received signal with the neighboring base station's long code scrambled pilot sequences. But the cross-correlation property of two random pilot sequences is not optimal, and thus a larger channel estimation error can be expected. Therefore, a need exists for a method and apparatus for pilot signal or preamble transmission that optimizes both the cross correlation between pilot signals, as well as optimizing each pilot signal's auto correlation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a communication system.

FIG. **2** illustrates pilot signal transmission for the communication system of FIG. **1**.

FIG. **3** is a flow chart showing pilot sequence assignment for the communication system of FIG. **1**.

DETAILED DESCRIPTION OF THE DRAWINGS

To address the above-mentioned need, a method and apparatus for pilot signal transmission is disclosed herein. In particular, pilot sequences are constructed from distinct "classes" of chirp sequences that have an optimal cyclic cross correlation property while satisfying the ideal cyclic autocorrelation requirement. Utilization of chirp sequences for pilot sequences results in pilot channels that have good cross correlation as well as having good auto-correlation.

The present invention encompasses a method for assigning a pilot sequence to communication units within a communication system. The method comprises the steps of assigning a first communication unit a first pilot sequence, wherein the first pilot sequence is selected from a group of pilot sequences constructed from a set of Generalized Chirp-Like (GCL) sequences, and then assigning a second communication unit a second pilot sequence taken from the group of pilot sequences constructed from the set of GCL sequences.

The present invention additionally encompasses a method comprising the steps of receiving a pilot sequence as part of an over-the air transmission, wherein the pilot sequence is constructed from a set of Generalized Chirp-Like (GCL) sequences, and utilizing the pilot sequence for at least acquisition and tracking of timing and frequency synchronization, estimation and tracking of desired channels for subsequent demodulation and decoding, estimation and monitoring of characteristics of other channels for handoff purposes, and interference suppression.

Finally, the present invention encompasses a communication unit comprising pilot channel circuitry for transmitting or receiving a pilot channel sequence, wherein the pilot channel sequence comprises a sequence unique to the communication unit and is constructed from a GCL sequence.

Turning now to the drawings, where like numerals designate like components, FIG. **1** is a block diagram of communication system **100** that utilizes pilot transmissions. Communication system utilizes an Orthogonal Frequency Division Multiplexing (OFDM) protocol; however in alternate embodiments communication system **100** may utilize other digital cellular communication system protocols such as a Code Division Multiple Access (CDMA) system protocol, a Frequency Division Multiple Access (FDMA) system protocol, a Spatial Division Multiple Access (SDMA) system protocol or a Time Division Multiple Access (TDMA) system protocol, or various combinations thereof.

transmit and receive unit that serves a number of remote units within a sector. As known in the art, the entire physical area served by the communication network may be divided into cells, and each cell may comprise one or more sectors. When multiple antennas are used to serve each sector to provide various advanced communication modes (e.g., adaptive beamforming, transmit diversity, transmit SDMA, and multiple stream transmission, etc.), multiple base units can be deployed. These base units within a sector may be highly integrated and may share various hardware and software components. For example, all base units co-located together to serve a cell can constitute what is traditionally known as a base station. Base units **101** and **102** transmit downlink communication signals **104** and **105** to serving remote units on at least a portion of the same resources (time, frequency, or both). Remote unit **103** communicates with one or more base units **101** and **102** via uplink communication signal **106**.

It should be noted that while only two base units and a single remote unit are illustrated in FIG. **1**, one of ordinary skill in the art will recognize that typical communication systems comprise many base units in simultaneous communication with many remote units. It should also be noted that while the present invention is described primarily for the case of downlink transmission from multiple base units to multiple remote units for simplicity, the invention is also applicable to uplink transmissions from multiple remote units to multiple base units. A base unit or a remote unit may be referred to more generally as a communication unit.

As discussed above, pilot assisted modulation is commonly used to aid in many functions such as channel estimation for subsequent demodulation of transmitted signals. With this in mind, base units **101** and **102** transmit known sequences at known time intervals as part of their downlink transmissions. Remote unit **103**, knowing the sequence and time interval, utilizes this information in demodulating/decoding the transmissions. Such a pilot transmission scheme is illustrated in FIG. **2**. As shown, downlink transmissions **200** from base units **101** and **102** typically comprise pilot sequence **201** followed by remaining transmission **202**. The same or a different sequence can show up one or multiple times during the remaining transmission **202**. Thus, each base unit within communication system **100** comprises pilot channel circuitry **107** that transmits one or more pilot sequences along with data channel circuitry **108** transmitting data.

It should be noted that although FIG. **2** shows pilot sequence **201** existing at the beginning of a transmission, in various embodiments of the present invention, the pilot channel circuitry may include pilot sequence **201** anywhere within downlink transmission **200**, and additionally may be transmitted on a separate channel. Remaining transmission **202** typically comprises transmissions such as, but not limited to, sending information that the receiver needs to know before performing demodulation/decoding (so called control information) and actual information targeted to the user (user data).

As discussed above, it is important for any pilot sequence to have optimal cross-correlation and ideal auto-correlation. With this in mind, communication system **100** utilizes pilot sequences constructed from distinct "classes" of chirp sequences with ideal cyclic auto-correlation and optimal cyclic cross-correlation. The construction of such pilot sequences is described below.

Construction of a Set of Pilot Sequences to Use within a Communication System

needed in a network (K) and a desired pilot length (N_p) where K cannot exceed N_p. In fact, the number of pilot sequences available that has the ideal cyclic auto-correlation and optimal cyclic cross-correlation is P−1 where P is the smallest prime factor of N_p other than "1" after factoring N_p into the product of two or more prime numbers including "1". For example, the maximum value that P can be is N_p-1 when N_p is a prime number. But when N_p is not a prime number, the number of pilot sequences often will be smaller than the desired number K. In order to obtain a maximum number of sequences, the pilot sequence will be constructed by starting with a sequence whose length N_G is a prime number and then performing modifications. In the preferred embodiment, one of the following two modifications is used:

1. Choose N_G to be the smallest prime number that is greater than N_p and generate the sequence set. Truncate the sequences in the set to N_p; or
2. Choose N_G to be the largest prime number that is smaller than N_p and generate the sequence set. Repeat the beginning elements of each sequence in the set to append at the end to reach the desired length N_p.

The above design of requiring N_G to be a prime number will give a set of N_G-1 sequences that has ideal auto correlation and optimal cross correlation. However, if only a smaller number of sequences is needed, N_G does not need to be a prime number as long as the smallest prime factor of N_G excluding "1" is larger than K.

When a modification such as truncating or inserting is used, the auto-correlation will not be precisely ideal and the cross-correlation will not be precisely optimal anymore. However, the auto- and cross-correlation properties are still acceptable. The modified pilot sequence can be referred to as nearly-optimal pilot sequences that are constructed from GCL sequences with optimal auto- and cross-correlation. Further modifications to the truncated/extended sequences may also be applied, such as applying a unitary transform to them.

It should also be noted that while only sequence truncation and cyclic extension were described above, in alternate embodiments of the present invention there exist other ways to modify the GCL sequences to obtain the final sequences of the desired length. Such modifications include, but are not limited to extending with arbitrary symbols, shortening by puncturing, etc. Again, further modifications to the extended/punctured sequences may also be applied, such as applying a unitary transform to them.

The length-N_p sequences are assigned to base units in communication system **100** as the time-domain pilot sequence, or as the frequency-domain pilot sequence (i.e., the entries of the sequence or its discrete IDFT will be assigned onto a set of subcarriers in the frequency domain). If the sequences obtained are used as the time-domain pilot, option 2 will be preferred because the autocorrelation over a size-N_G window is still ideal. If the sequences obtained are used as the frequency-domain pilot and the channel estimation is performed in the frequency domain, the autocorrelation is irrelevant (but the cross-correlation properties of the sequences can still be important in many situations). In this case, either modification 1 or 2 is acceptable with a preference to choosing N_G as the closest to N_p.

The final pilot sequences transmitted in time domain can be cyclically extended where the cyclic extension is typically longer than the expected maximum delay spread of the channel (L_D). In this case, the final sequence sent has a length equal to the sum of N_p and the cyclic extension length. The be an inherent part of the communication system used such as an Orthogonal Frequency Division Multiplexing (OFDM) protocol. The inserted cyclic prefix makes the ordinary auto- or cross-correlation appear as a cyclic correlation at any shift that ranges from 0 to the cyclic prefix length. If no cyclic prefix is inserted, the ordinary correlation is approximately equal to the cyclic correlation if the shift is much smaller than the pilot sequence length.

As discussed above, in the preferred embodiment of the present invention Generalized Chirp-Like (GCL) sequences are utilized for constructing pilot sequences. There exists a number of "classes" of GCL sequences and if the classes are chosen carefully (see GCL property 3 below), sequences with those chosen classes will have optimal cross-correlation and ideal autocorrelation. Class-u GCL sequence (S) of length N_G are defined as:

$$S_u=(a_u(0)b,\ a_u(1)b,\ \ldots,\ a_u(N_G-1)b), \quad (1)$$

where b can be any complex scalar of unit amplitude and

$$a_u(k) = \exp\left(-j2\pi u\frac{k(k+1)/2+qk}{N_G}\right), \quad (2)$$

where,

u=1, . . . N_G-1 is known as the "class" of the GCL sequence,

k=0, 1, . . . N_G-1 are the indices of the entries in a sequence,

q=any integer.

Each class of GCL sequence can have infinite number of sequences depending on the particular choice of q and b, but only one sequence out of each class is used to construct one pilot sequence.

It should also be noted that if an N_G-point DFT (Discrete Fourier Transform) or IDFT (inverse DFT) is taken on each GCL sequence, the member sequences of the new set also have optimal cyclic cross-correlation and ideal autocorrelation, regardless of whether or not the new set can be represented in the form of (1) and (2). In fact, sequences formed by applying a matrix transformation on the GCL sequences also have optimal cyclic cross-correlation and ideal autocorrelation as long as the matrix transformation is unitary. For example, the N_G-point DFT/IDFT operation is equivalent to a size-N_G matrix transformation where the matrix is an N_G by N_G unitary matrix. As a result, sequences formed based on unitary transformations performed on the GCL sequences still fall within the scope of the invention, because the final sequences are still constructed from GCL sequences. That is, the final sequences are substantially based on (but are not necessarily equal to) the GCL sequences.

If N_G is a prime number, the cross-correlation between any two sequences of distinct "class" is optimal and there will N_G-1 sequences ("classes") in the set (see properties below).

The original GCL sequences have the following properties:

Property 1: The GCL sequence has constant amplitude, and its N_G-point DFT has also constant amplitude.

Note that constant amplitude in both the time and frequency domain is desired for a pilot signal. Constant amplitude of the temporal waveform is ideal for a power amplifier to operate at higher output power without causing clipping. Constant amplitude in the frequency domain means that the subcarriers are equally excited and hence the channel estimates will not be biased. However, for multi-carrier systems such as OFDM, some of the subcarriers (typically the guard bands) are not used, making the pilot signal not of constant modulus anymore in the frequency domain. The corresponding time-domain pilot waveform is not of constant modulus anymore, but is essentially the result of interpolating the time-domain, i.e., over sampling the sequence to obtain a longer sequence after running it through a "sinc" filter. The resulting waveform still enjoys low peak-to-average ratio (PAPR is typically <3 dB).

Property 2: The GCL sequences of any length have an "ideal" cyclic autocorrelation (i.e., the correlation with the circularly shifted version of itself is a delta function)

Property 3: The absolute value of the cyclic cross-correlation function between any two GCL sequences is constant and equal to $1/\sqrt{N_G}$, when $|u_1-u_2|$, u_1, and u_2 are relatively prime to NG.

Assignment of Pilot Sequences within a Communication System

Each communication unit may use one or multiple pilot sequences any number of times in any transmission interval or a communication unit may use different sequences at different times in a transmission frame. Additionally, each communication unit can be assigned a different pilot sequence from the set of K pilot sequences that were designed to have nearly-optimal auto correlation and cross correlation properties. One or more communication units may also use one pilot sequence at the same time. For example where multiple communication units are used for multiple antennas, the same sequence can be used for each signal transmitted form each antenna. However, the actual signals may be the results of different functions of the same assigned sequence. Examples of the functions applied are circular shifting of the sequence, rotating the phase of the sequence elements, etc.

Receiver Functions that May Benefit from the Pilot Design:

A number of critical receiver functions are described that can benefit from the above-described pilot design. The examples given here are not exhaustive, and it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit of utilizing the good auto- and/or cross-correlation of the designed sequence.

1. Single Channel Estimation:

This section shows how the channel estimation can benefit from the above pilot design strategy. In essence, channel estimation can be performed easily by correlating the received data with the pilot sequence. Thanks to the ideal auto-correlation of GCL sequences, the output of the correlation provides the channel estimate. The channel estimate can then be refined, if desired, using a "tap selection" process. An example tap selection process is provided below. Also, time synchronization with the desired base station (BS) can be achieved straightforwardly because the arrival path can be detected easily. If channel information to an interference BS is also needed, it can be obtained from the correlation of the received data with the pilot sequence of that BS. The cross-correlation property increases the accuracy and detection reliability of the significant channel taps and reduces the false detections, as will be explained here.

The GCL sequence effectively spreads the power of each tap of the interference channel evenly across N_G taps thanks to the cross-correlation properties of GCL sequences. Therefore, after correlating with the desired sequence, the interference will be more evenly distributed in the time domain. The significant tap of the desired channel will be preserved better than the smaller taps. In comparison, if non-GCL sequences are used, the power of each tap of the interference will not be

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